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Effects of broadcasting calls on detection probability in occupancy analyses of multiple raptor species

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Abstract.—For population studies that rely on aural or visual observations of individuals, methods that induce a detectable response can greatly improve sample sizes and reduce costs. Numerous authors have reported improved detections using broadcast surveys in forested areas for various species of raptors; however, to our knowledge, none have attempted to quantify the effects of broadcast surveys on the detection probability (p) in the context of an occupancy study for multiple species. Our objective was to determine whether broadcasting conspecific and heterospecific calls (broadcast surveys) would increase p of raptor species compared to passive surveys. This comparison was accomplished by estimating p during both types of surveys using a multiscale occupancy framework. We conducted 8400 surveys for Cooper's Hawk (*Accipiter cooperii*), Swainson's Hawk (*Buteo swainsoni*), White-tailed Hawk (*Geranoaetus albicaudatus*), Harris's Hawk (*Parabuteo unicinctus*), Red-tailed Hawk (*Buteo jamaicensis*), and Great Horned Owl (*Bubo virginianus*) in 2015 and 2016 in south Texas. We conducted 10-min passive surveys in both years, 10-min broadcast surveys in 2015 including calls from each of the target hawk species, and 10-min broadcast surveys in 2016 using calls from Great Horned Owls. Our results suggest that p is improved with multiple-hawk broadcast surveys (0.16, SE 0.04) over passive surveys (0.04, SE 0.02) for Harris's Hawks; p was not affected in broadcast surveys for the other hawk species considered. Great Horned Owls had a higher p during broadcast surveys using Great Horned Owl calls (0.35, SE 0.04) than during passive surveys (0.19, SE 0.02). Our results do not support the use of broadcast surveys to improve the detection probability of multiple species of hawks. However, our results do indicate that using broadcast surveys for occupancy studies focused on Harris's Hawks or Great Horned Owls should significantly reduce the effort required over passive surveys, resulting in improved power and reduced costs.

Resumen.—Los métodos que inducen una respuesta detectable pueden mejorar significativamente el tamaño de muestra y reducir los costos de los estudios poblacionales que se basan en la observación visual o auditiva de individuos. Numerosos autores han reportado mejoradas en la detección de individuos, utilizando muestreos de emisión de llamados en áreas boscosas, para diferentes especies de aves de presa. Sin embargo, ninguno ha intentado cuantificar los efectos de los muestreos de emisión de llamados en la probabilidad de detección (p), en el contexto de un estudio de ocupación de múltiples especies. Nuestro objetivo fue determinar si la emisión de llamados de conspecíficos y heteroespecíficos, puede aumentar la p de especies de aves de presa, en comparación con muestreos pasivos, con el fin de estimar la p durante ambos tipos de muestreos, utilizando un marco de ocupación de múltiples escalas. Llevamos a cabo 8400 muestreos de emisión de llamados del gavilán de Cooper (*Accipiter cooperii*), el gavilán de Swainson (*Buteo swainsoni*), el gavilán coliblanco (*Geranoaetus albicaudatus*), el halcón de Harris (*Parabuteo unicinctus*), ratonero de cola roja (*Buteo jamaicensis*) y los búhos cornudos (*Bubo virginianus*) en el 2015 y 2016, en el Sur de Texas. De igual forma, realizamos muestreos pasivos de 10 minutos en ambos años. Los muestreos de emisión de llamados de 10 minutos en el 2015, incluyeron llamados de cada una de las especies de halcones estudiados. Mientras que en los muestreos de emisión de llamados del 2016, se usaron llamados de Búhos cornudos. Nuestros resultados sugieren que la p mejora con muestreos de emisión de llamados de múltiples halcones (0.16, E.E 0.04), por arriba de los muestreos pasivos (0.04, E.E 0.02) de los halcones de Harris. No encontramos que los muestreos de emisión de llamados afectaran la p, de las otras especies de halcones incluidas en el estudio. Los búhos cornudos tuvieron una mayor p durante los muestreos, usando llamados de conspecíficos (0.35, E.E 0.04), que usando los muestreos pasivos (0.19, E.E 0.02). Nuestros resultados no apoyan el uso de muestreos de emisión de llamadas para mejorar la probabilidad de detección de múltiples especies de halcones. No obstante, los resultados indican que el utilizar muestreos de emisión de llamadas para estudios de ocupación, enfocados en los halcones de Harris y/o los búhos cornudos, deberían reducir significativamente el esfuerzo requerido, en comparación a los muestreos pasivos, resultando en una mejora de poder de detección y reducción de costos.

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The precision of estimates and the power of monitoring programs are generally improved as the amount of data they are based on increases (Garton et al. 2005, Morrison et al. 2008). For studies that rely on detections of individuals, such as occupancy studies, methods that increase the likelihood of detecting individuals that are present (hereafter detection probability, or *p*) can greatly improve sample sizes and reduce costs. A higher *p* in occupancy studies also has the benefit of improving the precision of parameter estimates (MacKenzie et al. 2002, Tyre et al. 2003), which results in increased power to detect differences or changes in occupancy (Field et al. 2005). Finally, multiple authors have shown that occupancy studies with higher *p* require less effort allocated to repeat visits, freeing up more effort for expanding the number of sites or overall area sampled (Tyre et al. 2003, MacKenzie and Royle 2005).

Raptors are often monitored using observational studies (Andersen 2007). However, achieving large sample sizes can be challenging due to raptors' large home ranges, low densities, and cryptic behavior (Newton 1979, Andersen 2007). For studies that rely on aural or visual observations of individuals, methods that induce a detectable response will improve *p*. Numerous authors have reported improved detections using broadcast surveys in forested areas for various species, including Northern Goshawks (*Accipiter gentilis;* Kennedy and Stahlecker 1993, Watson et al. 1999), Red-shouldered Hawks (*Buteo lineatus;* McLeod and Andersen 1998, Mosher et al. 1990), Broad-winged Hawks (*Buteo platypterus;* Mosher at al. 1990), and Cooper's Hawks (*Accipiter cooperii;* Rosenfield et al. 1988, Mosher at al. 1990). Barnes et al. (2012) also found broadcasting calls useful for surveying Peregrine Falcons (*Falco peregrinus*) in the eastern Mojave Desert, USA, and Salvati et al. (2000) concluded that the use of broadcast surveys improved detections of Eurasian Kestrels (*Falco tinnunculus*) in urban areas in Rome, Italy.

Studies focused on a single raptor species have often used broadcast surveys with calls from conspecifics (Rosenfield et al. 1988, Kennedy and Stahlecker 1993, Watson et al. 1999). However, there is evidence that response rates may also be increased by broadcasting heterospecific calls (Balding and Dibble 1984, Bosakowski and Smith 1997), and specifically calls from Great Horned Owls (*Bubo virginianus*) because they are predators of many raptor species (Mosher and Fuller 1996). McLeod and Andersen (1998) suggested using calls from Great Horned Owls for broadcast surveys that specifically target multiple raptor species with a single effort.

Data collected as part of a large-scale bird monitoring project such as the Breeding Bird Survey are generally less informative for populations of raptors than they are for other species, particularly because the numbers of observations of raptors are small (Robbins et al. 1986). In developing a large-scale occupancy monitoring program for all birds, we were particularly interested to see detection probabilities of diurnal raptors during passive point-count surveys, and to see whether these could be improved by incorporating broadcast surveys at a subset of our survey locations. Although other studies have estimated the detection probability of raptors during focused occupancy studies using broadcast surveys (Hennemen et al. 2007, Beck et al. 2011, Carlson et al. 2015), we are unaware of any which were conducted during breeding bird surveys developed to detect nonraptor species as well, or which attempted to quantify the effect of broadcast surveys on *p*. Our objective was to determine whether broadcasting conspecific and heterospecific calls would increase *p* of raptor species compared with silent or passive surveys by estimating the *p* during both types of surveys as part of a broad study focusing on monitoring both raptor and nonraptor species in rangeland ecosystems. Our work has direct applicability to the design and implementation of raptor studies conducted in rangelands (primarily grassland and shrubland vegetation) around the world.

METHODS

We collected data on the 60,752-ha San Antonio Viejo (SAV; Jim Hogg and Starr Counties) and 10,984-ha El Sauz (ELS; Willacy and Kenedy Counties) ranches located in south Texas (Fig. 1). These ranches are owned by the East Foundation and managed as a working laboratory to support wildlife conservation, private land stewardship, and other public benefits associated with ecologically sound cattle ranching. The SAV ranch was a matrix of woodland (73%) and shrubland (18%), with

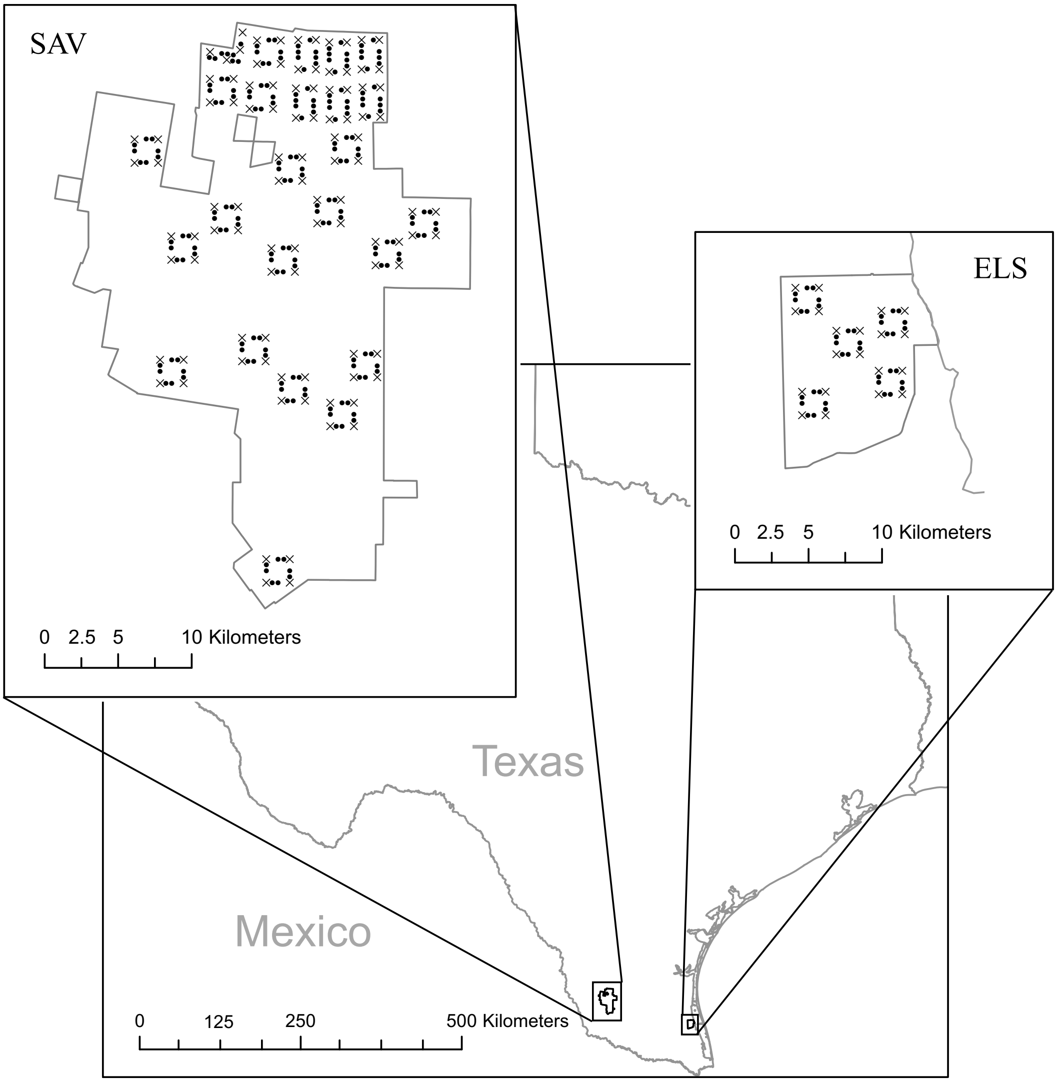

Fig. 1. Raptor survey transect configurations on the East Foundation's San Antonio Viejo Ranch (SAV) and El Sauz Ranch (ELS) in South Texas, 2015–2016. Dots represent locations where we conducted passive surveys; the symbol × represents locations where we conducted both broadcast and passive surveys.

approximately half of the ranch in the Coastal Sand Plain ecoregion and half in Texas-Tamaulipan Thornscrub (Diamond and Fulbright 1990, Fulbright et al. 1990, McLendon et al. 2013b). The El Sauz study area was located 117 km to the east of SAV and adjacent to the Laguna Madre along the Texas Gulf Coast. El Sauz was 36% woodland, 30% wetland vegetation, and 26% grassland (McLendon et al. 2013a). Sixty percent of ELS was in the Coastal Sand Plain ecoregion, with the remaining 40% split evenly between the Laguna Madre Barrier Islands and Coastal Marshes ecoregion and the Lower Rio Grande Valley ecoregion (Diamond and Fulbright 1990, Fulbright et al. 1990, Forman et al. 2009). Annual precipitation averages ranged from about 57 cm at the SAV ranch to about 66 cm at the ELS ranch (NOAA 2016).

Data Collection

We established 25 transects on SAV and 5 on ELS, each consisting of 12 points typically arranged in a square or rectangular shape

(Fig. 1). We located transects a minimum of 400 m from the edge of individual pastures or ranch boundaries, which we assumed was a sufficient distance to restrict observations to pastures or ranches under survey. The location of the northwest corner of each transect was randomly selected for all transects, with the exception of 10 on SAV, which were located to fit within specific pastures according to the previously mentioned restrictions. At each point along a transect, 2 observers independently conducted 10-min passive surveys where they recorded all birds (raptors and nonraptors) seen or heard within a 200-m radius. After sampling a single point, the observers walked to the next sampling point along the transect. Observers also conducted a 10-min broadcast survey for raptors at 4 of the points along each transect immediately following the initial passive survey. Points following a broadcast survey were spaced 800 m from the broadcast survey point; all others were spaced 400 m apart (Fig. 1). We assumed that this configuration resulted in independence among points (i.e., we were not detecting the same individuals from subsequent surveys of the same type).

Broadcast surveys consisted of alternating 30 s of recorded calls with 90 s of silent listening for the 10-min duration. We used FOXPRO NX4 Wildlife Callers® (FOXPRO Inc., Lewiston, PA) to broadcast calls and calibrated the volume level so that calls could be barely heard by a surveyor at an unobstructed distance of 200 m with the horn speaker. These callers had a horn speaker and a cone speaker on opposing ends of the unit, and observers held the device approximately 2 m above ground level and rotated it a complete 360° during each 30-s period of broadcasting. During broadcast surveys, one technician recorded the same data for raptor species as was recorded during a passive point count and the other operated the Wildlife Caller. Observers alternated tasks with each subsequent broadcast survey so that each observer was responsible for the same number of broadcast surveys. Since we were particularly interested in the efficacy of broadcast surveys for monitoring multiple species of raptors, in our broadcast surveys in 2015 we included calls from the 5 most frequently observed species detected during passive raptor surveys conducted in the fall of 2014 (unpublished data). Specifically, we broadcasted 30 s of alarm calls of each of Cooper's Hawk, Swainson's Hawk (*Buteo swainsoni*), White-tailed Hawk (*Geranoaetus albicaudatus*), Harris's Hawk (*Parabuteo unicinctus*), and Red-tailed Hawk (*Buteo jamaicensis*), separated by 90 s of silence for a total survey duration of 10 min. In 2016, we replaced each of the 30-s calls with 30 s of Great Horned Owl calls so we could quantify the effects of Great Horned Owl broadcasts on detection probability. We used the following recordings from the Macaulay Library at the Cornell Lab of Ornithology for our broadcast surveys: ML109074, ML 140257, ML 4313, ML 58969, ML 44692, ML 166694, and ML 22873.

We began sampling in the third week of April and resampled each transect every 2 weeks for a total of 6 visits in 2015 and 4 visits in 2016. Though the phenologies of the species we considered in this study vary for Texas, USA, these dates appear to cover typical egg laying and brood rearing, such that we expected adults to be defending territories for hunting during incubation and feeding young (Texas Breeding Bird Atlas 2017). We began surveying at the first point 0.5 h before sunrise; each transect required an average of 5 h to complete. We kept the starting point and the order in which each point was sampled within a transect consistent over both years of the study. We did not conduct surveys during heavy or persistent rain or in winds ≥20 kph as estimated by the Beaufort scale. We completed surveys in the final week of July in 2015 and the final week of June in 2016.

Data Analysis

Occupancy is defined as the proportion of sample sites occupied by a particular species. Measurement of occupancy relies on data collected during repeat visits to the same locations to generate estimates of p, which are then used to correct the record of detections to produce unbiased estimates of occupancy (MacKenzie et al. 2006). This analysis makes no assumptions regarding the breeding status of individuals detected; our use of the term "occupancy" is different from that of typical raptor studies that focus on occupancy status of known breeding territories. Furthermore, we recognize that entire home ranges of raptor species included in our study may not be entirely included within a single transect;

thus, our resulting estimates of occupancy should be interpreted as proportion of sites used (MacKenzie 2005, MacKenzie et al. 2006). We used the multiscale occupancy model (Pavlacky et al. 2012) in Program MARK (White and Burnham 1999) to generate estimates of p that were specific to the survey type (passive or broadcast) and broadcast recording (multiple hawks or Great Horned Owl) for individual species. We fit this model to our data to estimate the proportion of transects occupied by a species (Ψ), the probability that a single point within a transect is occupied given that the transect itself is occupied (θ), and the probability that the species is detected at a point within an occupied transect during a single survey (p). We conducted this analysis separately for each of the 5 hawk species that we included in the broadcast recordings used in 2015, as well as for Great Horned Owls.

The multiscale occupancy model uses subunits as primary samples and redundant surveys conducted at a single location as secondary samples. Points within a transect represented primary samples and pairs of independent observations recorded simultaneously during passive surveys, and all repeat visits to a point within a single year represented secondary samples in our data. This resulted in 12 secondary observations in 2015 and 8 in 2016 at each of 12 points within a transect for the passive point counts. Similarly, we conducted 6 secondary observations in 2015 and 4 in 2016 at 4 points in each transect for broadcast surveys. We considered *survey type* as a grouping covariate to facilitate testing for and estimating differences in p for passive surveys and the 2 types of broadcast surveys. Additionally, we included *ranch* as a grouping covariate so that we could test for and estimate differences in Ψ between our 2 study sites, and we included *year* as a grouping covariate to allow for changes in Ψ between 2015 and 2016. Because we limited use of each type of broadcast survey to a single year, and because most of the observers we used were unique to a single year of our study, we included a term for year in p so that any observer effects would not mask the effects of survey type. We recognize that our protocol resulted in confounding the variables of relative time of day with observation locations within a transect, since we did not change the starting location or order of points visited within each transect. However, since we were only interested in calculating an average p for all locations across the timeframe of our daily surveys, this confounding had no impact on our analysis or results.

Our global model included terms in p for survey type and year, along with an interaction term for these covariates. This model allowed p to vary among the 3 survey types and also within the passive surveys between years to detect any observer effects. We also considered a model that allowed p to vary among the 3 survey types but that was constrained to a single value for passive surveys conducted in both years. We further constrained this model such that p was allowed to vary between passive and broadcast surveys to determine whether the 2 types of broadcast surveys had a similar effect for any species. We also included models with a single term for year in p and no terms in p. We included terms for year and ranch, along with an interaction term for these covariates in Ψ for all 5 of these models. Finally, we included a model with no covariates to ensure that we were not overfitting models to the data. We fit all 6 models to data sets for each species separately. We evaluated models using Akaike's information criterion adjusted for small sample sizes (AICc; Burnham and Anderson 2002) and used the model within our candidate set with the most support for each species' data set in order to generate parameter estimates.

RESULTS

Over our 2-year study, we conducted 8400 surveys for raptors (7200 passive surveys, 720 broadcast surveys with multiple hawk calls, and 480 broadcast surveys with Great Horned Owl calls). We detected Cooper's Hawks during 18 surveys, White-tailed Hawks during 68 surveys, Harris's Hawks during 69 surveys, Red-tailed Hawks during 113 surveys, Swainson's Hawks during 134 surveys, and Great Horned Owls during 222 surveys. Our detections for Cooper's Hawks were too sparse for model fitting, so we made no attempt to produce parameter estimates for these data. Models including a term for survey type or year in p were not supported by the Swainson's Hawk data set (Table 1). The model with a single term for year in p gained the most support

TABLE 1. Model with the most support (lowest AICc) for each species in our study, total number of observations (n), model weight (w_i), number of parameters (k), resulting estimates of occupancy (Ψ) for the East Foundation's San Antonio Viejo Ranch (SAV) and El Sauz Ranch (ELS), availability (θ), and detection probability (p) during passive surveys, surveys broadcasting calls from multiple hawk species, and surveys broadcasting calls from Great Horned Owls (GHOW) for occupancy data collected in South Texas, 2015–2016. Numbers in parentheses are associated standard errors for each estimate. Dashes indicate that no term was included in the parameter in the most supported model and that resulting estimates were constant for all groups (years, ranches, or survey types).

					$\hat{\Psi}$					$\hat{p}$			
					SAV		ELS			2015		2016	
Species	Model[a]	n	w_i	k	2015	2016	2015	2016	$\hat{\theta}$	Passive	Multi	Passive	GHOW
Cooper's Hawk[b]		18											
Swainson's Hawk	Ψ(.) p(.)	134	0.345	3	0.76 (0.09)	—	—	—	0.16 (0.03)	0.14 (0.02)	—	—	—
White-tailed Hawk	Ψ(R×Y) p(Y)	68	0.521	7	0.24 (0.10)	0.42 (0.12)	0.71 (0.27)	0.84 (0.25)	0.16 (0.04)	0.09 (0.03)	—	0.17 (0.03)	—
Harris's Hawk	Ψ(R×Y) p(T×Y)	69	0.572	9	0.28 (0.11)	0.53 (0.12)	0.83 (0.14)	0.60 (0.15)	0.23 (0.06)	0.04 (0.02)	0.16 (0.04)	0.12 (0.03)	0.13 (0.05)
Red-tailed Hawk	Ψ(R×Y) p(Y)	113	0.679	7	1.0 (0.01)	0.88 (0.15)	0.50 (0.30)	1.0 (0.01)	0.13 (0.02)	0.09 (0.02)	—	0.16 (0.03)	—
Great Horned Owl	Ψ(R×Y) p(T×Y)	222	0.999	9	0.65 (0.14)	0.99 (0.05)	0.48 (0.27)	0.93 (0.13)	0.26 (0.03)	0.05 (0.02)	0.01 (0.01)	0.19 (0.02)	0.35 (0.04)

[a]Model notation: (.) indicates that no covariates for the parameter were included; R indicates that a covariate for ranch was included; Y indicates that a covariate for year was included; T indicates that a covariate for survey type was included.
[b]Insufficient data for model fitting.

for both the White-tailed and Red-tailed Hawk data sets, suggesting that there was a significant observer effect between the crews in the 2 years of our study, but that survey type did not affect detectability for these species (Table 1).

The top-supported model for the Harris's Hawk data set included terms for both year and survey type in p. Estimates from this model indicated that the multiple-hawk broadcast used in 2015 increased the $\hat{p}$ to 0.16 (95% CI 0.08–0.25) compared to a $\hat{p}$ of 0.04 (95% CI 0.01–0.08) for passive surveys. Conversely, this model indicated that our use of Great Horned Owl calls in 2016 ($\hat{p}$ = 0.13, 95% CI 0.04–0.24) had no measurable effect on our detections of Harris's Hawks ($\hat{p}$ for passive surveys in 2016 = 0.12, 95% CI 0.06–0.19).

Our data from detections of Great Horned Owls also supported the global model with terms for survey type and year in p (Table 1). Our 2015 broadcast surveys with the multiple species of hawks resulted in a $\hat{p}$ of 0.01 (95% CI 0.00–0.07), whereas passive surveys in the same year with the same crew resulted in a $\hat{p}$ of 0.05 (95% CI 0.03–0.10). Conversely, broadcast surveys in 2016 with Great Horned Owl calls appeared to increase $\hat{p}$ to 0.35 (95% CI 0.28–0.44), compared with passive surveys from the same year ($\hat{p}$ = 0.19, 95% CI 0.15–0.23).

DISCUSSION

Our results suggest that our broadcast calls may have had no impact on detecting Swainson's, White-tailed, or Red-tailed Hawks, but that they did improve p of Harris's Hawk during our multiple-species occupancy surveys using broadcasts of 5 hawk species. We were unable to fit models to the Cooper's Hawk data set due to insufficient data. We were unable to find any studies on the efficacy of broadcast surveys concerning Harris's, Swainson's, or White-tailed Hawks. Other authors have reported mixed results from broadcast studies for Red-tailed Hawks. Bosakowski and Smith (1997) reported that response rates were higher for Red-tailed Hawks than for any other species in their study during broadcast surveys in New Jersey; however, these authors did not have detection rates from passive surveys for comparison. Mosher et al. (1990) did not find that broadcast surveys improved detection rates for Red-tailed Hawks in a study conducted in forests in the eastern USA. They concluded that the lack of detectable effect was likely due to low density of nesting individuals in their study area.

The apparent lack of an effect of broadcast surveys on *p* for most species in our study may be explained by the geographic location and timing of our data collection. If response to broadcast calls by raptors is primarily a territorial behavior, we would expect broadcast surveys to be more effective in areas where species reestablish breeding territories each year, specifically when territories are being established. Except for Swainson's Hawks, all species we included in our analysis were non-migratory in our study area (Lockwood and Freeman 2004). Broadcast surveys may be effective at improving detections of Cooper's and Red-tailed Hawks in more northerly regions where these species are breeding migrants. McLeod and Andersen (1998) reported that Red-shouldered Hawks responded more to conspecific calls broadcasted in the earlier breeding phases than during nesting and fledging in central Minnesota, USA. Because we were primarily interested in the efficacy of monitoring occupancy for multiple species of hawks in association with a large-scale occupancy monitoring program for all birds, we conducted our studies when activity for all species was expected to be the greatest. Due to the latitude of our study sites, breeding seasons for hawks in our study area likely began prior to our sampling (Texas Breeding Bird Atlas 2017). Broadcast surveys may increase detections for other hawk species in our study area if surveys begin early enough to include each species' courtship phase. This could be challenging for a study focused on multiple species in our study area, considering that species such as Harris's Hawks are known to breed almost continuously throughout the year during good conditions (Ellis and Whaley 1979, Bednarz 1987a). Furthermore, it may be desirable to survey raptors during nonbreeding periods, in which case the use of broadcast surveys may not be as useful (Barnes et al. 2012).

We suggest that the social system of Harris's Hawks may explain why this was the only hawk species for which we detected an effect of broadcast surveys. Harris's Hawks are the most social of any hawks in our study and are often observed hunting and nesting in groups of more than 2 individuals (Bednarz 1987b, Clark 2017). This complex social structure may result in a greater responsiveness to conspecific calls than other species of hawks exhibit. Alternatively, the larger average group size typical of Harris's Hawks may result in improved ability to detect a perceived threat (many-eyes hypothesis), which may increase responsiveness to heterospecific calls. However, we cannot conclude whether the positive response to broadcast surveys we observed for Harris's Hawks was in response to Harris's Hawk calls or to one of the other 4 heterospecific calls.

Since our objectives included quantifying the efficacy of broadcast surveys specifically in the context of monitoring numerous species, we did not attempt to quantify *p* while broadcasting conspecific calls from any single hawk species during a 10-min sampling period, nor did we attempt to attribute detections of any raptor to a particular segment of the multiple-hawk broadcasts. It is possible that certain hawk species in our study may have responded positively to one species' calls, but negatively to other species' calls, thereby masking our ability to detect any effect. However, we suspect that this result was highly unlikely, as it would require the negative and positive responses to be of the same magnitude, such that no net difference in detections would be detectable between the passive surveys and the multiple-hawk broadcast surveys.

Studies for Great Horned Owls are generally designed to be conducted in the evening, as the species is more active from late afternoon into the evening (Maser et al. 1970). Although Great Horned Owls are considered primarily nocturnal or crepuscular, they can be regularly observed hunting during the daytime (Newell and Newell 1994, Michener 2001, Bogardus et al. 2007). Our intent was not to test the efficacy of diurnal broadcast surveys for Great Horned Owls, and we suspect nighttime surveys are still more efficient than daytime surveys. However, our results show that with a large sample it is possible to get precise estimates of *p;* therefore, precise estimates of Ψ for the species using daytime surveys specifically designed for general bird occupancy monitoring can also be obtained. Furthermore, our data showed that broadcasts of conspecific calls can increase the *p* from

0.19 to 0.35 for Great Horned Owls during a 10-min daytime survey, a roughly 85% increase, whereas broadcasting calls from multiple hawk species effectively reduced the *p* to 0.

Our top-supported models for most of our species' data sets indicated that there were differences in our observers' ability to detect raptors between the 2 years of our study and that, on average, observers in 2016 were better at detecting raptors than those in 2015. Estimates from our passive surveys suggest that our observers in 2016 were able to detect 7%–8% more White-tailed Hawks, Harris's Hawks, and Red-tailed Hawks that were present, and 14% more Great Horned Owls that were present than the crew from 2015. This effect is termed "observer bias" and is common in bird surveys based on counts (Sauer et al. 1994, Nichols et al. 2000, Diefenbach et al. 2003, Alldredge et al. 2007), including those focusing on raptors (Nolte et al. 2016).

Our results indicate that broadcasts can improve the efficacy of raptor surveys conducted in rangeland ecosystems. To determine the optimal number of repeat visits for an occupancy study, the probability of confirming species presence in an occupied area (p^*) is recommended to be 0.85–0.95 (MacKenzie and Royle 2005). According to the *p* estimates obtained from our highest-supported model for Harris's Hawk occupancy, calculated with data collected in 2015, it would take 46 repeat visits to each point using passive 10-min counts to reach a p^* of 0.85, whereas the same level of confirmation would be reached in only 11 visits using 10-min surveys with multiple-hawk broadcasts. While the overall decrease in effort required will depend on multiple variables, including the average observer's ability to detect a given species and the specific study objectives, the reduction in required effort from our 2015 data was >75% when broadcasts of multiple hawk species were employed. Similarly, our results suggest that the number of repeat visits to reach a p^* of 0.85 for Great Horned Owls was reduced from 9 with passive surveys to 5 with surveys broadcasting Great Horned Owl calls.

Our results do not support the use of broadcast surveys to improve the detection probability of multiple species of hawks, and we do not recommend implementing either of the types of broadcast surveys that we used at a subset of sampling locations for monitoring occupancy of all or many species of birds. However, we would suggest employing broadcast surveys for studies that are focused on Harris's Hawks or Great Horned Owls. We estimate that doing so would result in a significant decrease in the effort required to meet recommendations for p^*, which in turn should improve the power to detect differences and reduce survey costs. We also suggest that those considering using broadcast surveys for Harris's Hawks conduct a pilot study to determine whether conspecific or heterospecific calls are superior for inducing the greatest *p*.

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