


Evaluating abundance estimates and evidence of breeding for Bobolinks from transect and point-count surveys

Andrew J. Campomizzi,^{1,3}  Zoé M. Lebrun-Southcott,¹ and Christopher M. Lituma²

¹Bird Ecology and Conservation Ontario, Toronto, Ontario M6C 2M1, Canada

²Davis College of Agriculture, Natural Resources and Design, West Virginia University, Morgantown, West Virginia 26506-6108, USA

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ABSTRACT. Estimating the abundance and breeding success of territorial songbirds is challenging. Various types of surveys and analyses are available, but all receive some criticism in the literature, and most methods are rarely compared with results obtained using intensive monitoring efforts. We assessed the efficacy of transect and point-count surveys to estimate the abundance of male Bobolinks (*Dolichonyx oryzivorus*) and detect evidence of nesting and fledging by comparing the results of those surveys to results from more intensive monitoring (i.e., spot mapping and nest monitoring). We monitored 36 fields (254 ha) of late-harvest hay, restored grassland, and fallow fields in the Luther Marsh Wildlife Management Area and on four farms in southern Ontario, Canada, in 2018. Compared to the number of territories identified based on spot mapping (197), distance sampling analysis of transect survey data provided a more accurate estimate of the abundance of male Bobolinks (230, 95% CI: 187, 282) than *N*-mixture models of transect (668, 95% CI: 332, 1342) and point-count (337, 95% CI: 203, 559) data. Three visits to survey transects and five to point counts did not effectively detect evidence of Bobolink breeding (i.e., nesting or fledging) in fields compared to spot mapping and nest monitoring. Distance sampling analysis of transect data appears promising for estimating the number of Bobolink territories in an area, e.g., those impacted by conservation programs. If estimates of the number of nesting Bobolinks and frequency of fledging are of interest, spot mapping and nest monitoring could be implemented at a subset of sampled fields. Our results suggest that additional studies to evaluate model-based estimates of abundance with the best available information (e.g., from spot mapping of marked or unmarked populations and nest monitoring) would be useful to ensure that robust estimates are provided to support population estimates and conservation actions.

RESUMEN. Evaluación de los estimadores de abundancia y evidencia de reproducción de *Dolichonyx oryzivorus* a partir de monitoreo por transectos y puntos de conteo.

Estimar la abundancia y el éxito reproductivo de aves territoriales es un reto. Están disponibles varios tipos de monitoreo y análisis, pero todos reciben algún criticismo en la literatura y la mayoría de los métodos son raramente comparados con resultados obtenidos utilizando esfuerzos intensivos de monitoreo. Determinamos la eficacia de monitoreos por transecto y puntos de conteo para estimar la abundancia de machos de *Dolichonyx oryzivorus* y detectar evidencia de anidación y la presencia de volantones, comparando los resultados de estos monitoreos con resultados obtenidos por monitoreos más intensivos (i.e. mapeo por puntos y monitoreo de nidos). Monitoreamos 36 campos (254 ha) de heno de recolección tardía, pastizales restaurados y campos de cultivo en recuperación en el área de manejo de vida silvestre Luther Marsh y cuatro granjas en el sur de Ontario en Canadá durante 2018. Comparado con el número de territorios identificados utilizando mapeo por puntos (197), el análisis de muestreo por distancia de los datos obtenidos utilizando monitoreos por transecto derivaron en un estimador más preciso de la abundancia de machos de *Dolichonyx oryzivorus* (230, 95% CI: 187, 282) que los modelos de *N*-mezclas utilizando datos de transectos (668, 95% CI: 332, 1342) y puntos de conteo (337 95% CI: 203, 559). Las tres visitas de los monitoreos por transectos y los cinco utilizando puntos de conteo no fueron suficientes para detectar evidencia de reproducción en *Dolichonyx oryzivorus* (i.e. a nidación o presencia de volantones) en los campos comparado con el mapeo por puntos y el monitoreo de nidos. Los análisis de muestreo por distancia de los datos de los transectos parecen ser prometedores para estimar el número de *Dolichonyx oryzivorus* en un área, e.g., impactadas por programas de conservación. Si los estimados del número de *Dolichonyx oryzivorus* anidando y la frecuencia de volantones son las variables de interés, mapeo por puntos y el monitoreo de nidos pueden ser implementados en un subconjunto de los campos muestreados. Nuestros resultados sugieren que estudios adicionales para evaluar los estimados de abundancia basados en modelos con la mejor información disponible (e.g., proveniente de mapeo por puntos de poblaciones marcadas o no marcadas y monitoreo de nidos) pueden ser útiles para asegurar que se provean estimados robustos para soportar estimadores poblacionales y acciones de conservación.

³Corresponding author. Email: andy@beco-birds.org

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Decades of population declines of birds that nest in North American grasslands have led to conservation concern for some of these species (Sauer et al. 2013, 2017, Rosenberg et al. 2019). Accurate estimates of abundance and breeding success are essential for understanding reasons for population declines and supporting conservation actions for species recovery. Various types of survey methods and statistical analyses exist for estimating grassland songbird abundance and breeding success, but the accuracy of these methods may vary among species and ecosystems (DeSante 1986, Buckland 2006, Johnson 2008), underscoring the need to evaluate commonly used methods.

Estimating the abundance and breeding success of territorial songbirds using non-intensive surveys (e.g., transect surveys and point counts) can be challenging. Surveys of relative abundance have been used for decades to estimate trends (e.g., North American Breeding Bird Survey; Robbins et al. 1989). However, abundance indices have largely been replaced by statistical analyses that allow incorporation of covariates and estimates of detection probability to provide estimates of absolute density or abundance (Johnson 2008, Hutto 2016). Monitoring breeding success can be prohibitively time-consuming, and use of an index of breeding success has had mixed success (Vickery et al. 1992, Christoferson and Morrison 2001, Rivers et al. 2003, Morgan et al. 2010). Identifying efficient methods that provide reliable estimates of abundance and breeding success are essential for conservation planning (e.g., targeting areas of high abundance and breeding success).

Avian ecologists use various types of surveys and analyses to estimate songbird abundance (e.g., Thompson et al. 1998, Pierce et al. 2012). No single method is perfect; selecting the most appropriate methods depends on particular monitoring goals and study designs (Block et al. 2001, Morrison et al. 2008, Johnson 2012). Although spot mapping (i.e., delineating locations used by unmarked territorial birds) provides reliable and detailed information about songbird abundance

(Williams 1936, Stewart et al. 1952), the method is labor-intensive (Thompson et al. 1998) and has limitations (Best 1975, Verner and Milne 1990). Use of less-intensive survey types (e.g., transect surveys and point counts; Thompson et al. 1998) is common. Typical analytical methods used with these survey types include distance sampling (Buckland et al. 1993a) and *N*-mixture models (Royle 2004). The reliability of these field and analytical methods to provide accurate estimates under particular conditions (e.g., species or landscape of interest) is uncertain unless evaluated with intensive methods (i.e., spot mapping).

The results of previous studies have revealed that distance sampling based on transect and point-count surveys underestimates density or provides unbiased results compared to data from spot mapping. For example, Newell et al. (2013) found that, compared to spot mapping, 100-m radius point counts and distance sampling underestimated the density of common species of forest songbirds. Buckland (2006) reported that transect surveys and distance sampling provided unbiased density estimates of common songbirds in Scotland compared to spot mapping. Gottschalk and Huettmann (2011) found that 150-m radius point counts and distance sampling produced estimates of density that were 24% lower than spot mapping for common species across four landscapes. Model assumptions of distance sampling are that (1) all individuals at zero distance from the observer are detected, (2) detection probability declines monotonically with distance from the observer, (3) individuals are detected before moving, (4) estimated distances to individuals are accurate, and (5) locations of individuals are independent of sampling locations (Johnson 2008, Thomas et al. 2010, Miller et al. 2019). Although some model assumptions can be relaxed under some conditions (Thomas et al. 2010, Miller et al. 2019), distance sampling has been criticized because field data will always violate some of these assumptions to some degree. For example, birds frequently move (Hutto 2016) and estimating distances to birds based on

vocalizations is challenging (Alldredge et al. 2007, Johnson 2008, Hutto 2016).

Investigators have also compared abundance estimates from *N*-mixture models based on point counts with spot mapping data. Hunt et al. (2012) found that *N*-mixture models (referred to as binomial mixture models [BMM] in their paper) tended to overestimate abundance of male Golden-cheeked Warblers (*Setophaga chrysoparia*) compared to spot mapping. Using some of the same Golden-cheeked Warbler data, Warren et al. (2013) found that *N*-mixture models overestimated abundance at low-abundance study sites and underestimated abundance at high-abundance point count locations compared to spot mapping. We found no published studies in the literature where abundance estimated from transect survey data analyzed with *N*-mixture models was compared to spot mapping. Assumptions of *N*-mixture models are that (1) individuals are homogeneously distributed as a Poisson point process randomly in space, (2) the population is closed during the sample period, and (3) data lack false positives (Royle 2004). *N*-mixture models have been criticized on theoretic grounds and for model assumptions (Barker et al. 2018, Duarte et al. 2018, Link et al. 2018). For instance, Barker et al. (2018) criticized the assumption that populations are closed, that individuals do not get double-counted, and that individual heterogeneity in detection probability (Lituma et al. 2017) or other uncontrolled variation in detection probability can be addressed by including covariates. Simulations showed that small samples sizes, low detection probabilities, and heterogeneity in abundance during the sample period or in individual detection probability can have large effects on abundance estimates (Barker et al. 2018, Duarte et al. 2018).

Assessing the breeding success of songbirds while avoiding labor-intensive field surveys, such as nest monitoring, is also challenging. Vickery et al. (1992) introduced an index of breeding success based on behavioral observations collected across multiple visits to territories during the breeding season (i.e., from lowest rank of territorial male to highest rank of fledging two broods). Rivers et al. (2003) and Morgan et al. (2010) found that the Vickery index did not reliably identify

fledging success of either Dickcissels (*Spiza americana*) or Savannah Sparrows (*Passerculus sandwichensis*) across the breeding season. However, Christoferson and Morrison (2001) reported that the Vickery index accurately identified the current breeding status of three species of riparian songbirds that had been determined by nest monitoring. The reliability of the Vickery index should be evaluated with more intensive survey methods before implementation for monitoring a particular species or ecological system.

Our goal was to evaluate the efficacy of transect and point-count surveys to assess the abundance of male Bobolinks (*Dolichonyx oryzivorus*) and evidence of breeding in grasslands. Bobolinks are migratory songbirds that nest on the ground in grasslands in southern Canada and the northern United States (Renfrew et al. 2015). Although listed as a species of least concern on the IUCN Red List (BirdLife International [online] 2016), Bobolinks are a species of conservation concern in multiple jurisdictions, including Canada (Government of Canada [online] 2017), because of population declines (Sauer et al. 2017). Reliable information about abundance and evidence of breeding is essential for Bobolinks because conservation programs commonly target reduction of incidental mortality of eggs and young from hay harvest and cattle grazing, while birds are nesting (Committee on the Status of Endangered Wildlife in Canada [COSEWIC] 2010, McCracken et al. 2013, Ministry of the Environment, Conservation and Parks [MECP] [online] 2015, Ontario Soil and Crop Improvement Association [OSCIA] 2018).

For comparison with transect and point-count surveys, we considered that spot mapping and nest monitoring would provide the best available information about abundance and breeding success that we could acquire. Our objectives were to compare (1) spot-mapped abundance to abundance estimates of male Bobolinks using distance sampling of transect surveys, *N*-mixture models of transect surveys, and *N*-mixture models of point counts and (2) evidence of nesting and fledging in fields based on spot mapping and nest monitoring to the Vickery index on transect and point-count surveys. We are not promoting one method over another, but present differences in the accuracy of abundance

estimation techniques from status quo approaches for bird surveys.

METHODS

Bobolinks have a large breeding range across southern Canada and the northern United States (Renfrew et al. 2015). The population has declined by an average of 2.0% per year from 1966 to 2015 (Sauer et al. 2017). Most adults arrive in breeding areas in May (Renfrew et al. 2015). Bobolinks nest in various types of grasslands, including native and agricultural (i.e., hay fields and pastures; Renfrew et al. 2015). The typical duration of nesting is ~28 days, including ~5 days for egg laying (one egg laid per day and a mean clutch size of 5), ~12 days of incubation, and ~11 days from hatch to fledge (Martin 1971, Pietz et al. 2012, Renfrew et al. 2015). Female Bobolinks rarely raise > 1 brood per year, but may attempt a second nest following an initial nest failure (Martin 1971, Gavin 1984, Renfrew et al. 2015). Males and females are easily distinguished during the breeding season because the species is sexually dichromatic and males sing, but females do not (Renfrew et al. 2015).

Study area. In 2018, we studied Bobolinks in southern Ontario in the Luther Marsh Wildlife Management Area (WMA) and on four farms within 42 km of the Luther Marsh WMA (study area center: 44°02', -80°17'). The study area is in the Mixedwood Plains EcoZone (Ontario GeoHub 2012). We monitored Bobolinks in 36 fields, totaling 254 ha. Fields ranged in size from 2 to 23 ha (xx000AF; = 7 ha). We monitored nine hay fields, 18 fields seeded with native grasses and forbs for grassland restoration (hereafter, restored fields), and nine fallow fields (i.e., no longer farmed and left to naturalize). Across hay, restored, and fallow fields, vegetation was primarily non-native cool-season grasses and native and non-native forbs; some seeded native species were present in restored fields, but were not dominant. Vegetation in hay fields was primarily grasses, e.g., timothy (*Phleum pratense*), brome species (*Bromus* spp.), redtop (*Agrostis gigantea*), and secondarily forbs, e.g., alfalfa (*Medicago sativa*) and red clover (*Trifolium pratense*). Restored fields tended to have more

forb cover, e.g., goldenrod (*Solidago* spp.) and vetch (*Vicia* spp.), than grasses, e.g., timothy and redtop. The proportion of grass cover, e.g., Canada bluegrass (*Poa compressa*) and redtop, and forbs, e.g., goldenrod species and bird's-foot trefoil (*Lotus corniculatus*), varied among fallow fields. Restored fields were planted between 2010 and 2015 to support grassland birds and other wildlife (L. Campbell, pers. comm.). Fallow fields had various management histories, but all were formerly hay or crop fields (at least four fields had not been farmed for at least 8 yr). All surveyed fields were undisturbed by land management activities (e.g., hay harvest) during May, June, and the first week of July (i.e., when surveys occurred).

Study design. We used spot mapping and nest monitoring to acquire the most accurate assessment possible of absolute abundance and evidence of nesting and fledging in each field. We conducted transect and point-count surveys and compared abundance estimates to spot mapping to assess the accuracy of these less-intensive survey types. We also assessed the usefulness of transect and point-count surveys to detect evidence of nesting and fledging at the field level compared to spot mapping and nest-monitoring data.

Spot mapping and nest monitoring. We used a modified spot mapping method (*sensu* Wiens 1969) to delineate and monitor Bobolink territories (see Campomizzi et al. 2019). From mid-May to mid-July, we visited each field approximately twice per week to search for Bobolinks. We spot-mapped each pair or individual about once per week, following the bird(s) for up to 30 min, recording three to six global positioning system (GPS) locations and bird behavior at each location to document breeding activity. We delineated territories based on clusters of GPS locations collected across visits and the number of individuals we detected on each visit. We classified behavioral observations using a modified Vickery index of breeding status (Vickery et al. 1992), resulting in evidence of nesting, fledging, or neither for each territory. Evidence of nesting included nest building, incubating, food carried to nest, agitated alarm calling, or evidence of fledging. Evidence of fledging included one or more adults delivering food to multiple locations after evidence of a nest

was observed, flightless and dependent fledglings, or adults carrying food for ≥ 11 days in a territory. We considered adults carrying food to one location for ≥ 11 days as evidence of fledging because young remain in the nest for ~ 10 –11 days (Martin 1971, Gavin and Bollinger 1988, Pietz et al. 2012, Renfrew et al. 2015). We considered a field to have zero territories if we never observed Bobolinks or, as occurred in two fields, we detected Bobolinks, but determined that nesting occurred in an adjacent field.

We searched for Bobolink nests during and after spot mapping, about once per week per territory using behavioral cues and systematic searching (Martin and Geupel 1993, Winter et al. 2003, Campomizzi et al. 2019). We did not visit nests when females were building to minimize the risk of nest abandonment (Renfrew et al. 2015). Once incubation began, we visited nests approximately once every three days, on the expected fledge date, and on subsequent days until a nest was no longer active. On each visit, we recorded the number of eggs, number of young, approximate age of young, condition of the nest, and adult behavior. We considered several factors to determine if young fledged, including if we observed ≥ 1 flightless and dependent fledgling(s) near a nest, adults alarm calling near a nest that had large nestlings on the previous visit, adults delivering food near a nest that had large nestlings on the previous visit, and nest condition (e.g., white feces on nest rim or nest pulled apart by presumed predator). Based on nest-monitoring data and nesting phenology (see above), we estimated the first-egg date, hatch date, and fledge date for nests with sufficient data.

Transect and point-count surveys. We used aerial photographs in QGIS (version 2.14.19, QGIS Development Team 2017) to determine survey locations in each field. Transect surveys were located to get the best coverage of each field, generally by bisecting the length of a field. Transect lines were separated into 100-m segments; each transect included at least one 100-m segment. Fields usually contained one transect line, but included two if their area was large enough to separate transect lines by ≥ 250 m to minimize the chance of counting the same individuals on multiple surveys. We walked at a pace of one step per second and stopped

when we detected a Bobolink to record its perpendicular distance from the transect line when first detected; we only recorded detections ≤ 75 m on either side of the transect line. We visited transects during two discrete time periods, while most Bobolinks were nesting, including 17–26 May and 8–17 June. To provide additional data about evidence of nesting and fledging, we visited fields that had ≥ 1 Bobolink territory, based on spot mapping, a third time from 1 to 4 July using the same transect survey protocol.

Most point-count surveys were located at the approximate center of each field. We usually conducted one point count per field, but conducted multiple point counts if the field area was large enough to separate point-count centers by ≥ 250 m to minimize the chance of counting the same individuals on multiple surveys. We conducted 5-min, 75-m radius circular point counts. To estimate abundance, we visited point-count locations during four discrete time periods, including 17–25 May, 29 May–6 June, 8–18 June, and 20–29 June. To provide additional data about evidence of nesting and fledging, we visited fields with ≥ 1 Bobolink territory, based on spot mapping, a fifth time from 1 to 4 July using the same point-count protocol.

On transect and point-count surveys, we recorded the sex and behavior of each individual. For behavior, we recorded the highest-ranked evidence of breeding based on a modified Vickery index (Vickery et al. 1992). We considered a detection of one or more of the following to be evidence of nesting: nest building, incubating, food carried to nest, agitated alarm calling, or evidence of fledging. Evidence of fledging included detections of food being carried to fledglings or detections of dependent fledglings.

We conducted surveys from sunrise to 10:00, but not during periods of rain or excessive wind that could affect Bobolink activity and the ability of observers to detect birds. Wind during surveys was ≤ 3 on the Beaufort scale during May and June and ≤ 5 in July (National Oceanic and Atmospheric Administration (NOAA) [online] 2018). To minimize differences among the four observers, we regularly practiced surveys together with a laser rangefinder to ensure consistency of survey techniques and detections of Bobolinks.

Analyses. We used program R (version 3.5.1, R Core Team 2018) for all analyses. We first assessed the efficacy of transect and point-count surveys to capture male Bobolink abundance. We used the `cor.test` function to calculate the Spearman correlation (ρ and test statistic S ; Zar 1999) between the number of territories in each field, based on spot mapping, and the maximum number of males detected in each field on any one visit during May or June for (1) transect surveys and (2) point counts. The maximum number of males detected in each field for transect and point-count surveys included all males detected across multiple transect lines or point counts on any one visit to each field. For descriptive purposes, we compared the sum of the maximum number of males detected in each field to the sum of the mean number of males detected across visits for transect and point-count surveys.

We analyzed transect surveys with distance sampling (Buckland et al. 1993a), specifically the Distance package (Miller 2019), to estimate the total number of male Bobolinks across the sum of the area of all fields surveyed. Distance sampling produces estimates of abundance, density, and detection probability based on the distance of detected individuals from the transect line. For analyses, we only used detections of males in May and June, excluding detections of males in July and all detections of females and fledglings. We ran models for each key function (half-normal, hazard, and uniform) and compared relative model performance using the second-order Akaike's information criterion (AICc; Akaike 1974, Burnham and Anderson 2002). We considered models with $\Delta\text{AICc} < 7$ (calculated using the `aictabCustom` function in the R package `AICcmodavg` [Mazerolle 2019]) to have some support compared to the best-supported model (Burnham et al. 2011). We included continuous covariates relevant to detection in models (i.e., date and minutes since sunrise; Best 1981, Robbins 1981, Farnsworth et al. 2002). We normalized continuous covariates (centered around 0 and variance = 1; Zuur et al. 2007) to ensure our models converged. We did not include categorical covariates (e.g., observer) because models would not converge. We used the `gof_ds` function to apply the Cramer-von Mises test to evaluate goodness-of-fit and

considered P values < 0.05 as evidence of poor model fit. We used transect length and the sum of the area of all fields in the dataset to estimate abundance for the entire area of surveyed fields. We compared the estimate of the abundance of males for all fields combined to the sum of territories for all fields based on spot mapping.

We used N -mixture abundance models (Royle 2004, Kéry and Royle 2016) to estimate the abundance of male Bobolinks (again only using detections of males in May and June) separately for transect and point-count surveys (`pcount` function in R package `Unmarked`; Fiske and Chandler 2011). N -mixture models were developed to estimate abundance from repeated counts, while accounting for imperfect detection (Royle 2004). We checked to determine if either zero-inflated Poisson (ZIP) or negative binomial models better explained the variation in the system than Poisson models (Kéry 2018). We normalized continuous detection covariates (date and minutes since sunrise) to ensure our models converged. To evaluate reduced and null models, we used an information-theoretic approach and considered models with $\Delta\text{AICc} < 7$ to have some support compared to the best-supported model (Burnham et al. 2011). We did not include covariates relevant to abundance; our interest was in comparing abundance estimates among analytical techniques and survey methods. We ran the same set of models three times to assess variation in estimated abundance across two, three, and four point-count surveys, which could be caused by violations to the population closure assumption. We checked goodness-of-fit using a Pearson chi-square statistic in the R package `AICcmodavg` (Mazerolle 2019) and considered P values < 0.05 (1000 simulations) as evidence of poor model fit. To compare with the sum of territories for all fields based on spot mapping, we estimated the number of male Bobolinks from the best-supported model for transects by multiplying the predicted abundance per 100-m transect section by the number of transect sections ($N = 105$) and, for point counts, by multiplying the predicted abundance per point by the number of survey points ($N = 46$; Royle 2004).

We used descriptive statistics to evaluate the efficacy of transect and point-count

surveys to detect evidence of breeding (using detections of males, females, and fledglings in May, June, and July) compared to spot mapping and nest monitoring. For comparison with spot mapping and nest-monitoring data, we calculated the percent of fields with (1) detections of male Bobolinks, (2) evidence of nesting, and (3) evidence of fledging separately for transect and point-count surveys.

RESULTS

We found Bobolink territories in 78% of the fields (28 of 36) based on spot mapping. Transect surveys correctly identified Bobolink presence in all fields with territories and detected the species in one field that did not have a territory. Point counts failed to detect Bobolinks in two fields with territories and detected Bobolinks in one field with no territories.

Observed abundance. The sum of the maximum number of males detected on transect surveys in each field was 193, similar to the 197 territories based on spot mapping, whereas the sum of the maximum number of males detected on point counts in each field

was 118 (Fig. 1). The maximum number of males detected on one visit in each field for transect ($S = 382.9$, $P < 0.001$, $\rho = 0.95$; Fig. 2) and point-count ($S = 1117.2$, $P < 0.001$, $\rho = 0.86$; Fig. 2) surveys was strongly correlated with the number of territories in each field. On transect surveys, we detected the maximum number of males on the second visit in 13 fields and on the first visit in 12 fields (11 fields were tied). For point counts, we detected the maximum number of males most frequently on the fourth visit (nine fields) and least frequently on the first visit (two fields). The sum of the mean number of males detected across visits was lower than the sum of the maximum number of males detected for both transect (159, 193) and point-count (68.5, 118) surveys.

Estimated abundance. During transect surveys, we detected 318 male Bobolinks, 152 during visit one and 166 during visit two. The best-supported distance sampling model had date and minutes since sunrise as covariates and a hazard-rate key function (Tables 1 and 2). We found minimal model uncertainty because the second model had $\Delta AICc$ 3.46

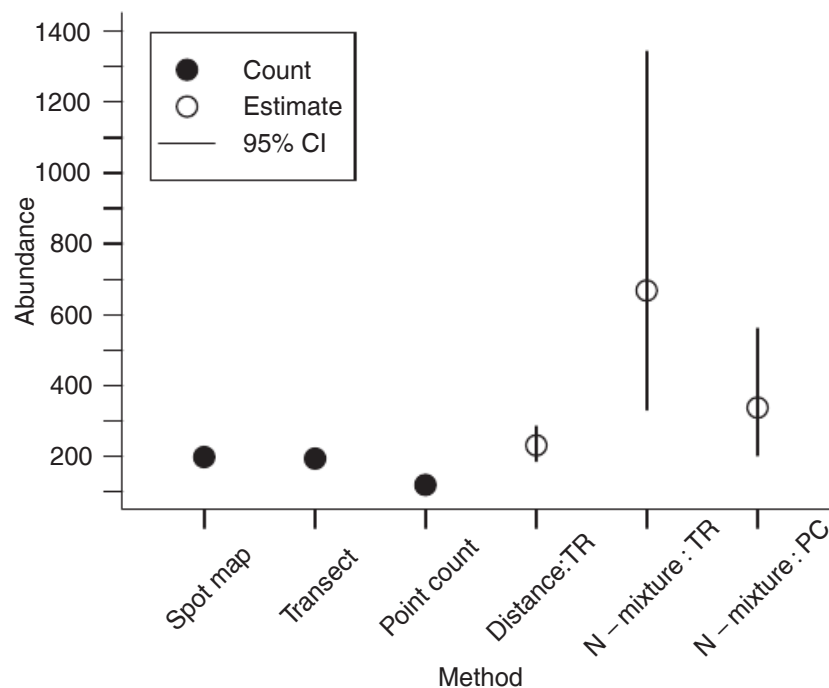


Fig. 1. The number of male Bobolinks observed or estimated across survey and analysis methods (i.e., spot mapping, transect survey, point count, distance sampling for transects, N -mixture model for transects, and N -mixture model for point counts [four visits]) in 36 fields in southern Ontario in 2018. Observed abundance for transect survey and point count is the sum of the maximum number of males detected on any one visit to each field.

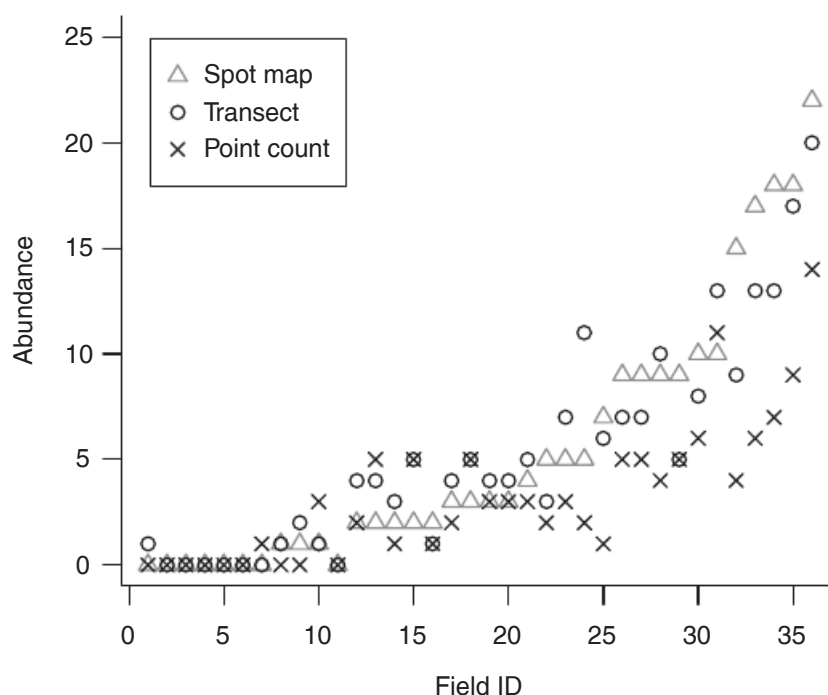


Fig. 2. The maximum number of male Bobolinks observed in each field with two visits to conduct transect surveys and four visits to conduct point counts was correlated with the number of territories in each field, based on spot mapping. Surveys were conducted in 36 fields in southern Ontario in 2018.

and was similar to the best-supported model, lacking only the minutes since sunrise covariate (Table 1). Detection probability was high, 0.95 (SE = 0.04), based on the best-

supported model. Estimated abundance from the best-supported model was 230 male Bobolinks (95% CI: 187, 282) in the 254 ha of surveyed fields (Fig. 1).

Table 1. Model results for distance sampling analysis of transect survey data to estimate abundance of male Bobolinks in hay fields, restored grasslands, and fallow fields ($N = 36$) in southern Ontario in 2018.

Model ^a	Key function	K ^b	$\Delta AICc^c$	P^d	Detection ^e	Abundance ^f
Date + min since sunrise	Hazard-rate	4	0.00	0.19	0.95	230
Date	Hazard-rate	3	3.46	0.18	0.95	229
Date + min since sunrise	Half-normal	3	15.37	0.11	0.89	244
Date	Half-normal	2	15.66	0.14	0.91	239
Date × min since sunrise	Half-normal	4	17.62	0.07	0.88	247
Date × min since sunrise	Hazard-rate	5	18.66	0.11	0.95	229
Intercept	Half-normal	1	22.30	0.11	0.95	230
Intercept	Uniform, cosine adjustment	1	22.74	0.11	0.96	228
Intercept	Hazard-rate	2	23.63	0.12	0.96	227
Min since sunrise	Half-normal	2	23.72	0.20	0.94	232
Min since sunrise	Hazard-rate	3	23.98	0.27	0.96	227

^aModels with an interaction term (×) also include additive effects of covariates. Date = normalized ordinal date, min since sunrise = normalized minutes since sunrise.

^bNumber of parameters in model.

^cAICc for best-supported model = 2724.91.

^dCramer–von Mises goodness-of-fit test.

^eEstimated probability of detection for male Bobolinks on transect surveys.

^fEstimated abundance of male Bobolinks in 254 ha of surveyed fields.

Table 2. Parameters for the best-supported distance sampling model from analysis of transect survey data to estimate abundance of male Bobolinks in hay fields, restored grasslands, and fallow fields ($N = 36$) in southern Ontario in 2018.

Coefficients	Parameter ^a	Estimate	SE
Scale	Intercept	4.947	0.318
	Date	-0.706	0.292
	Min since sunrise	0.056	0.038
Shape	Intercept	4.722	8.093

^aDate = normalized ordinal date, min since sunrise = normalized minutes since sunrise.

The best-supported N -mixture model for transect surveys had minutes since sunrise as a detection covariate and a zero-inflated Poisson distribution (Tables 3 and 4). There was model uncertainty because other competitive models ($\Delta\text{AICc} < 7$) included an intercept-only model and a combination of the detection covariates minutes since sunrise and date for models with the zero-inflated Poisson

distribution. Detection probability was moderate in competitive models (0.45–0.49; Table 3). Estimated abundance from the best-supported model was 668 males (95% CI: 332, 1342; Fig. 1) within the surveyed area of transects.

During point counts, we detected 274 males, 53 on visit one, 59 on visit two, 68 on visit three, and 94 on visit four. The best-supported N -mixture model for data across all four visits had minutes since sunrise as a detection covariate and a zero-inflated Poisson distribution (Tables 5 and 6). Other competitive models ($\Delta\text{AICc} < 7$) included a combination of the detection covariates minutes since sunrise and date, and the zero-inflated Poisson or negative binomial distribution. Detection probability was moderately high in competitive models (0.61–0.69; Table 5). Estimated abundance from the best-supported model was 337 males (95% CI: 203, 559; Fig. 1) within the surveyed radius of point counts. Estimated abundance increased with the number of visits included in the dataset, but mean estimates were within 95% CI (two

Table 3. Results for N -mixture models from analysis of transect survey data to estimate abundance of male Bobolinks in hay fields, restored grasslands, and fallow fields ($N = 36$) in southern Ontario in 2018.

Model ^a	Distribution ^b	K ^c	ΔAICc^d	P^e	Detection ^f	Abundance ^g
$\lambda(.)$ $p(\text{min since sunrise})$	ZIP	4	0.00	0.38	0.48	668
$\lambda(.)$ $p(\text{min since sunrise} + \text{date})$	ZIP	5	1.78	0.37	0.49	661
$\lambda(.)$ $p(.)$	ZIP	3	3.33	0.34	0.45	716
$\lambda(.)$ $p(\text{min since sunrise} \times \text{date})$	ZIP	6	3.99	0.37	0.49	655
$\lambda(.)$ $p(\text{date})$	ZIP	4	4.93	0.33	0.46	709
$\lambda(.)$ $p(\text{min since sunrise})$	NB	4	8.39	0.73	0.47	575
$\lambda(.)$ $p(\text{min since sunrise} + \text{date})$	NB	5	10.15	0.72	0.48	569
$\lambda(.)$ $p(.)$	NB	3	11.07	0.76	0.42	674
$\lambda(.)$ $p(\text{min since sunrise} \times \text{date})$	NB	6	12.32	0.72	0.48	569
$\lambda(.)$ $p(\text{date})$	NB	4	12.63	0.76	0.42	661
$\lambda(.)$ $p(\text{min since sunrise})$	Poisson	3	14.68	0.00	0.66	381
$\lambda(.)$ $p(\text{min since sunrise} + \text{date})$	Poisson	4	16.32	0.01	0.66	381
$\lambda(.)$ $p(\text{min since sunrise} \times \text{date})$	Poisson	5	18.50	0.00	0.66	381
$\lambda(.)$ $p(.)$	Poisson	2	18.93	0.00	0.64	397
$\lambda(.)$ $p(\text{date})$	Poisson	3	20.34	0.00	0.64	393

^aModels with an interaction term (\times) also include additive effects of covariates. Date = normalized ordinal date, min since sunrise = normalized minutes since sunrise.

^bNB = negative binomial, ZIP = zero-inflated Poisson.

^cNumber of parameters in model.

^dAICc for best-supported model = 663.04.

^eChi-square goodness-of-fit test.

^fEstimated probability of detection for male Bobolinks on transect surveys.

^gEstimated abundance of male Bobolinks within 75 m of either side of the transect line for all transects.

Table 4. Parameters for the best-supported *N*-mixture model from analysis of transect survey data to estimate abundance of male Bobolinks in hay fields, restored grasslands, and fallow fields ($N = 36$) in southern Ontario in 2018.

	Parameter ^a	Estimate	95% CI
Abundance	Intercept	1.850	1.154, 2.548
Detection	Intercept	−0.951	−1.898, −0.004
	Min since sunrise	0.177	0.022, 0.332

^aMin since sunrise = normalized minutes since sunrise.

visits [204; 95% CI: 82, 506], three visits [283; 95% CI: 127, 637]).

Evidence of nesting and fledging. The earliest date Bobolinks laid eggs was 18 May, and the latest date of nesting activity (i.e., young fledged) was 23 July. Peak dates in nesting phenology, based on nest monitoring, were 20–29 May for first-egg date ($N = 207$), 4–13 June for hatch date ($N = 201$), and 14–23 June for fledge date ($N = 153$; Fig. 3). Bobolinks nested in and fledged young from all fields with territories (i.e., 78% [28 of 36]), based on spot mapping and nest monitoring. We detected evidence of nesting in 61% of fields with point counts, compared to 50% of fields with transect surveys. In contrast, we detected evidence of fledging in more fields with transect surveys (28%) than point counts (8%). We had no false-positive detections of nesting or fledging in fields with either transect or point-count surveys. With transect surveys, we detected no evidence of fledging until our third visit to fields from 1 to 4 July, although we did detect evidence of nesting in June during our second visit to fields (Fig. 4). Agitated alarm calling by adults was the breeding behavior detected most frequently during transect (65%, $N = 92$) and point-count (82%, $N = 97$) surveys.

DISCUSSION

We evaluated the efficacy of three techniques for estimating abundance and compared their accuracy to abundance determined by spot mapping, which provided the best

possible count of the number of breeding territories. Overall, we found that distance sampling analysis of transect survey data provided a better estimate of the abundance of male Bobolinks than estimates from *N*-mixture models based on transect or point-count surveys. Further, our results are consistent with previous studies indicating that transects provide more accurate and precise estimates of density than point counts for Bobolinks (Bollinger et al. 1988) and also provide more precise estimates of abundance for other species of grassland birds (Golding and Dreitz 2016). Criticisms of *N*-mixture models have focused on implications of violated model assumptions, specifically effects on detection probabilities. Critics have used simulations to show the magnitudes of effects created by model violations (Barker et al. 2018, Duarte et al. 2018). Rather than simulate those effects and differences, we used field-collected data to compare estimates among commonly used abundance estimation techniques. Our results suggest that distance sampling analysis of transect survey data is a promising method for estimating the number of Bobolink territories in fields during the breeding season. However, both transect and point-count surveys were unreliable for assessing evidence of breeding in fields, underestimating the number of fields where Bobolinks nested and fledged young compared to spot mapping and nest monitoring. Thus, detecting nesting and fledging in fields may require either surveys conducted during different periods of time or more frequent visits than in our study, and estimating fledging success likely requires more intensive methods.

We found that the detection probability of male Bobolinks with a distance sampling analysis of transect survey data was high (i.e., 0.95), which is largely consistent with previously published estimates. For example, Lueders et al. (2006) estimated the detection probability of male and female Bobolinks as 1.0, based on distance sampling of point-count data. Shustack et al. (2010) found that the detection probability of male Bobolinks was > 0.99 within 50 m of point counts, based on Huggin's closed capture removal models. Rotella et al. (1999) reported that the detection probability of male Bobolinks was 0.91 at 50 m and 0.80 at 75 m, based on distance sampling of point-count data.

Table 5. Results for N -mixture models from analysis of point-count data (four visits) to estimate abundance of male Bobolinks in hay fields, restored grasslands, and fallow fields ($N = 36$) in southern Ontario in 2018.

Model ^a	Distribution ^b	K ^c	$\Delta AICc^d$	P^e	Detection ^f	Abundance ^g
$\lambda(.)$ $p(\text{min since sunrise})$	ZIP	4	0.00	0.08	0.69	337
$\lambda(.)$ $p(\text{min since sunrise} + \text{date})$	ZIP	5	1.83	0.07	0.69	337
$\lambda(.)$ $p(\text{min since sunrise})$	NB	4	5.35	0.85	0.61	319
$\lambda(.)$ $p(\text{min since sunrise} + \text{date})$	NB	5	7.19	0.82	0.61	324
$\lambda(.)$ $p(.)$	ZIP	3	11.26	0.04	0.86	409
$\lambda(.)$ $p(\text{date})$	ZIP	4	13.54	0.03	0.61	413
$\lambda(.)$ $p(.)$	NB	3	15.77	0.86	0.69	561
$\lambda(.)$ $p(\text{date})$	NB	4	18.04	0.86	0.40	575
$\lambda(.)$ $p(\text{min since sunrise})$	Poisson	3	30.47	0	0.86	174
$\lambda(.)$ $p(\text{min since sunrise} + \text{date})$	Poisson	4	31.89	0	0.86	176
$\lambda(.)$ $p(.)$	Poisson	2	46.44	0	0.83	190
$\lambda(.)$ $p(\text{date})$	Poisson	3	48.56	0	0.83	190
$\lambda(.)$ $p(\text{min since sunrise} \times \text{date})$	NB	6	109.25	0.08	0.66	335
$\lambda(.)$ $p(\text{min since sunrise} \times \text{date})$	Poisson	5	175.80	0	0.83	176
$\lambda(.)$ $p(\text{min since sunrise} \times \text{date})$	ZIP	6	216.55	0.86	0.59	315

^aModels with an interaction term (\times) also include additive effects of covariates. Date = normalized ordinal date, min since sunrise = normalized minutes since sunrise.

^bNB = negative binomial, ZIP = zero-inflated Poisson.

^cNumber of parameters in model.

^dAICc for best-supported model = 544.33.

^eChi-square goodness-of-fit test.

^fEstimated probability of detection for male Bobolinks on point counts.

^gEstimated abundance of male Bobolinks within the 75-m survey radius of all point counts.

Table 6. Parameters for the best-supported N -mixture model from analysis of point-count data (four visits) to estimate abundance of male Bobolinks in hay fields, restored grasslands, and fallow fields ($N = 36$) in southern Ontario in 2018.

	Parameter ^a	Estimate	95% CI
Abundance	Intercept	1.990	1.481, 2.497
Detection	Intercept	-1.070	-1.746, -0.393
	Min since sunrise	0.289	0.125, 0.453

^aMin since sunrise = normalized minutes since sunrise.

However, lower detection probabilities have been reported that are similar to and lower than the moderate detection probabilities we estimated from transect (0.45–0.49) and point-count (0.61–0.69) survey data using N -mixture models. Thompson et al. (2014) found that the detection probability for

Bobolinks was 0.68 early in the breeding season and 0.34 during late-season point counts, based on multinomial-negative binomial mixture models. We suspect that the detection probability is higher for male Bobolinks than females because females are often inconspicuous during incubation (whereas males do not incubate), and males sing and females do not. Detection probability may also be low for other grassland birds. For example, Diefenbach et al. (2003) found that up to 60% of grassland birds in Pennsylvania went undetected > 50 m from transects based on distance sampling, underscoring the importance of estimating or addressing detection probability when estimating abundance.

Because detection probability of male Bobolinks on transect surveys was high, the sum of the maximum number of males we detected in each field across two transect surveys (193) was similar to the sum of the number of territories across all fields based on spot mapping (197). Mean abundance across multiple visits is often used as an index of abundance (Betts et al. 2005), but we found

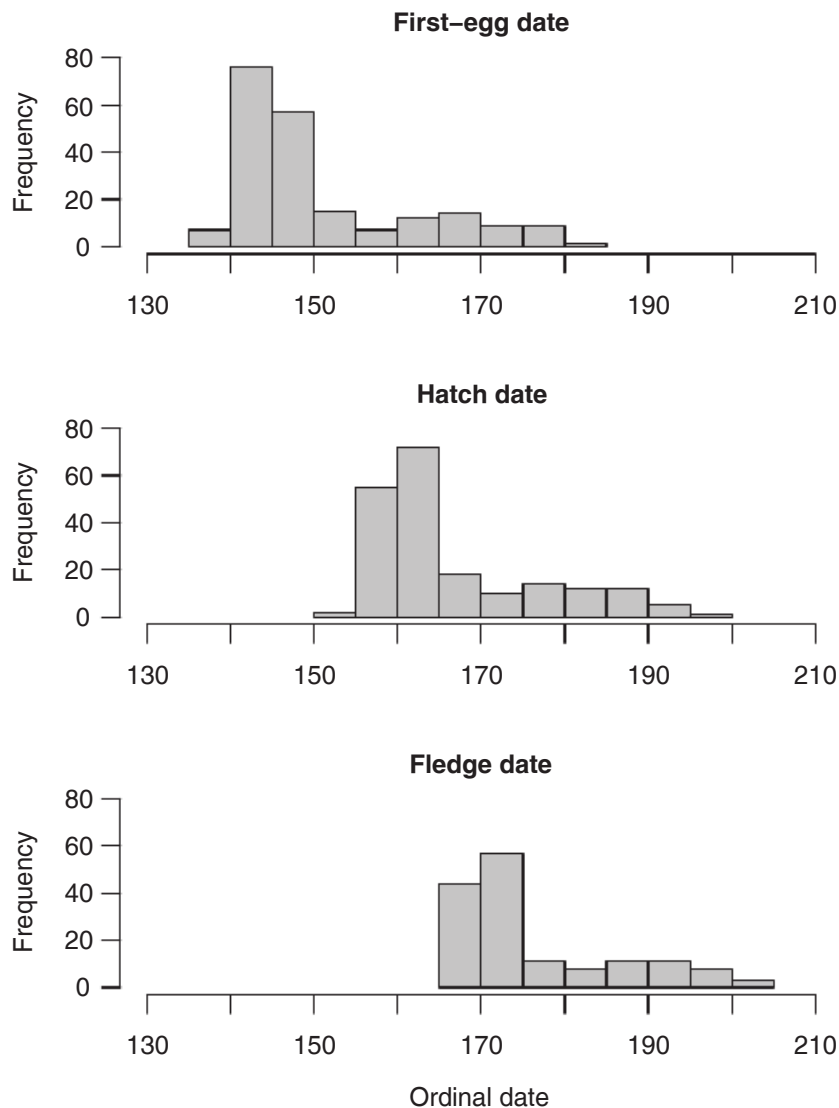


Fig. 3. Histograms showing peak dates in Bobolink nesting phenology (based on nest monitoring), including 20–29 May for first-egg date ($N = 207$), 4–13 June for hatch date ($N = 201$), and 14–23 June for fledge date ($N = 153$). Nest data are binned in five-day increments across the breeding season for nests monitored in hay fields, restored grasslands, and fallow fields in southern Ontario in 2018. Dates are ordinal dates (i.e., day 1 to 365 of the year). Ordinal date 130 = 10 May and 210 = 29 July.

that the maximum number of males detected across visits was an accurate estimate of the number of territories. Although indices of abundance have their uses for monitoring (Johnson 2008), not accounting for imperfect detection of birds on surveys can lead to biased abundance estimates (Nichols et al. 2000, Farnsworth et al. 2002, Buckland 2006). Using transect surveys as an index of abundance for Bobolinks may be acceptable in some cases (e.g., fixed-area surveys; Hutto 2016, 2017), but is likely to be criticized by some researchers because of the substantial literature about model-based estimates of

detection probability (Anderson 2001, Ellingson and Lukacs 2003, Kellner and Swihart 2014, Hayward et al. 2015, Marques et al. 2017). Additionally, indices of abundance could be biased because of visual obstructions in fields, particularly shrub cover. Impacts of detection probability could bias an index of abundance across a gradient of percent shrub cover or temporal trends if shrub cover increases across years or shrub cover is cleared for grassland management. The probability of detecting Bobolinks could also vary by date and minutes since sunrise, as we found, and among observers (Ramsey and Scott 1981,

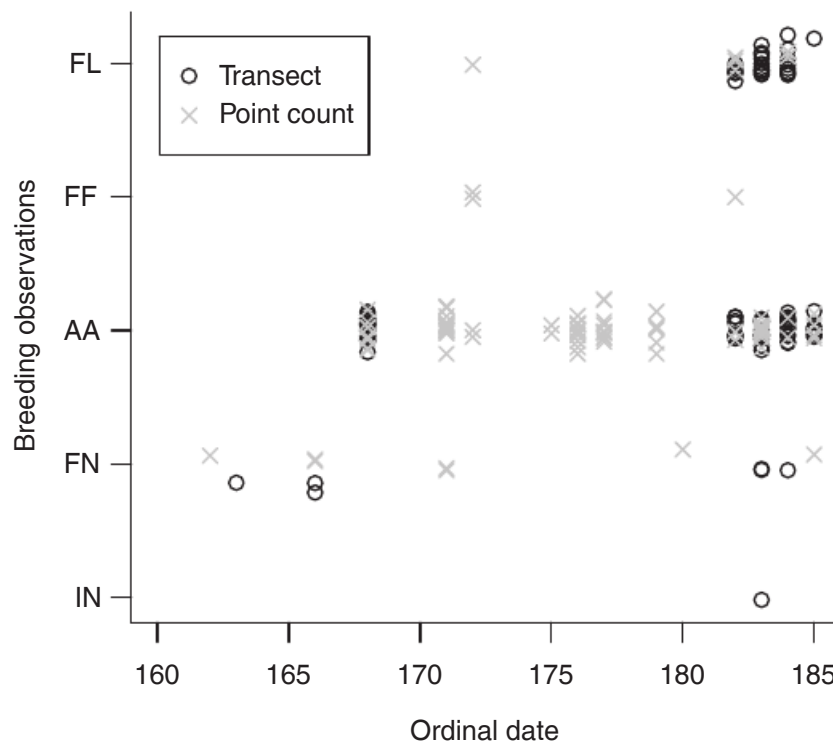


Fig. 4. Detections of Bobolink breeding behaviors across the breeding season during transect and point-count surveys in 36 fields in southern Ontario in 2018. Breeding behaviors were as follows: IN = incubating, FN = food carry to nest, AA = agitated alarm calling, FF = food carry to fledgling(s), and FL = dependent fledgling(s) observed (incapable of sustained flight, fed by adults). We made three visits to conduct transect surveys and five visits to conduct point counts from 17 May to 4 July. Dates are ordinal dates (i.e., day 1 to 365 of the year). Ordinal date 160 = 9 June and 185 = 4 July. Data points were jittered on the y-axis to make points visible.

Diefenbach et al. 2003, Alldredge et al. 2007). We recommend that estimates of Bobolink abundance include estimates of detection probability to provide rigorous results that are likely to be widely accepted, can be compared across time and space, and can be used to support conservation efforts (Kellner and Swihart 2014, Hayward et al. 2015). We also recommend additional study to evaluate model-based estimates of abundance with the best available information (e.g., from spot mapping of marked or unmarked populations and nest monitoring).

Surveys conducted later in the breeding season may give higher estimates of male abundance than early-season surveys for two reasons. We suspect that we detected slightly more male Bobolinks during visit two than during visit one of transect surveys, and on each subsequent point count visit, because adults often gave alarm calls and approached observers when caring for mature nestlings or young fledglings. Additionally, Bobolinks

disperse from hay fields and pastures after mowing and heavy grazing during the breeding season. Dispersal and mortality during the breeding season is problematic for some methods of estimating occurrence or abundance, e.g., the geographic closure assumption in occupancy (MacKenzie et al. 2002) and population closure assumption in *N*-mixture modeling (Royle 2004). Based on spot mapping, we did not observe substantial immigration of adults to surveyed fields in June after hay harvest began at other locations in our study area. Across the 197 territories we monitored, we estimate that five territories were established after the initial establishment of most territories during the third week of May and one male abandoned a territory in late May. We noted one mortality; we found a dead female adjacent to a predated nest, but the male remained. More dispersal may occur in other years or fields. Conducting surveys after Bobolinks begin their first nesting attempt, but before dispersal from fields

disturbed by agricultural activity, will likely provide the most accurate estimates of male abundance. Therefore, the best timing for surveys in our study area would likely be during the last week of May and first week of June.

Distance sampling analysis of transect survey data provided a reasonable estimate of the abundance of male Bobolinks across the fields we surveyed. Although the mean estimate of abundance was higher than the number of territories, the number of territories was within the 95% confidence interval for abundance. In contrast, estimated abundance from *N*-mixture models for transect and all point-count data was substantially higher than the number of territories, and the lower bound of the 95% confidence intervals (332 and 203, respectively) was higher than the number of territories (197). The area covered by each transect and point-count survey and the sum of the area covered by each survey type varied in our study, which likely influenced the number of males detected, and thus, estimates of abundance for each survey type. In future studies, investigators could examine the use of distance sampling with point-count data, something we were unable to address.

Distance sampling analysis of transect survey data appears promising for estimating the number of Bobolink territories in an area, such as those impacted by future stewardship programs, and is less time-consuming than spot mapping (Thompson et al. 1998). As with any method, there are challenges to overcome and assumptions to meet. For example, a minimum of 60 to 80 detections of the focal species is recommended to analyze data using distance sampling (Buckland et al. 1993b). Additionally, substantial effort is needed to design surveys and meet the assumptions of distance sampling (Buckland et al. 1993b). Given various analysis options and criticisms thereof (e.g., Johnson 2008, Hutto 2016, Link et al. 2018), distance sampling is a viable option that is well accepted in the literature and straightforward to implement in the field. Software is also available for planning study design and sampling for research and monitoring (Thomas et al. 2010).

Compared to other co-occurring grassland bird species, estimating the abundance of male Bobolinks has unique advantages and

disadvantages that makes the implications of our results to other species unclear. A primary advantage is that detection probability is high, based on our results and those of other investigators (Rotella et al. 1999, Lueders et al. 2006, Shustack et al. 2010), reducing the sampling effort and number of visits to survey locations needed to obtain sufficient detections than would be the case for species with lower detection probabilities. Estimating the abundance of Eastern Meadowlarks (*Sturnella magna*), for example, may be more challenging because their territories are larger (Jaster et al. 2012, Renfrew et al. 2015), increasing the chance of detecting an individual at multiple survey locations, and the species was less common than Bobolinks based on observations in our study area. Study design, survey protocol, and analysis methods for estimating the abundance of male grassland birds should be optimized for the target species. Ultimately, accuracy of surveys and resulting analyses can be species-specific (DeSante 1986, Buckland 2006, Johnson 2008).

Three visits to conduct transect surveys and five visits to conduct point counts did not allow us to effectively detect evidence of Bobolink breeding (i.e., nesting or fledging). Although we found no previous assessments of how to detect evidence of breeding with low-intensity surveys for Bobolinks, other studies have revealed weaknesses with the Vickery index (Vickery et al. 1992) for other species of grassland birds (Rivers et al. 2003, Morgan et al. 2010). Low-intensity surveys (i.e., transect surveys) may be suitable for assessing overall evidence of breeding in a field if fields are visited more often than the three visits used in our study or if visits occur when there is a greater chance of observing breeding behaviors (e.g., late June and early July in our study area; Put et al. 2020). If estimates of the number of nesting Bobolinks and frequency of fledging are of interest, then perhaps spot mapping (*sensu* Wiens 1969) and nest monitoring (Martin and Geupel 1993) could be implemented at a representative subset of monitored fields.

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