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Identifying when bobolink finish breeding to guide timing of agricultural activity

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1 Introduction

Bird conservation on private land is essential for reaching conservation goals in North America (Ciuzio et al. 2013). Private rural land is often in a working landscape (e.g., agricultural); therefore, finding a balance between the needs of landowners and conservation is essential for simultaneously maintaining working landscapes and advancing conservation (Kremen and Merenlender 2018). Long-term population declines of songbirds (i.e., order Passeriformes) that breed in grasslands in North America (Sauer et al. 2017) have led to conservation concern for some of these species. Most extant grasslands in North America are used for agriculture and occur in agricultural landscapes (Sampson and Knopf 1994, Brennan and Kuvlesky 2005, Hoekstra et al. 2005). Thus, the conservation of grassland obligate songbirds is inextricably linked to agricultural landscapes.

Bobolink (*Dolichonyx oryzivorus*) is a species at risk in multiple jurisdictions because of a 2.0% average annual population decline from 1966 to 2015 across their North American breeding range (Sauer et al. 2017). The International Union for Conservation of Nature lists bobolink as least concern because of the species' large population and breeding range (IUCN 2018). However, bobolink are listed as threatened by the Canadian (Government of Canada 2018) and Ontario (MNRF 2018) governments. Ontario has a substantial role to play in bobolink conservation because 13% of the global population breeds in the province, which is the largest percent for any province and is surpassed by the states of North Dakota (22%) and Minnesota (13%) only (Partners in Flight Science Committee 2013). Bobolink conservation in Ontario includes a provincial government plan for recovery (MNRF 2015) to counter the 2.6% average annual population decline in the province (based on Breeding Bird Survey data for Ontario from 1968 to 2008; COSEWIC 2010). The bobolink population decline likely has multiple causes, including habitat loss and a decrease in habitat quality on breeding grounds (COSEWIC 2010, McCracken et al. 2013, MNRF 2015, Ethier and Nudds 2017). Agricultural practices on breeding grounds can decrease habitat quality (e.g., hay harvest and livestock grazing during the breeding season), resulting in direct and indirect destruction of nests (Bollinger et al. 1990, Perlut et al. 2006, MacDonald and Nol 2017).

Common conservation practices implemented on farms to support nesting bobolink in Ontario include delaying grazing and hay harvesting until mid-July (e.g., MNRF 2015, OSCIA 2018). Mid-July appears to be a reasonable approximation of when bobolink finish nesting in most hay fields and pastures in southern and eastern Ontario (Renfrew et al. 2015, Brown and Nocera 2017, Diemer and Nocera 2016, MacDonald and Nol 2017). However, bobolink breeding phenology and temporal changes in forage quality of hay fields and pastures can vary geographically (Nocera et al. 2005, Perlut et al. 2011, Diemer and Nocera 2016). Additionally, assessing when bobolink are finished nesting in a particular field could provide advantages over, or in addition to, a general conservation guideline of mid-July. For example, some bobolink nests are active after mid-July; viable eggs have been observed in a nest as late as 16 July (Peck and James 1987). We have monitored nests that fledged as late as 22 July in eastern Ontario (A. J. Campomizzi, Bird Ecology and Conservation Ontario, unpublished data). Considering that young bobolink are incapable of sustained flight for about 1 week after leaving the nest (Renfrew et al. 2015), delaying agricultural activity until early August would have been necessary to avoid impacts on all breeding bobolink in these particular fields. In contrast, in some of the fields we monitored in 2017, we did not observe bobolink nesting activity after late June. Presumably, most farmers want to delay grazing and hay harvesting as little as possible to maximize nutritional content of forage, which declines for protein across June and July (Brown and Nocera 2017).

Our goal was to test the efficacy of various field survey types to identify when bobolink finish breeding in pastures, hay fields, fields seeded for grassland restoration, and fallow fields. Identifying an appropriate field survey method will enable the development of a reliable approach of determining when grazing or hay harvest in a particular field will avoid impacting nesting bobolink and thus, maximize the conservation benefit of the field for this species. We used spot mapping and nest monitoring to determine when bobolink finished breeding in a field and compared the efficacy of less intensive field surveys (i.e., transect surveys in fields, point counts in fields, and roadside counts). We predicted that (1) transect surveys would detect breeding evidence more frequently than point counts and roadside counts and (2) some less intensive survey types could be used to accurately assess whether bobolink were still breeding in a field.

2 Methods

2.1 Study species

Bobolink have a large breeding range across southern Canada and the northern USA (Renfrew et al. 2015). In contrast, the species has a relatively small non-breeding range in the southern interior of South America, primarily in Paraguay, eastern Bolivia, northeastern Argentina, and southwestern Brazil (COSEWIC 2010, Renfrew et al. 2015). The spring trans-equatorial migration begins in late March and early April (Renfrew et al. 2015). The typical duration of nesting is ~28 days (1 egg laid per day [mean clutch size = ~5], incubation begins on the day the last egg is laid, 12 days of incubation, 11 days from hatch to fledge; Renfrew et al. 2015). The earliest date young fledged from nests was 18 June in 2017 and 15 June in 2018. Bobolink rarely raise > 1 brood per year; however, individuals may attempt a second nest following an initial nest failure (Renfrew et al. 2015). Nests initiated late in the season led to young fledging as late as on 22 July in 2017 and 23 July in 2018. Additionally, bobolink young are incapable of sustained flight for about 1 week after leaving the nest (Renfrew et al. 2015). The breeding phenology of bobolink often overlaps with dates of cattle grazing and hay harvest on farms.

2.2 Study area

In 2017, we studied bobolink on 10 cattle farms in the Ottawa Valley (< 20 km from the town of Cobden [45°37´36´´, -76°52´53´´]) in Renfrew County in eastern Ontario, Canada). In 2018, we studied bobolink in the Luther Marsh Wildlife Management Area (43°57´45´´, -80°24´2´´) in Dufferin and Wellington counties in southern Ontario and on 4 farms within 42 km. Over these 2 years, we monitored bobolink in 54 fields, 29 in 2017 and 25 in 2018. All fields had evidence of breeding in May, June, or both, based on spot mapping and nest monitoring. In 2017, we monitored fields on beef farms that were rotationally-grazed (n = 19), continuously-grazed (n = 5), or un-grazed (n = 5). Cattle moved through $\geq$ 3 paddocks of subdivided pasture during the grazing season in rotationally-grazed fields; whereas, cattle had unrestricted access to a pasture for the entire grazing season in continuously-grazed fields (OMAFRA 2012). In 2018, we monitored hay fields (n = 9) on 3 farms, fields seeded for grassland restoration (n = 10) in the Luther Marsh WMA, and fallow fields (n = 6) in the Luther Marsh WMA and on 1 farm.

2.3 Study design

We used spot mapping and nest monitoring to acquire the most accurate assessment possible of breeding status in each field. We used 3 additional less intensive survey types and compared results to assess whether these surveys could be used to reliably identify when bobolink finish breeding in July. For analysis and results, we refer to combined data from nest monitoring and spot mapping as spot map. We visited each field approximately twice per week to conduct spot mapping, nest monitoring, and the 3 less intensive surveys types (i.e., transect surveys, point counts, roadside counts [where possible]).

2.4 Spot mapping and nest monitoring

We used a modified spot mapping method (*sensu* Wiens 1969) to delineate and monitor bobolink territories. From mid-May through July, we visited each field approximately twice per week (unless cattle were present in rotationally-grazed fields) to search for bobolink. When we detected a bobolink, we followed the individual or pair for up to 30 min, if possible. For each individual or pair, we recorded 3 to 6 global positioning system (GPS) locations per visit and recorded bird behaviour at each location to document breeding activity. Repeated visits enabled us to delineate territories based on clusters of GPS locations and the number of individuals we detected on each visit. We classified behavioural observations using a modified Vickery index of breeding status (Table 1; Vickery et al. 1992), providing evidence of nesting (i.e., adult(s) incubating a nest or carrying nest material or food) and fledging (i.e., adult(s) delivering food to multiple locations after evidence of a nest observed, flightless dependent fledglings, or adults carrying food for $\geq$ 11 days) in each bobolink territory. We considered adults carrying food to 1 location for $\geq$ 11 days as evidence of fledging because bobolink young remain in the nest for 10 to 11 days (Renfrew et al. 2015). In 2018, we added a behavioural observation category to record an adult bobolink behaviour we called agitated alarm calling, indicating the presence of mature nestlings or young fledglings. We did not consider observations of male-female interactions (e.g., courtship) as evidence of breeding. In July, we recorded the presence of a bobolink flock in each field during spot mapping visits. We defined a flock as a group of non-breeding bobolink that remained in a group while foraging, preening, and vocalizing.

During spot mapping, we also searched for bobolink nests. We used behavioural cues and systematic searching to locate nests (Martin and Geupel 1993, Winter et al. 2003). We did not approach nests when females were building to minimize disturbance when the chance of nest abandonment can be high (Renfrew et al. 2015). Once bobolink were incubating eggs, we visited nests approximately once every 3 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, age of young, condition of the nest, and adult behaviour. We considered several factors to determine if a nest fledged, including if we observed $\geq$ 1 flightless dependent fledgling near a nest, adults alarm calling near a nest that had large nestlings on the previous visit, and adults delivering food near a nest that had large nestlings on the previous visit. For each nest with sufficient data, we estimated the first-egg date, hatch date, and fledge date based on our observations and previously documented time periods (i.e., 1 egg laid per day, incubation begins on the day the last egg is laid, 12 days of incubation, 11 days from hatch to fledge; Renfrew et al. 2015).

To determine if breeding was occurring in a field for each visit in July, we primarily used nest monitoring data and secondarily spot mapping data if there was evidence of an active nest we were unable to find. To correspond with survey data (see below), we determined if there was breeding during each 3- to 4-day visit period. If breeding ended in a field during a 3- to 4-day visit period in July, we classified the status of bobolink as breeding for that visit period, to enable comparisons with survey data, which we also collected twice per week. We considered a field to have evidence of breeding until 7 days after the last nest fledged because young bobolink are incapable of sustained flight for about 1 week after leaving the nest (Renfrew et al. 2015), making them vulnerable to field management, such as hay harvest.

2.5 Transect, point count, and roadside surveys

We used aerial photographs in QGIS (version 2.14.19, qgis.osgeo.org, accessed 23 Sep 2017) to determine survey locations in each field. Transect surveys were located so that each transect line bisected a field, with transect lines separated into 100-m segments. Each transect included at least one 100-m survey segment. Fields usually contained 1 transect line, but included 2 transect lines if their area was large enough to separate transect lines by $\geq$ 250 m to minimize the chance of counting the same individuals on multiple surveys. We walked a pace of 1 step per second and stopped when we detected a bobolink to record its distance from the transect line when first detected; we recorded detections $\leq$ 75 m from the transect line.

Point count surveys were located approximately in the centre of each field. Fields usually contained 1 point count, but included 2 point counts if their area was large enough to separate 2 point counts by $\geq$ 250 m to minimize the chance of counting the same individuals on multiple surveys. We conducted 5-min, 75-m radius circular point counts, recording bobolink detections within distance bands of 0 to 25, $>$ 25 to 50, and $>$ 50 to 75 m.

Roadside counts were located on a roadside or right-of-way adjacent to each field. Fields were excluded from roadside surveys if they were not adjacent to a road or right-of-way, or if their area could not accommodate a 75-m radius survey. We conducted 10-min, 75-m radius half-circle point counts from roadsides, recording bobolink within distance bands of 0 to 25, $>$ 25 to 50, and $>$ 50 to 75 m.

On all 3 survey types, we recorded sex, detection method (i.e., song, call, visual), and behaviour for each individual. For behaviour, we recorded the highest ranked evidence of breeding based on a modified Vickery index (Table 1;

Vickery et al. 1992). In 2018, we added the agitated alarm calling behavioural class to our modified Vickery index, which is exhibited by adults caring for mature nestlings or dependent fledglings. We considered a detection of 1 or more of the following to be evidence of nesting: nest building, incubating, food carry to nest, agitated alarm calling, food carry to fledgling(s), dependent fledgling(s) (Table 1).

We conducted transect surveys and point counts at 54 fields and roadside counts at a subset of 19 fields twice per week in July. From 04 to 21 July 2017, we conducted surveys until breeding activity ceased in each paddock, based on evidence from spot mapping and nest monitoring, resulting in a maximum of 5 visits per field. We did not conduct surveys when cattle were present in rotationally-grazed paddocks; therefore, some visits were missed. From 01 to 27 July 2018, we conducted surveys twice per week or, in some cases, until hay was harvested, resulting in a maximum of 8 visits per field. We surveyed from sunrise to 1000 in conditions with little to no fog or rain. In 2017, we did not conduct surveys in wind > 3 on the Beaufort scale (NOAA 2018). In 2018, it was often windy in our study area. To ensure an adequate number of surveys, we occasionally conducted surveys in wind up to 5 on the Beaufort scale. Breeding bobolink have high detectability compared to other grassland songbirds (Nocera et al. 2007); thus, conducting surveys in moderately windy conditions likely did not affect our ability to detect breeding bobolink. Often, we initially detected bobolink by sight (47% of detections on transects in 2018) and typically our detections by song (5%) or call (48%) were followed by seeing the vocalizing bobolink. Six observers conducted surveys across the 2 years. To limit differences among observers, observers regularly practiced surveys together to ensure consistency of survey techniques and detections of bobolink.

Table 1: Behavioural classes recorded for each bobolink detected on surveys in fields. Behavioural classes are ranked from lowest (i.e., loafing) to highest (i.e., dependent fledgling(s) observed) evidence of breeding activity.

Code[a]	Description	Breeding behaviour[b]
LO	Loafing	No
VO	Vocalizing	No
FO	Foraging	No
TE	Territorial or aggressive interactions toward conspecifics or heterospecifics	No
CO	Courtship interactions; female-male interactions, displays, copulations, male feeding female	No
NB	Nest building, carrying nest material	Yes
IN	Incubating	Yes
FN	Food carry to nest	Yes
AA	Agitated alarm calling	Yes
FF	Food carry to fledgling(s)	Yes
FL	Dependent fledgling(s) observed (incapable of sustained flight, fed by adults)	Yes

[a] AA code was not recorded for individual bobolink detections in 2017

[b] CO was insufficient to confirm breeding

2.6 Analyses

To test our prediction that transect surveys would detect breeding evidence more frequently than point counts and roadside counts, we used a generalized linear mixed model (GLMM; Bolker et al. 2009). We used the `glmer` function in the `lme4` package in `R` (version 3.5.1, cran.r-project.org, accessed 23 Oct 2018) to run GLMMs and considered $\alpha < 0.05$ statistically significant. The response variable was evidence of breeding detected in each field for each visit (yes or no, binomial distribution) on any of the 3 survey types. The predictor variable of interest was survey type (i.e., transect, point count, roadside count). We included the following covariates in models: surveyed area, visit number, min since sunrise. Surveyed area was different among survey types (1 transect section = 1.5 ha, point count = 1.8 ha, roadside count = 0.9 ha). There were often multiple transect sections (mean = 2.6, range = 1 to 8) and occasionally > 1 point count (mean = 1.1, range = 1 to 3) in a field. Thus, we measured the total area surveyed in each field for each survey type, which we termed surveyed area. Additionally, visit number increased with ordinal date, and because breeding in fields often ends during July, we expected breeding to have a negative relationship with visit number. Lastly, we included min since sunrise for each survey, because the detectability of many songbird species is affected by time of day (Farnsworth et al. 2002). We z-transformed surveyed area, visit number, and min since sunrise to ensure models converged. We also included random effects in the models for site (i.e., farm or area of Luther Marsh WMA) and field; field was nested in site. We did not include field type (pasture, hay, restored, and fallow) in models because models would not converge. Instead, we used field as a random effect to explain some of the variation that would otherwise have been potentially explained by field type.

To test our prediction that surveys could be used to accurately assess whether bobolink were still breeding in a field, we used 2 GLMMs. The response variable was evidence of breeding detected on each visit to each field based on spot mapping and nest monitoring data (yes or no; binomial distribution). The predictor variable of interest was evidence of breeding detected on 1 of the survey types (i.e., 1 model for each survey type). We included visit number as a covariate, same as the model above. We also included covariates for field size (ha; because large fields have more survey effort and likely more bobolink, increasing the chance of detecting breeding) and field type (i.e., pasture, hay, restored, fallow; because of differences in management practices and vegetation). We z-transformed visit number and field size to ensure models converged. Additionally, we included site as a random effect. We planned to add min since sunrise for each survey as a covariate if it was a significant predictor in the previous GLMM. Additionally, if the previous GLMM showed no significant difference between 2 or among all 3 survey types for predicting detection of breeding evidence on each visit to each field, then we planned to use a separate GLMM for each survey type.

We used the `vif` function in the `car` package to calculate the variance inflation factors for each model to avoid including collinear predictor variables in models (Graham 2003). We considered a variance inflation factor of < 3 as indicating predictor variables were not collinear (Zuur et al. 2010). We used a Hosmer-Lemeshow goodness-of-fit test for each model and considered resulting P-values > 0.05 as evidence of acceptable model fit (Hosmer and Lemeshow 2000). We used the `hoslem.test` function in the `ResourceSelection` package to run goodness-of-fit tests.

3 Results

The median date bobolink finished breeding in a field ($n = 54$) was 08 July, based on spot map data (Table 2). The latest evidence of breeding was a nest that fledged on 23 July 2018; fledglings from this nest would have been 7 days old and capable of sustained flight by 30 July (Table 3). As evidence of breeding decreased throughout July, there was an increase in detections of flocks and co-occurrence of breeding and flocks, based on spot map data (Figure 1). Evidence of the co-occurrence of breeding and flocks in fields was higher in 2018 than 2017 across survey types (Table 3). We detected co-occurrence of breeding and flocks on 24% of spot map visits to fields in 2018, which was a higher frequency than other survey types and years (Table 3).

Table 2: Summary of fields where we surveyed to assess when bobolink finished breeding in July 2017 and 2018. In 2017, we surveyed fields on beef-cattle farms in the Ottawa Valley (in Renfrew County in Eastern Ontario, Canada). In 2018, we surveyed hay fields, restored grasslands, and fallow fields in the Luther Marsh WMA (in Dufferin and Wellington counties in southern Ontario) and on 4 farms in the region. Breeding evidence was based on nest monitoring and spot mapping data (i.e., spot map). We considered breeding finished in a field 7 days after the last nest fledged because fledglings are incapable of sustained flight for about 1 week after leaving the nest.

Field type	Year	No. of fields	Total area (ha)	Date breeding finished (mean, range)
Pasture	2017	29	142	07 July (13 June to 29 July)
Hay	2018	9	57	12 July (26 June to 24 July)
Restored	2018	10	98	12 July (24 June to 30 July)
Fallow	2018	6	37	07 July (25 June to 18 July)

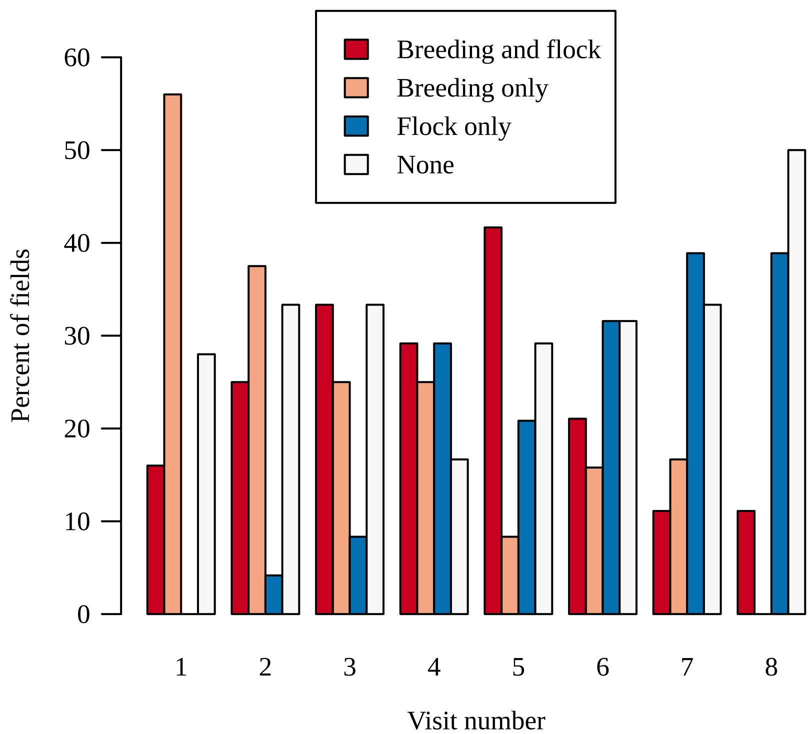

Figure 1: Percent of fields with evidence of bobolink breeding, flock, or both in July 2018 on each of 8 visits to hay fields (n = 9), restored grasslands (n = 10), and fallow fields (n = 6). Fields were in the Luther Marsh WMA (in Dufferin and Wellington counties in southern Ontario) and on 4 farms in the region. We visited the 25 fields twice per week from 01 through 28 July to record whether a flock was present. Breeding evidence was based on nest monitoring and spot mapping data where there was evidence that at least 1 nest was active in a field or had fledged within the last 7 days.

Table 3: Evidence of bobolink breeding and flocks in 54 fields surveyed with 3 methods across July 2017 and 2018 compared to spot mapping and nest monitoring (i.e., spot map) data. Evidence of breeding and flock co-occurrence is reported as a percentage of visits, not summarized across all visits to each field. In 2017, we surveyed fields on beef-cattle farms in the Ottawa Valley (in Renfrew County in Eastern Ontario, Canada). In 2018, we surveyed hay fields, restored grasslands, and fallow fields in the Luther Marsh WMA (in Dufferin and Wellington counties in southern Ontario) and on 4 farms in the region. We conducted each survey type approximately twice per week in each field.

			Fields			Surveys	
Survey type	Year	Latest breeding	% with breeding	% with flock	n	% with breeding-flock co-occurrence	n
Spot map	2017	29 July	66	28	29	12	101
	2018	30 July	72	80	25	24	176
Transect	2017	21 July	45	38	29	7	117
	2018	27 July	80	72	25	17	176
Point count	2017	21 July	28	21	29	5	118
	2018	25 July	72	72	25	13	176
Roadside count	2017	17 July	11	0	9	0	40
	2018	18 July	30	60	10	8	61

In 54 fields, we conducted 293 transect surveys (i.e., 100-m segments), 294 point counts, and 101 roadside counts across July 2017 and 2018. With the addition of the agitated alarm calling behavioural class in 2018, we detected evidence of breeding more frequently in 2018 than in 2017 on all 3 survey types (Table 4). When we detected breeding behaviours on surveys, the vast majority of these observations accurately identified breeding confirmed through spot map data (Table 5). We rarely detected some breeding behaviours on surveys (Table 5). In particular, detections of incubating and food carry to fledgling(s) correctly identified breeding 100% of the time; however, we detected these behaviours infrequently (i.e., 1 to 3 detections per survey type per year; Table 5). Whereas, agitated alarm calling was the breeding behaviour we detected most frequently on surveys (e.g., 127 detections on transect surveys in 2018) and often correctly identified breeding (i.e., 84% for transect surveys in 2018).

Table 4: The number of times we detected evidence of bobolink breeding on each survey type (i.e., no. of records) and the percent of detections for each behavioural class. We conducted each survey type twice per week in 29 fields in eastern Ontario in 2017 and 25 fields in southern Ontario in 2018. The number of occasions a behavioural class was recorded is in parentheses beside each percent. Behavioural classes are hierarchical; we recorded the highest rank detected, which provided the strongest evidence of breeding activity. Breeding behaviours observed from lowest to highest evidence of breeding activity were: NB = nest building, carrying nest material; IN = incubating; FN = food carry to nest; AA = agitated alarm calling; FF = food carry to fledgling(s); FL = dependent fledgling(s) observed (incapable of sustained flight, fed by adults).

			% of detections					
			Nesting codes % (n)			Breeding code % (n)[a]	Fledging codes % (n)	
Survey type	Year	No. of records	NB	IN	FN	AA	FF	FL
Transect	2017	18	(0)	6 (1)	17 (3)		17 (3)	61 (11)
	2018	188	(0)	1 (2)	9 (17)	68 (127)	1 (2)	21 (40)
Point count	2017	5	(0)	(0)	(0)		60 (3)	40 (2)
	2018	91	(0)	(0)	14 (13)	73 (66)	3 (3)	10 (9)
Roadside count	2017	1	(0)	100 (1)	(0)		(0)	(0)
	2018	16	(0)	(0)	6 (1)	56 (9)	(0)	38 (6)

[a] AA code was not recorded for individual bobolink detections in 2017

Table 5: The number of times we detected evidence of bobolink breeding on each survey type and the percent of detections that correctly identified breeding in a field, based on spot map data. We conducted each survey type twice per week in 29 fields in eastern Ontario in 2017 and 25 fields in southern Ontario in 2018. Breeding behaviours observed from lowest to highest evidence of breeding activity were: NB = nest building, carrying nest material; IN = incubating; FN = food carry to nest; AA = agitated alarm calling; FF = food carry to fledgling(s); FL = dependent fledgling(s) observed (incapable of sustained flight, fed by adults).

			% accuracy					
			Nesting codes % (n)			Breeding code % (n)[a]	Fledging codes % (n)	
Survey type	Year	No. of records	NB	IN	FN	AA	FF	FL
Transect	2017	18	(0)	100 (1)	100 (3)		100 (3)	91 (11)
	2018	188	(0)	100 (2)	82 (17)	84 (127)	100 (2)	88 (40)
Point count	2017	5	(0)	(0)	(0)		100 (3)	100 (2)
	2018	91	(0)	(0)	100 (13)	82 (66)	100 (3)	100 (9)
Roadside count	2017	1	(0)	100 (1)	(0)		(0)	(0)
	2018	16	(0)	(0)	100 (1)	100 (9)	(0)	83 (6)

[a] AA code was not recorded for individual bobolink detections in 2017

The percent of fields where we detected evidence of breeding across visits using the 3 survey types more closely matched the spot map data in 2018 compared to 2017, particularly for transect surveys (Figure 2). However, for all 3 survey types, we consistently detected evidence of breeding in fewer fields than the percent of fields with breeding confirmed by spot mapping and nest monitoring (Figure 2). The percent of fields where we detected bobolink using the 3 survey types, not limited to detections of breeding behaviour, appeared to match the evidence of breeding from spot map data more closely than detections of breeding behaviour on surveys (Figure 3 compared to Figure 2). This pattern was particularly noticeable for 2017 transect surveys and 2018 transect and point count surveys (Figure 3).

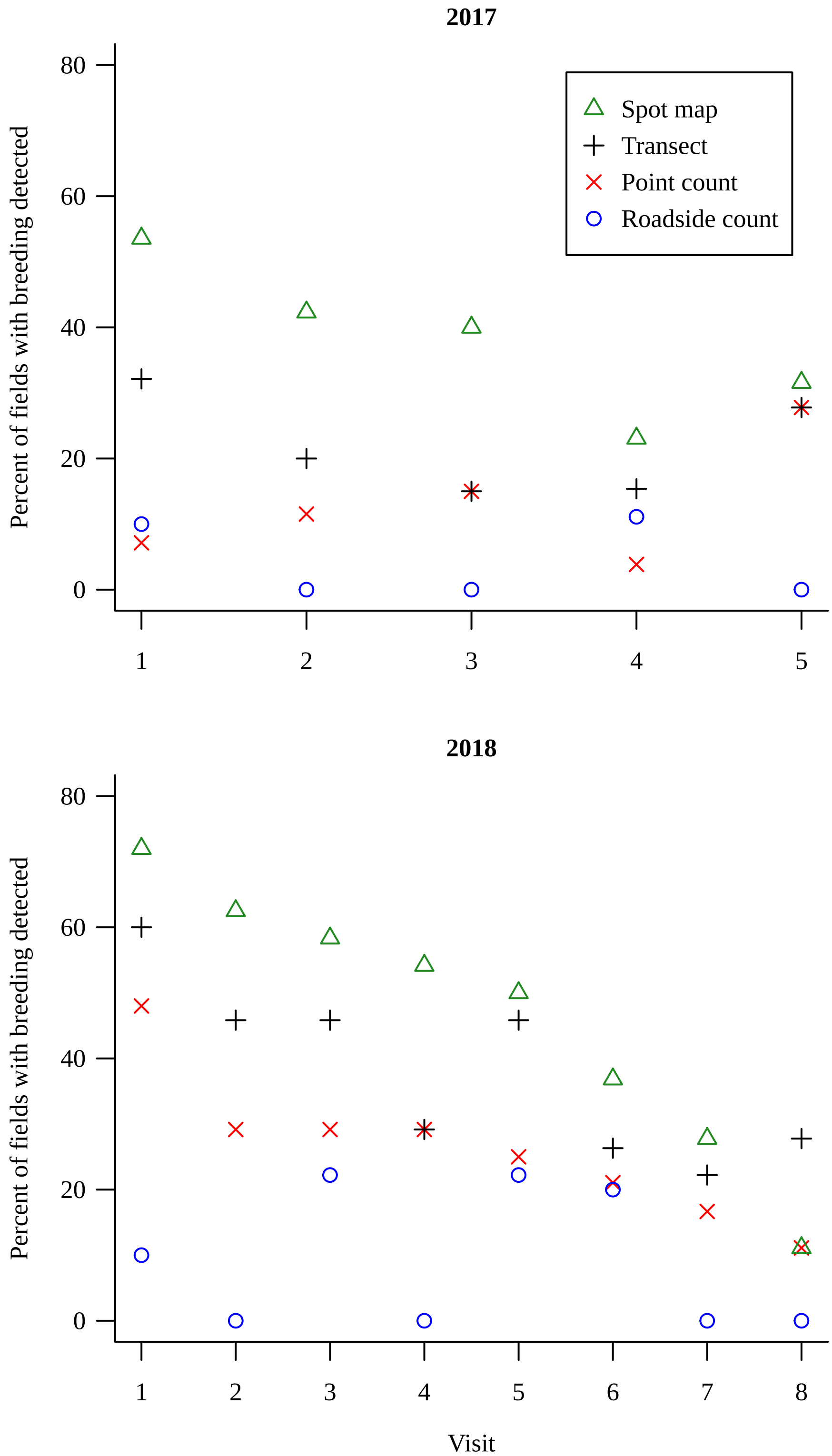

Figure 2: Percent of fields with bobolink breeding behaviour detected on spot map, transect surveys, point counts, and roadside counts across July 2017 and 2018. We conducted each survey type twice per week in 29 fields in eastern Ontario in 2017 and 25 fields in southern Ontario in 2018. Evidence of breeding for spot map was based on nest monitoring and spot mapping data that indicated there was at least 1 active nest or young fledglings (fledged within the last 7 days [i.e., incapable of sustained flight]) in each field. Breeding evidence from transect surveys, point counts, and roadside counts was based on detections of behaviour indicative of breeding: nest building, carrying nest material; incubating; food carry to nest; agitated alarm calling; food carry to fledgling(s); dependent fledgling(s) observed (incapable of sustained flight, fed by adults).

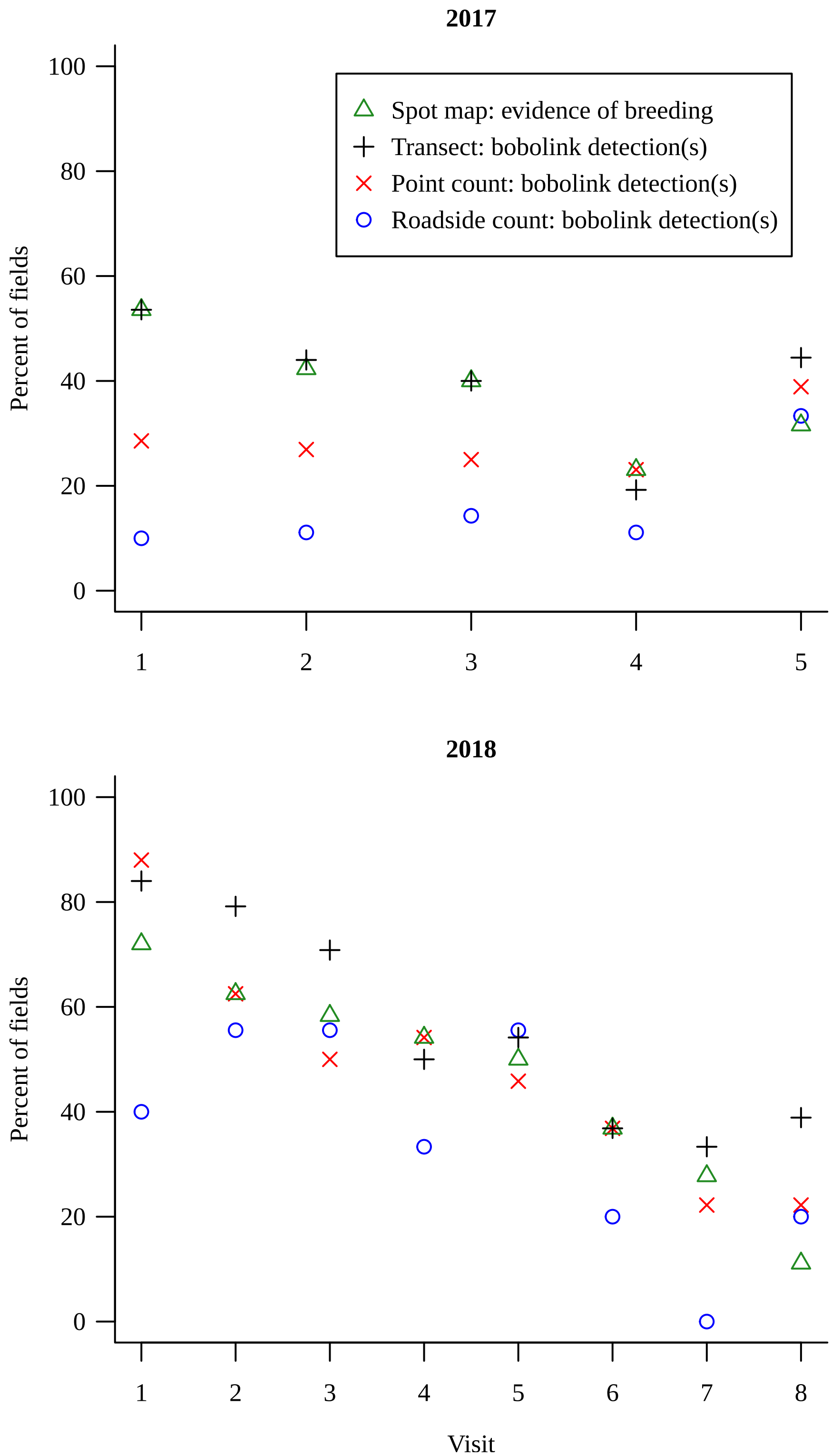

Figure 3: Percent of fields with detections of bobolink on transect surveys, point counts, and roadside counts compared to the percent of fields with breeding based on spot map data across July 2017 (29 fields) and 2018 (25 fields). Evidence of breeding for spot map was based on nest monitoring and spot mapping data that indicated there was at least 1 active nest or young fledglings (fledged within the last 7 days [i.e., incapable of sustained flight]) in each field. We included all detections of breeding and non-breeding bobolink on transect surveys, point counts, and roadside counts, but excluded detections of individuals that were part of a flock.

3.1 Comparing survey types

We detected evidence of breeding more frequently on transect surveys than on roadside counts ($P = 0.034$; Table 6). However, we did not detect evidence of breeding more frequently on transect surveys compared to point counts ($P = 0.983$; Table 6). The probability of detecting evidence of breeding was positively associated with surveyed area in a field ($P = 0.002$; Table 6). Additionally, the probability of detecting evidence of breeding was negatively associated with visit number ($P < 0.001$; Table 6).

Table 6: Variance and standard deviation (SD) of random effects and coefficients, standard errors (SE), and P-values of fixed effects of a generalized linear mixed model. The response variable was evidence of breeding bobolink (yes or no, binomial distribution) detected on any survey type (transect survey, point count, roadside count) for each visit to each field in July (29 fields in 2017 and 25 fields in 2018). The predictor variable of interest was evidence of breeding detected on each visit to each field for each survey type. Transect survey was the reference survey type. We also included covariates: surveyed area per field (ha), visit number, and min since sunrise; we z-transformed continuous variables. Each model included site (e.g., farm) and field as random effects, with field nested in site.

Random effects	Variance	SD	Fixed effects	Estimate	SE	P-value
Field:Site	2.59	1.61	Intercept	-2.03	0.44	< 0.001
Site	0.75	0.86	Survey type - Point count	0.01	0.37	0.983
			Survey type - Roadside count	-1.36	0.64	0.034
			Surveyed area (ha)	0.81	0.26	0.002
			Visit number	-0.46	0.13	< 0.001
			Min since sunrise	0.12	0.13	0.329

3.2 Comparing surveys to spot map data

Evidence of breeding detected on transect surveys was positively associated with evidence of breeding from spot map data ($P < 0.001$; Table 7). The probability of detecting evidence of breeding on a transect survey in a pasture (i.e., the reference field type for models) was 0.71 (i.e., $-1.44 + 2.32$ transformed from the logit scale), while holding continuous predictor variables at their z-transformed mean (i.e., 0). Thus, under the same conditions, the probability of not detecting evidence of breeding on 2 visits to transect surveys in a pasture was 0.09 (i.e., $[1 - 0.71]^2$). Evidence of breeding detected on point counts was also positively associated with evidence of breeding from spot map data ($P < 0.001$; Table 8). The probability of detecting evidence of breeding on a point count in a pasture was 0.80 (i.e., $-1.29 + 2.66$ transformed from the logit scale), while holding continuous predictor variables at their z-transformed mean (i.e., 0). Thus, under the same conditions, the probability of not detecting evidence of breeding on 2 visits to point counts in a pasture was 0.04 (i.e., $[1 - 0.80]^2$). In both models, visit number was negatively associated with evidence of breeding from spot map data ($P < 0.001$; Tables 7, 8). For transect surveys, the probability of detecting evidence of breeding (in pasture for mean field size) decreased from 0.91 to 0.19 across visit number; whereas, for point counts the probability decreased from 0.95 to 0.26. Other covariates (i.e., field size and field type) were not associated with evidence of breeding detected from spot map data (Tables 7, 8).

Table 7: Variance and standard deviation (SD) of random effects and coefficients, standard errors (SE), and P-values of fixed effects of a generalized linear mixed model to assess the predictive capability of transect surveys to detect breeding behaviour. The response variable was evidence of breeding bobolink (yes or no, binomial distribution) from spot map data for each visit to each field in July (29 fields in 2017 and 25 fields in 2018). Spot map data included spot mapping and nest monitoring. The predictor variable of interest was evidence of breeding detected on each visit to each field on transect surveys. We also included covariates: field size (ha), visit number, and field type (i.e., pasture, hay, restored, or fallow); we z-transformed continuous variables. Pasture was the reference field type. The model included site (e.g., farm) as a random effect.

Random effects	Variance	SD	Fixed effects	Estimate	SE	P-value
Site	2.99	1.73	Intercept	-1.44	0.64	0.025
			Transect breeding evidence	2.32	0.42	< 0.001
			Field size (ha)	0.28	0.27	0.306
			Visit number	-1.10	0.22	< 0.001
			Field type - Fallow	-0.71	1.25	0.571
			Field type - Hay	0.04	1.27	0.976
			Field type - Restored	1.86	1.25	0.139

Table 8: Variance and standard deviation (SD) of random effects and coefficients, standard errors (SE), and P-values of fixed effects of a generalized linear mixed model to assess the predictive capability of point counts to detect breeding behaviour. The response variable was evidence of breeding bobolink (yes or no, binomial distribution) from spot map data for each visit to each field in July (29 fields in 2017 and 25 fields in 2018). Spot map data included spot mapping and nest monitoring. The predictor variable of interest was evidence of breeding detected on each visit to each field on point counts. We also included covariates: field size (ha), visit number, and field type (i.e., pasture, hay, restored, or fallow); we z-transformed continuous variables. Pasture was the reference field type. The model included site (e.g., farm) as a random effect.

Random effects	Variance	SD	Fixed effects	Estimate	SE	P-value
Site	3.15	1.77	Intercept	-1.29	0.65	0.047
			Point count breeding evidence	2.66	0.55	< 0.001
			Field size (ha)	0.30	0.28	0.285
			Visit number	-1.16	0.23	< 0.001
			Field type - Fallow	-0.62	1.27	0.624
			Field type - Hay	0.13	1.30	0.923
			Field type - Restored	1.87	1.27	0.139

4 Discussion

We found that transect surveys and point counts detected evidence of breeding bobolink at a similar frequency and more frequently than roadside counts. Additionally, transect surveys and point counts identified bobolink breeding reasonably accurately compared to the best available information about breeding status in a field from spot mapping and nest monitoring data. Transect surveys and point counts were also good predictors of evidence of breeding in a field, based on spot mapping and nest monitoring data. Our results indicate that transect surveys or point counts could be used to determine when bobolink finish breeding in a field and thus, when agricultural activity (e.g., livestock grazing, hay harvest) can occur to avoid impacting breeding.

We rarely detected evidence of bobolink breeding on roadside counts compared to transect surveys and point counts. There is a plethora of literature about the impacts of roads on bird occurrence, abundance, and species richness (e.g., Forman et al. 2002, Fahrig and Rytwinski 2009, Griffith et al. 2010, Summers et al. 2011). We suspect that we rarely detected evidence of breeding on roadside counts because birds were breeding in fields rather than near field edges at roads. Additionally, we may have rarely detected evidence of breeding on roadside counts because surveyed area was a statistically significant predictor variable in the GLMM and roadside counts had a smaller surveyed area than transect surveys and point counts.

We found that a modified Vickery index (Vickery et al. 1992) enabled accurate identification of bobolink breeding status in a field using transect surveys and point counts, compared to spot mapping and nest monitoring data. Previous studies have documented weaknesses of the Vickery index to correctly identify breeding success compared to nest monitoring for other grassland bird species: Savannah sparrow (*Passerculus sandwichensis*; Morgan et al. 2010) and dickcissel (*Spiza americana*; Rivers et al. 2003). In contrast, Christoferson and Morrison (2001) found that the Vickery index accurately identified the breeding status of 3 western songbird species along creeks compared to nest monitoring. Similar to Christoferson and Morrison (2001), we identified breeding status on each visit to a field, rather than estimating the number of nests or territories that fledged young. Additionally, bobolink are gregarious birds, making many of their behaviours easily observable, especially the agitated alarm calling of adults tending to mature nestlings or young dependent fledglings.

Unsurprisingly, we found that the probability of detecting evidence of breeding decreased with increasing visit number to a field across July, following breeding phenology. Young began fledging in mid-June. Breeding activity in July was primarily a result of late nesting attempts following nest failure early in the season because bobolink rarely raise > 1 brood per year (Renfrew et al. 2015). We first detected non-breeding bobolink gathering in flocks in fields during the first week of July.

We found that time of day was not a good predictor of detecting evidence of breeding on transect surveys and point counts. Surveys for songbirds are typically restricted to time periods of frequent vocalizations, from around sunrise until late morning (e.g., Hutto et al. 1986). Additionally, time of day is often associated with probability of detecting various songbird species (e.g, Farnsworth et al. 2002, Solymos et al. 2013). However, we recorded behavioural observations (e.g., agitated alarm calling by adults with young), not bird detections only, which might partially explain why time of day was not associated with detections of evidence of breeding in our study. Additionally, most of our detections of bobolink were visual because bobolink are often conspicuous in fields.

We detected evidence of breeding, flock, and breeding-flock co-occurrence more frequently in 2018 than 2017 across survey types. We added a behavioural category on surveys in 2018 for agitated alarm calling by adults with mature nestlings or young fledglings, which helped us detect bobolink breeding activity more frequently. Additionally, in 2017 we surveyed pastures only and some pastures were not used by bobolink after grazing, resulting in less frequent detections compared to 2018. In 2018, fallow and restored fields were undisturbed by agricultural activity, resulting in frequent use by bobolink in July. We also monitored delayed-harvest hay fields in 2018, which were frequently used by bobolink in July until hay was cut.

Our results indicate that transect surveys or point counts could be used by field biologists to assess whether bobolink are finished breeding in a field. Common conservation guidelines in Ontario suggest delaying livestock grazing and hay harvest until mid-July to avoid negative impacts on nesting bobolink (e.g., MNRF 2015, OSCIA 2018). However, grazing livestock and harvesting hay earlier than mid-July may be possible in some cases if bobolink are finished breeding, which would likely provide forage quality benefits (Brown and Nocera 2017).

Placing surveys to thoroughly cover fields is essential for detecting breeding bobolink, if they are present. We recommend that a transect line (i.e., 150-m wide belt transect) bisect a field, including as many 100-m length segments as possible. If a field is large enough, biologists should place as many transect lines as possible that can be separated by ≥ 250 m between the centre line of each transect to minimize the chance of counting the same individuals on multiple belt transects. For point counts, we recommend at least one 75-m radius count per field and including as many point counts as possible that can be separated by ≥ 250 m between points in a field. Transect surveys and point counts should be placed to maximize the survey area that occurs within the field being surveyed (i.e., overlapping adjacent fields and other land cover as little as possible). Surveying early in July is best because we found probability of detecting breeding activity was high early in July and decreased across the month. To minimize impacts of agricultural activity on nesting bobolink, we recommend delaying livestock grazing and hay harvest until mid-July or until 2 consecutive survey visits to a field in July fail to detect bobolink breeding activity. Each visit should include surveys of all point counts or transects in a field.

5 Survey protocol

The purpose of this survey protocol is to assess when bobolink finish breeding in fields (e.g., hay field, pasture) that are intended to provide undisturbed breeding areas for the species. Determining when bobolink finish breeding in a field is important for guiding the timing of agricultural activity (e.g., hay harvest, livestock grazing) to minimize negative impacts on breeding birds. While delaying agricultural activity until mid-July is a reasonable overall guideline, determining when bobolink are finished breeding in a particular field may indicate that agricultural activity can occur earlier than mid-July, without negatively impacting breeding, or that agricultural activity may need to be delayed beyond mid-July to allow birds to finish breeding. Surveys should be conducted by observers who have experience with bird survey methods and best practices to minimize disturbance to nesting birds.

For fields that are accessible for monitoring, we recommend using transect surveys or point counts to assess when bobolink finish breeding in a field. Each transect should contain the number of 100-m segments needed to bisect the entire field length. Fields contain at least one transect line, but should include multiple transect lines if the area of a field is large enough to separate transect lines by $\geq$ 250 m to reduce the chance of counting the same individuals on multiple surveys. Use a geographic information system (GIS; e.g., QGIS: https://www.qgis.org/en/site/) and aerial photographs to determine locations of transects in each field before conducting surveys. Aerial photos are available from Land Information Ontario (https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/main.home). If surveyors are unable to use GIS for planning surveys, one could use other software, such as Google Maps or Google Earth.

A surveyor (i.e., field biologist) visits each transect twice per week from 01 to 31 July until bobolink breeding behaviour is not detected in a field on 2 consecutive visits. Surveys should be conducted between sunrise and 1000 in weather conditions conducive to detecting breeding birds (i.e., little to no fog or rain and wind $<$ 4 on the Beaufort scale [NOAA 2018]). On each survey, a surveyor walks a pace of one step per second. The surveyor stops walking to record each bobolink detected by sight or sound within 75 m of either side of the transect line. The surveyor notes the detection method (i.e., detected by sight, call, or song), sex, distance from transect line, and behaviour indicating the highest evidence of breeding activity for each bobolink (Table 1). Observations of nest building, incubating, food carry to nest, agitated alarm calling, food carry to fledgling(s), and dependent fledgling(s) all indicate that bobolink are actively breeding in a field (Table 1). The detection of a flock of non-breeding bobolink does not mean that all bobolink in a particular field have finished breeding.

If a surveyor is using point counts instead of transects, each field should contain at least 1 point count, but should include multiple point counts if the area of the field is large enough to separate point counts by $\geq$ 250 m. A surveyor visits each point count twice per week from 01 to 31 July until bobolink breeding behaviour is not detected in a field on 2 consecutive visits. During each 5-min point count, a surveyor records each individual bobolink detected, noting the detection method (i.e., detected by sight, call, or song), sex, distance band (0 to 25, $>$ 25 to 50, and $>$ 50 to 75 m), and behaviour indicating the highest evidence of breeding activity for each bobolink (Table 1). Observations of nest building, incubating, food carry to nest, agitated alarm calling, food carry to fledgling(s), and dependent fledgling(s) all indicate that bobolink are actively breeding in a field (Table 1). As with transect surveys, point counts should be conducted in appropriate weather conditions and detections of bobolink flocks do not indicate breeding is finished in a field.

We do not recommend surveys from roadsides to assess when bobolink finish breeding because, based on the infrequent detections of breeding in our data, we suspect these surveys are unreliable.

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