

Benefits and risks of agro-ecosystem
management to grassland birds in Nova Scotia

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Executive Summary

Although numerous large-scale management programs exist, severe declines in many populations of grassland birds have continued over the last few decades; the entire group of North American grassland birds is declining faster than any other bird guild in the world. This has largely been attributed to a loss of hayfields and earlier dates of harvest that conflict with bird nesting. My research responded to this in two ways: (1) by developing broad environmental correlate models for three species of grassland birds in Nova Scotia: bobolink (*Dolichonyx oryzivorus*), savannah sparrow (*Passerculus sandwichensis*), and Nelson's sharp-tailed sparrow (*Ammodramus nelsoni subvirgatus*) using several population response parameters simultaneously (occurrence, abundance, and reproductive activity), and (2) by assessing the breeding phenology of these species under delayed hay cutting regimes (post 1 July) and how the nutrition of delayed hay is affected by this management practice.

Bobolink occupancy, abundance, and reproductive activity all showed a strong positive relationship to vegetation height-density, which was also borne out across regions and habitat types; height-density was an important term in all top models from independent Iowa and Wisconsin datasets. Abundance and reproductive activity were also linked to the abundance of several insect orders. In contrast, savannah sparrows showed a negative relationship between vegetation height-density and both abundance and occupancy. Savannah sparrow occupancy was positively related to the abundance of Carabid beetles and negatively to forb cover (seen also for reproductive activity). Nelson's sharp-tailed sparrow occupancy was positively related to abundance of caterpillars and spiders, and length of agricultural ditches (also seen in the top model for abundance). These hayfield ditches likely contain structural cues Nelson's sharp-tailed sparrows use as a surrogate for more traditional salt-marsh habitat. The top model for Nelson's sharp-tailed sparrow reproductive activity was a positive association with both vegetation height-density and spider abundance.

These results generate two easily implemented distribution-wide baseline recommendations for management.

- (1) ensure ditches are left with an uncut buffer around them to benefit Nelson's sharp-tailed sparrows in agricultural lands during the breeding season, and**
- (2) ensure fields are not cut late (> 15 Aug) the preceding year (allowing extra growth prior to overwintering) to promote reproductive activity for Nelson's sharp-tailed sparrow and bobolink, and bobolink occupancy and abundance.**

Weekly changes were monitored in several measures of hay nutritional quality (percent crude protein (CP %), acid detergent fibre (ADF), calcium (Ca) and phosphorus (P)). Timing of peak fledging was variable across years, but generally occurred in the first week of July. Delay of cutting by one week in late June or early July resulted in a small reduction in hay nutritional quality. However, that hay would still meet energy and CP % requirements for non-lactating beef cows. Regression models showed that a delay of 1.5 weeks (from 20 June to 1 July) in cutting translated to a mean decrease in CP % of 2.1. Conversely, this delay secured an increase in the rate of fledgling, from zero to 20% for bobolink, 56% for savannah sparrow, and 44% for Nelson's sharp-tailed sparrow. Postponing cut by one more week (to a minimum of July 7) gave the benefit of allowing maximum fledging rates for all species, while CP % lost 3.5. While this level of CP % is unlikely to support high maintenance periparturient cows and feeder / finisher cattle, it could be made profitable through mineral supplementation. ADF levels were considerably elevated, while Ca and P improved in the same time period. This elicits a major point:

- (1) delayed hay cutting (> 1 July) can ensure successful bird breeding in hayfields, and it can be a viable option for some farmers.**

The feasibility of delaying cut varies with a farm's specialization, and to a degree, breed kept. Such practices can be incorporated into a holistic approach to agroecosystem management.

Preface

From 2002-2004, the Nova Scotia Conservation Habitat Fund provided financial support for my project *“Benefits and Risks of Agro-ecosystem Management to Grassland Birds in Nova Scotia”*. The major objective of this research, broadly defined, was to model the habitat use of grassland agricultural fields and lands by grassland birds, and evaluate the efficacy of managed agro-ecosystems in the region (particularly the Belleisle Marsh WMA).

The field research for this project ended in August 2004, brought to completion in large part by the contribution of Fund and the assistance from local farmers and residents. This document constitutes the final report to the Fund. This report is presented in two parts: (1) results and recommendations from the modelling research, and (2) an assessment of management practices at Belleisle Marsh as it relates to grassland bird breeding. These two parts are, in themselves, separate manuscripts. Part I will soon be submitted to an academic journal. Part II is ‘in press’ with the journal *Agriculture, Ecosystem, and Environment*.

I thank the Fund, and all its contributors, for deciding to support me in this work. I hope this report adequately summarizes my attempts to provide informed management for conservation of agro-habitats and the wildlife that inhabit them. I look forward to further writing and dissemination of the knowledge gained from this work.

A final copy of my Ph.D. dissertation, of which this work was a part, will be forwarded to the Fund as further available documentation when it is complete by the end of 2005.

J. Nocera, Feb 2005.

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This project would not have been possible were it not for the willingness and helpfulness of those who farm the land. I thank them for their help and generosity, and it is these people on whom wildlife conservation in farmland depends.

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¹ Transcription of manuscript: Nocera, J.J., G.J. Forbes, and G.R. Milton. Unpublished manuscript. Geographically robust environmental correlate models of occurrence, abundance, and reproductive activity for three species of grassland birds.

² Reprint of manuscript: Nocera, J.J., G.J. Parsons, G.R. Milton, and A.H. Fredeen. 2005. Compatibility of delayed cutting regime with bird breeding and hay nutritional quality. *Agriculture, Ecosystems and Environment*, in press.

Geographically robust environmental correlate models of occurrence, abundance and reproductive activity for three grassland bird species¹

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Abstract

Although numerous large-scale agro-ecosystem management programs exist, severe declines in many populations of grassland birds have been ongoing; the entire group of North American grassland birds is declining faster than any other bird guild in the world. Despite some straightforward management options, basic conservation recommendations for this group of birds are hindered by lack of knowledge of habitat needs within and between species. Models developed for grassland birds are often restricted to specific areas or habitat types, include mostly local habitat variables of unknown importance, and are of varying applicability across the species' range. These models not only lack predictive power because of this, but also tend to focus on only one parameter of a breeding population. To respond to this, we developed much broader environmental correlate models for three species of grassland birds in Atlantic Canada: bobolink (*Dolichonyx oryzivorus*), savannah sparrow (*Passerculus sandwichensis*), and Nelson's sharp-tailed sparrow (*Ammodramus nelsoni subvirgatus*) using several population response parameters (occurrence, abundance, and reproductive activity). We estimate model predictive error and examine accuracy and robustness of these models against independent data from two other regions, collected in other habitat types: Iowa (prairie) and Wisconsin (pasture).

In our Atlantic Canada models, bobolink occupancy, abundance, and reproductive activity all showed a strong positive relationship to vegetation height-density. The importance of vegetation height-density to bobolinks was also borne out across regions and habitat types; height-density was an important term in all top models of the Iowa and Wisconsin data. Abundance and reproductive activity were also linked to the abundance of several insect orders. In contrast, savannah sparrows showed a negative relationship between vegetation height-density and both abundance and occupancy. This variable was also retained in the top Iowa and Wisconsin models, again highlighting the ubiquity of this variable's importance. Savannah sparrow occupancy was positively related to the abundance of Carabid beetles and negatively to forb cover (seen also for reproductive activity). Nelson's sharp-tailed sparrow occupancy was positively related to abundance of caterpillars and spiders, and length of agricultural ditches (also seen in the top model for abundance). The top model for Nelson's sharp-tailed sparrow reproductive activity was a positive association with both vegetation height-density and spider abundance.

We conclude two easily implemented distribution-wide baseline recommendations for management. First, ensuring ditches are left with an uncut buffer around them would benefit Nelson's sharp-tailed sparrows in agricultural lands during the breeding season. Second, because vegetation height-density in the spring was the single most important variable among our models, ensuring fields are not cut late in the preceding year, to allow for some extra growth and height prior to overwintering, will promote the likelihood of increased reproductive activity for Nelson's sharp-tailed sparrow and bobolink, and both bobolink occupancy and abundance. Combined with the other prescriptions, a protocol of not harvesting too early (e.g. before early July) or too late (e.g. after mid-August) is recommended.

Although our models describing the environmental correlates of three population level parameters underwent conservative model building and are geographically robust, we have not modeled habitat “selection” and we suggest that further refinements assess true choice behavior. Few studies have provided this level of generality, and the net benefit derived from any of the management suggestions presented here is likely to be substantial. Such studies that include multiple responses, study sites, and broad habitat assessments are likely to accrue further conservation benefit.

Keywords: accumulated prediction error; agriculture; Akaike’s and Bayesian information criteria; grassland birds; habitat model; harvest dates; insect abundance; model selection; vegetation height-density.

1. Introduction

Although numerous large-scale agro-ecosystem management programs exist (e.g. the Conservation Reserve Program, Permanent Cover Program), severe declines in many populations of North American grassland birds have continued over the last few decades (Bollinger et al. 1990, Herkert 1997, Vickery et al. 1999, Madden et al. 2000). In particular, the North American Breeding Bird Survey has detected precipitous declines (Peterjohn and Sauer 1999) and the entire group of North American grassland birds is declining faster than any other bird guild in the world (Knopf 1994). For instance, in Atlantic Canada, two obligate grassland nesting species, bobolink (*Dolichonyx oryzivorus*) and savannah sparrow (*Passerculus sandwichensis*), are in decline. Bobolinks showed an annual decrease of -2.5% across Canada during the period 1966-2003, whereas savannah sparrows fared better at -0.75% decline in the same period (Sauer et al. 2004). Atlantic Canada also hosts the eastern allopatric subspecies of Nelson’s Sharp-tailed sparrow (*Ammodramus nelsoni subvirgatus* – Acadian race) that primarily breeds in saltmarsh, but commonly shows facultative breeding in wetter areas of agricultural land (Nocera et al. unpublished data), similar to the midwestern subspecies (*A. n. nelsoni*; Murray 1969, Greenlaw and Rising 1994). Because of this population’s isolation, and a lack of baseline research, the *subvirgatus* subspecies is one of the top priorities for conservation in the region (Partners in Flight; Rosenberg and Hodgman 2000).

Many authors attribute these declines to reduction in available hayfields and grasslands along with changes in timing of hay cutting (Bollinger et al. 1990, Dale et al. 1997, Herkert 1997, Nocera et al., *in press*). However, despite some straightforward management options (e.g. delayed hay harvest to allow for increased breeding times; Bollinger et al. 1990; Dale et al. 1997; Nocera et al., *in press*), our ability to supply recovery or basic conservation recommendations for this group of birds is hindered by a lack of knowledge of broad-scale habitat needs within and between species. An enormous amount of information exists on response to local landscape structure and the correlates and use patterns for particular species (reviewed within, e.g., Poole and Gill 1992-2002, Best et al. 1995, Johnson et al. 2004), but it has primarily been collected at a local extent and only inferred to apply to species needs across its entire distribution. We have yet to accurately determine the structural cues (Smith and Shugart 1987) that these species use to determine the quality of, and subsequently select, habitats. In general, most models that have been created to describe habitat use and correlates of grassland birds have focused on vegetation parameters (e.g. Bollinger 1995, Davis et al. 1999, Moreira 1999, Norment et al. 1999, Bradbury et al. 2000). Few modeling efforts have included prey (although see, e.g., Wittenberger 1980, Clere and Bretagnolle 2001) or other parameters that may act as habitat selection cues over broad

geographic regions largely due, presumably, to logistical difficulties. This likely presents a serious shortfall in many previous modeling attempts, considering that incidence functions for farmland birds (and grassland birds by extension) have been shown to track invertebrate abundance (Söderström et al. 2001).

Because these models are often restricted to specific areas or habitat types, include mostly vegetation-related variables, and are of unknown applicability across the species range, they not only lack predictive power, but also tend to focus on only one aspect or parameter of a breeding population (e.g. abundance or reproductive success). Results from such studies may be particularly misleading because reproductive vital rates and abundance parameters may not be correlated (Winter and Faaborg 1999, Fletcher and Koford 2002) and can provide very different indications of habitat quality and population persistence from which to direct subsequent management efforts (Van Horne 1983). If management is to be more directed and effective, then models need to be developed that are broader in scope by including more predictive variables of biological relevance such as habitat structure and prey, incorporating more than one population response (e.g. abundance, residency, and at least some population vital rate), and testing their predictive accuracy both within the generating dataset and against completely independent datasets from other regions. Only by combining these improvements into a single modeling effort will we be able to simultaneously improve model precision, accuracy, and generality.

In this study, we develop a cohesive set of environmental correlate models for three species of grassland birds: bobolink, savannah sparrow, and Nelson's sharp-tailed sparrow (Acadian race). Our objective was to overcome the typical limitations of modeling habitat use of these species by examining several population response parameters (occurrence, abundance, and reproductive activity) with habitat structure, management activity, *and* prey abundance. We estimate the predictive error of these models and, as a final check, examine the accuracy and geographic robustness of these models for two of our study species against independent data sets from elsewhere in North America (Iowa and Wisconsin) in different habitat types (prairie and pasture, respectively).

2. Methods

2.1. Study Sites

From May-August of 2002-2004, we conducted surveys across four study sites in hayfields of the western Annapolis Valley, Nova Scotia, Canada (centered on 44°45'N, 65°31'W): Belleisle (210 ha), Upper Belleisle (116 ha), Queen Anne (180 ha), and Pea Round (142 ha). These sites are dyked marshes and drained to a state suitable for agriculture. Belleisle and Upper Belleisle are part of a crown-owned Wildlife Management Area (WMA), while Queen Anne and Pea Round are privately owned agricultural areas. Fields at Queen Anne (totaling 84 ha), Belleisle (77 ha) and Upper Belleisle (43 ha) are mixtures of timothy (*Phleum pratense*), meadow fox-tail (*Alopecurus pratensis*), various bluegrass species (*Poa* spp.), and reed canary grass (*Phalaris arundinacea*). The same mixtures of grasses are planted across Pea Round, with the addition of several homogenous alfalfa swards (*Medicago sativa*).

None of fields at our study sites were grazed, planted in non-forage crops, or received any pesticide applications during the study. Date of first hay harvest at Queen Anne, Upper Belleisle, and Belleisle is much later than is typical for the region (post 1 July), except for a small field cut early for silage at Queen Anne. There is a gradient (staggering) of harvest dates within sites as not all fields at each site are cut simultaneously. Pea Round is cultivated solely to

support dairy operations, and therefore most of the harvest is for silage; first-cut begins relatively early (pre 15 June).

2.2. Breeding Bird Sampling

Three focal grassland bird species (bobolink, savannah sparrow, and Nelson's sharp-tailed sparrow) were surveyed at 52 point-count plots (50 m radii; Hutto et al. 1986). To reduce any contribution of spatial autocorrelation to pseudo-replication, we distributed our point-count plots >175 m from each other across the four study sites. This distance is beyond the typical territory size for bobolink (Martin and Gavin 1995), our study species with the greatest area requirements. We are also confident this level of observation (52 plots x 3 years, visited 8-12 times per year (\bar{x} = 9.96 counts per plot)) is adequate to allow predictive error determination in model estimation (Karl et al. 2000). Our five min point-count surveys were conducted between 30 min post-sunrise and 1000 AST (weather permitting: wind <25kph, no precipitation). Counted birds were visually followed to limit double counting. All observers were trained with an experienced observer by conducting simultaneous point-counts, to establish a consistent protocol before they proceeded to collect data independently. All point-count data were summarized by mean abundance, to reduce the inflationary effect of floaters and non-residents on overall analyses (Betts et al., *in press*). From these, we model total abundance for all three study species with the sexes combined, but also model the abundance of each single sex for bobolinks as they are sexually dichromatic and the only species reliably identified to sex in the field.

Reproductive activity was measured by monitoring breeding activity and phenology of birds whose territories included the point-count plot (*sensu* Vickery et al. 1992, Christoferson and Morrison 2001). Based on these behavioral observations, each point was ascribed a numerical reproductive activity index, for each species, for the season. As per Vickery et al. (1992) we attributed an index score of 0 when no, or few, birds were present; 1 for male presence only (3+ weeks); 2 for male and female presence only (3+ weeks); 3 for a confirmed pair present, seen w/ nesting material, or exhibiting other signs of breeding; 4 for adults seen carrying food to presumed nestlings; and 5 for confirmed evidence of fledging success.

2.3. Predictive variable sampling

We measured 27 variables with which to model breeding bird responses (listed in short form in Table 1). These predictive variables were sampled in one of three broad categories: vegetation, prey, and other (non-vegetation, non-prey).

Vegetation measurements were made twice per season, first during the territory establishment period in late May, and again in late June. Grass height (growth rate) and density were measured simultaneously in each point-count plot using a visual obstruction "Robel pole" (Robel et al. 1970) placed ~5 m from the plot center in each cardinal direction. Percent cover, and the percentage of that cover which was grass or forbs were determined within plots using Daubenmire frames (Daubenmire 1959) thrown (a minimum of 5 m) in each cardinal direction from the plot center. Litter depth was measured within the Daubenmire frame with a ruler against a profile cut from the soil. Presence/absence of alfalfa, which is known to be negatively correlated with bobolink abundance (Bollinger 1988; Bollinger et al. 1990), and freshwater cordgrass (*Spartina pectinata*), which is known to be positively correlated with Nelson's sharp-tailed sparrow occurrence (Murray 1969) was determined per plot.

Terrestrial arthropod prey abundance (summarized as catch-per-unit-effort) was sampled using pitfall traps checked weekly throughout the study season. One pitfall trap was placed 10 m

north and south of each point-count plot center. Pitfall traps were 15 cm deep plastic cups, flush to soil surface, with 3-5 cm of soap and water mixture on the bottom. All captured specimens were identified to Order, or further when possible. Although pitfall traps captured specimens from a large number of groups, those Orders (unless specified) that are best represented by this method, and reported here, are Aranea (spiders), Class Chilopoda (centipedes), Coleoptera (beetles), Class Diplopoda (millipedes), Isopoda (sowbugs), Lumbricina (earthworms; Class Oligochaeta), Stylommatophora (slugs; Class Gastropoda), and Opiliones (harvestmen).

TABLE 1. List of 27 predictive variables used in modeling and their shorthand notation applied throughout text.

Model acronym	Variable description
ALF	Presence/absence of Alfalfa
ARA	Abundance of Aranea in pitfalls
CHI	Abundance of Chilopoda in pitfalls
COLS	Abundance of Coleoptera in sweeps
COLP	Abundance of Coleoptera in pitfalls
COV	Percentage of live vegetative cover in a frame
DIP	Abundance of Diptera in sweeps
DIPL	Abundance of Diplopoda in pitfalls
DIT	Linear length of ditch (m)
FORB	Percentage of forb cover in a frame
GR	Percentage of grass cover in a frame
HARV	Harvest date in the current year
HD	Height/density (as per Robel et al. 1970) of vegetation in late May
HEMI	Abundance of Hemiptera in sweeps
HPY	Harvest date in the preceding year
HYM	Abundance of adult Hymenoptera collected in sweeps
ISO	Abundance of Isopoda collected in pitfalls
LEP	Abundance of adult Lepidoptera collected in sweeps
LHL	Abundance of Lepidoptera and Hymenoptera larvae in sweeps
LIT	Litter depth
LUM	Abundance of Lumbricina in pitfalls
ODO	Abundance of Odonata collected in sweeps
OPIL	Abundance of Opiliones in pitfalls
ORTH	Abundance of Orthoptera collected in sweeps
SPT	Presence/absence of <i>Spartina</i> spp. (cordgrass)
STY	Abundance of Stylommatophora in pitfalls
YR	2002, 2003, or 2004

Note: COLS and COLP represent prey abundance estimates from the same taxonomic order, but were considered as separate variables because they reliably sampled different families (Elateridae (click beetles) by sweeps, and Carabidae (ground beetles and tiger beetles) by pitfalls).

Aerial arthropod prey abundance (summarized as catch-per-unit-effort) was sampled via sweep netting, likewise conducted weekly, which involved a series of horizontal sweeps with a sailcloth sweep net through the grass canopy along a 10 m transect east and west of point-count plot centers. All captured specimens were identified to Order, or further when possible. Although sweeps captured specimens from a large number of groups, the Orders that are best represented by this method, and reported here, are Coleoptera (beetles), Diptera (flies), Hemiptera (true bugs), Hymenoptera (wasps, bees, ants), Lepidoptera (moths, butterflies), Odonata (primarily damselflies), and Orthoptera (grasshoppers). Both adults and larvae were captured for Hymenoptera and Lepidoptera, and we use the Order name in reference to only

adults. Because some larval forms of these two Orders can be difficult to separate without rearing or other labor-intensive techniques, we collapsed larvae data to a composite variable of “Lepidoptera and Hymenoptera larvae” (LHL, Table 1) that can be more simply viewed as “caterpillars”. Note that Coleoptera was the only Order sampled adequately by both techniques, and we separate these in our modeling according to capture method (Table 1) because sweeps were more representative of Elateridae (click beetles) and pitfalls were the more efficient capture technique for Carabidae (ground beetles and tiger beetles).

Lastly, we included five other variables not related to prey or vegetation. Each point-count plot was located in a field of greater extent, and was harvested as hay annually (see Nocera et al., *in press*). We monitored the date of harvest for each plot and converted it to an annual-Julian date. In our modeling we use date of harvest in the current year (HARV; Table 1) and for the same plot in the previous year (HPY; Table 1). To control for seasonal effects we included the sample year as a variable. Because pilot work (Nocera and Milton, unpublished data) conducted in our study sites (2000-2001) indicated that Nelson’s sharp-tailed sparrow frequented hayfield drainage ditches, we also quantified the linear length of ditch contained in each point-count plot (measured from 1:10,000 air photos). Lastly, as a *de facto* method of controlling for site effects, we include a covariate of ‘conditional detection probability’ (Royle and Nichols 2003) for each site per species (see section 2.5).

2.4 Independent data sets.

The first independent dataset is a random subsample consisting of 50 point-counts conducted each year from 1997-1999 across any of 74 pastures within six counties in southwestern Wisconsin (supplied by Renfrew 2002; see also Renfrew and Ribic 2002). Point-counts of five min duration with a fixed 100 m radius were conducted twice per year (once in May and June) during which all individuals seen or heard were counted. Savannah sparrows and bobolinks are the two species in common with the present study that were sampled in comparable densities.

Vegetation measurements were conducted in late May along four transects (at right angles) in each point-count plot. Those amenable to the present study (as per Table 1) were % live cover (COV), % of that cover that was forbs (FORB), and litter depth (LIT), which were estimated to the nearest 5% in Daubenmire frames. Also, visual obstruction measurements were taken using a Robel pole (see above; HD as per Table 1), modified slightly from the method of Robel et al. (1970) as readings were taken at a height of 1.5 m. Cover measurements were very similar to the present study, but because the study was conducted in grazed pastures, both HD ($\bar{x} = 0.87$ dm) and LIT measurements ($\bar{x} = 1.02$ cm) were expectedly below what was seen in our Nova Scotia hayfields ($\bar{x} = 3.0$ dm and 3.3 cm, respectively).

The second independent dataset is a random subsample consisting of 279 point-counts and 42 transects conducted from 1999-2000 across any of 20 prairie/restored grassland sites in northern Iowa (supplied by Fletcher 2003; see also Fletcher and Koford 2002, 2003). Point-counts of 10-min duration with a fixed 50 m radius, and counts along 25 m width transects of 100-400 m length, were conducted three times per year (generally once in late May, mid-June, and early July) during which all individuals seen or heard were counted. Bobolinks were sampled in comparable densities to the present study, however savannah sparrows were encountered at comparably reduced densities.

Iowa vegetation measurements were conducted in July at four locations within each point-count plot, and at five locations in each 25 m increment of a transect route. Those amenable to

the present study (as per Table 1) were % cover (COV), and the % of that cover that was forbs (FORB) and grass (GR), estimated in Daubenmire frames. Also, visual obstruction measurements were taken using a Robel pole (see above; HD as per Table 1), where litter depth (LIT) measurements were also taken. Cover measurements were very similar to the present study, but because measurements were taken later in the season, HD is, on average greater ($\bar{x} = 4.7$ dm; Fletcher and Koford 2002) than ours sampled in May ($\bar{x} = 3.0$ dm)

We subjected both the Iowa and Wisconsin data to the same modeling procedure as for our Nova Scotia data, using only the predictor terms with analogs in our study, but with no pre-modeling variable selection (outlined in 2.5 below). We then compared the top models to determine which variables were retained in common across the three study regions.

2.5 Statistical analysis.

All statistical tests were conducted using *R* version 2.0.1 (R Development Core Team 2004). Although we describe each analysis in detail below, in general our modeling consisted of a five-step process. The first primary step was to reduce the set of 27 predictive variables to a smaller group of best-fit variables. Variables were log transformed whenever it resulted in improvement of variance homogeneity and brought the distribution closer to normality (through visual assessment of qq-norm plots). To reduce the need to provide for interactions, we eliminated the variable that showed the strongest multicollinearity within a pair (Graham 2003) from the candidate variable list (e.g. grass (GR) and forb (FORB) cover showed strong collinearity, often resulting in elimination of GR, with the strongest collinear parameters, from the candidate variable list). Because of very strong collinearity between May and June vegetation height-density measurements (seen in other studies as well, e.g. Winter and Faaborg 1999), we eliminated the June height-density samples from all of our analyses, and used May samples as being representative. After variable transformation and selection, we followed with steps to: 2. Generate an all-subsets model set using the retained variables; 3. Use a stepwise selection algorithm to reduce to the top model using Akaike's Information Criterion (AIC; Akaike 1974), AIC controlled for small sample size (AIC_c; Hurvich and Tsai 1989) and the Bayesian Information Criterion (BIC; Schwarz 1978); 4. Calculate the Accumulated Prediction Error (APE; de Luna and Skouras 2003) using leave-one-out cross-validation for each top model chosen by each information criterion, and; 5. Select the model that minimizes APE. We employ such a cautious 'meta-selection' process, following the guidelines of de Luna and Skouras (2003) because the most common model selection criteria (i.e. AIC, AIC_c, and BIC) employ very different assumptions (see Rust et al. 1995) that can alter final model inference. A reduction in APE indicates greater model precision and is sensitive to both the potential over-penalization for parameters with AIC and the inherent reductionism of BIC. We use APE as derived by Rissanen (1986) and de Luna and Skouras (2003) through the minimization of

$$\sum_{i=m}^n L(x_i, \hat{x}^{i-1}(p)) \quad (1)$$

Where for each i , x_i is forecasted by $\hat{x}^{i-1}(p)$ and L is a function that measures how well the model (p) fits the data.

To prevent imbalanced posterior assessment, we do not employ model averaging to determine a variable's overall contribution to models chosen by AIC or AIC_c. Because BIC provides a close approximation of the Bayes Factor (Volinsky and Raftery 2000) and the model

selected is intrinsically considered as correct, no analog exists to calculate variable contribution for this selection criterion.

Abundances differ between sites, which creates heterogeneity in detection probability. Although grassland birds occur in very open areas, and yield a high degree of detection during point-counts (particularly at ranges <50 m; Rotella et al. 1999), we felt it necessary to account for any latent detection heterogeneity by *a posteriori* calculation of a ‘conditional detection probability’ (\bar{p}_c ; Royle and Nichols 2003) for each site. The probability \bar{p}_c was calculated by

$$\bar{p}_c = \sum_{k=1}^{\infty} \Pr(y > 0 | N = k) \frac{\Pr(N = k)}{y} \quad (2)$$

where y is the number of animals observed per unit, N is between-site variation in abundance, and ϕ is the probability of occupancy (a presence). K is a probability parameter (the number of ‘support points’) for a particular $N = k$ distribution (Poisson in our case). We then used the resultant \bar{p}_c as a covariate in all site occupancy models.

Site occupancy models were generated using Poisson logistic regression (Generalised Linear Model; GLM) on point-count data reduced to binary presence/absence. For each species model set, candidate predictive variables were selected from the 27 measured by retaining only those singular variables with a Mallows’ C_p score above that of a null model. The candidate model set then contained the global model and all possible combinations of retained variables. Stepwise model selection (package ‘*mass*’ in *R*; Venables and Ripley 2002) using AIC was first used to select the top model from the candidate model set. We then used the same stepwise algorithm to calculate BIC and AIC_c. We then conducted 1000 cross-validation resamplings and selected the model chosen by an information criterion that minimized APE as the top model for the set. To measure model accuracy of each GLM, we calculated the area-under-curve (AUC) from a receiver-operating characteristic (ROC) that characterizes the difference in model predictions for true/false positive and negative values (Hanley and McNeil 1982). The lowest bound of AUC at 0.05 represents a very poor model. In general, model predictive accuracy is considered low if AUC<0.07, acceptable if between 0.7-0.8, and excellent if >0.8 (Hosmer and Lemeshow 2000).

Abundance (mean) and reproductive activity (categorical from 0-5) were modeled using Poisson regression (linear model). For each species model set, the upper 50% of the 27 candidate predictive variables with the highest singular F-statistic, which also had at least 0.10 $\text{pr}(|t|)$ were retained for inclusion in the candidate model set. The candidate model set then contained the global model and all possible combinations of retained variables. Model stepwise reduction, information criteria calculation, and cross-validation resampling were then conducted as for the GLM’s to select the top model.

3. Results

3.1. Occupancy models

In general, the conditional detection probability estimates (\bar{p}_c) were similar across glms. There was a slight difference in \bar{p}_c between sites for all three study species (e.g. greatest range was for Nelson’s sharp-tailed sparrow: $\bar{p}_c = 0.346-0.415$), but was not strong enough to be retained in any top model as an important term (site effect).

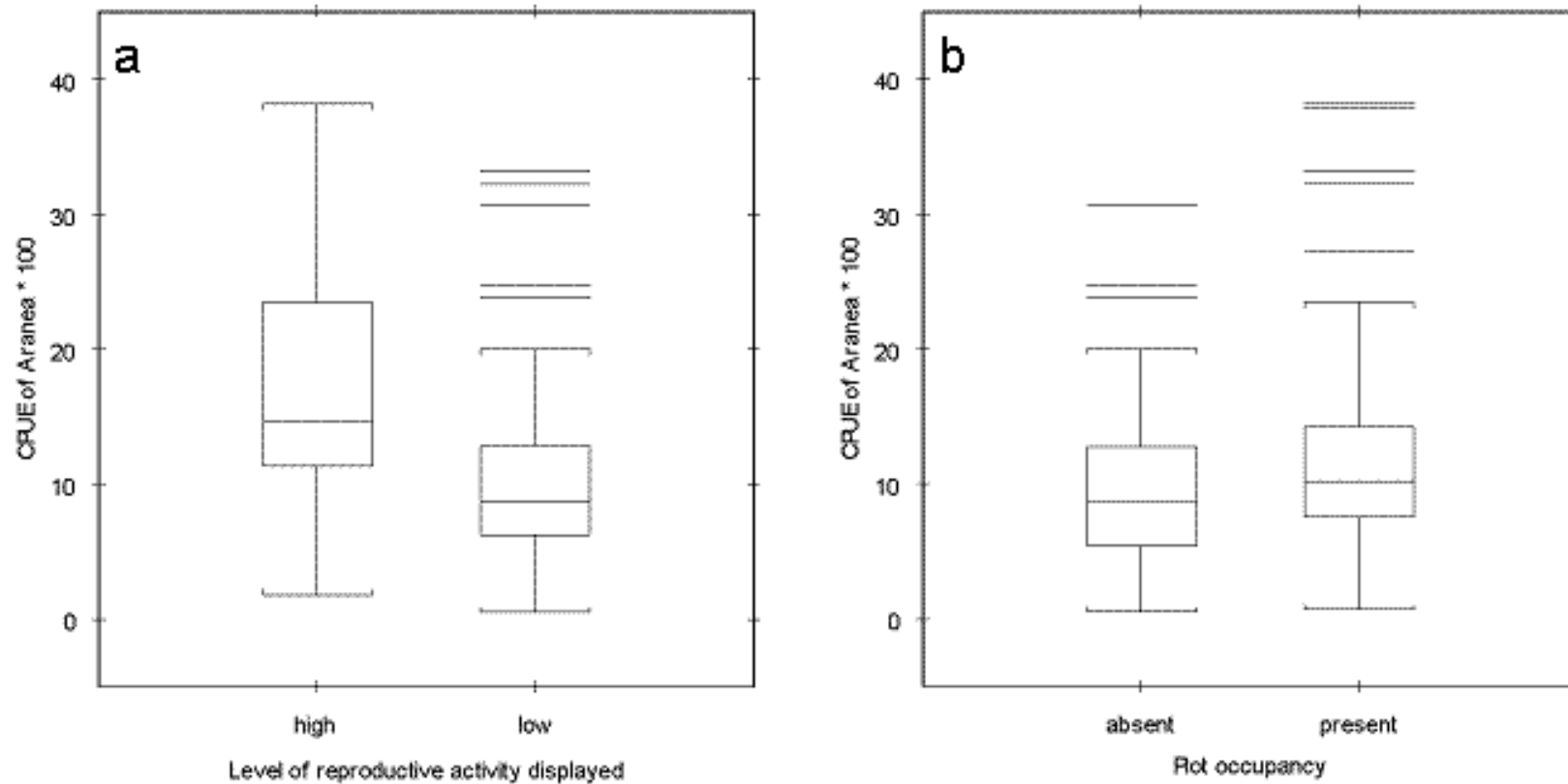
Bobolink presence-absence models were generated from a set of 6 variables that had a Mallows’ C_p lower than that for a null model: COV, DIP, FORB, HARV, HD, and LIT (refer to Table 1 for model variable notation). The top model (Table 2) contained only HD as a single

positive term, which was chosen by BIC (0.029 less APE than AIC) and held an area-under-curve of 0.70, indicating reasonable accuracy. Savannah sparrow candidate models were generated from 7 retained variables: COLP, COLS, DIPS, DIT, FORB, HD, and LIT. The top model for Savannah sparrow (Table 2), chosen by BIC (0.004 less APE than AIC), was that of a positive relationship with COLP and negative relationships with HD and FORB, with a very large area-under-curve of 0.91. Nelson's sharp-tailed sparrow models were created from 7 retained variables of ALF, ARA, DIT, HARV, LHL, LIT, and SPT. The top model (Table 2) of LHL + ARA + DIT was selected by AIC (with an APE reduction of 0.104 over AIC_c) and held an area-under-curve of 0.64 (indicating only mild model accuracy, reflected by weak differences in occupancy levels in Fig. 1).

TABLE 2. Top models for abundance, occupancy, and reproductive activity of bobolink, savannah sparrow, and Nelson's sharp-tailed sparrow. Model notation follows Table 1. Each model is followed by the selection criterion (either Akaike's Information Criterion (AIC), AIC corrected for small sample size (AIC_c), or Bayesian Information Criterion (BIC)) used to select the top model because it minimized accumulated prediction error (APE; shown in parentheses). The second best selection criterion is also shown, with APE, to illustrate the difference in performance between the top two selection criteria.

Model for	Top Model	Model selection criteria used (w/ APE)	Model selection criteria (w/ next lowest APE)
Bobolink			
abundance (male + female)	HD + HEMI	BIC (0.123)	AIC (0.173)
abundance (males only)	COV+ HEMI – FORB - ALF - SPT	AIC (0.529)	BIC (0.546)
abundance (females only)	HD + HEMI	BIC & AIC (0.072)	AIC _c (1.488)
occupancy	HD	BIC (0.113)	AIC (0.142)
reproductive activity	HD + ARA + DIP + ODO	BIC (0.493)	AIC (0.510)
Nelson's sharp-tailed sparrow			
abundance	DIT + ORTHO	BIC (0.031)	AIC (0.054)
occupancy	DIT + ARA + LHL	AIC (0.197)	AIC _c (0.301)
reproductive activity	HD + ARA	BIC (0.344)	AIC (0.345)
Savannah sparrow			
abundance	DIP – CHIL – STY - HD	AIC (0.159)	BIC (0.162)
occupancy	COLP – FORB - HD	BIC (0.083)	AIC (0.087)
reproductive activity	OPIL - FORB	BIC (0.213)	AIC (0.265)

FIG. 1. Response of Nelson's sharp-tailed sparrow reproductive activity (a) and abundance (b) to abundance of spiders (Aranea) expressed as catch-per-unit-effort (CPUE) * 100. Aranea CPUE was retained in the top model for both response parameters. Poisson generalized linear models (glm) were used to model occupancy, and Poisson regression modeled reproductive activity (although response is illustrated as binary "high" and "low" for comparison).



3.2. Abundance models

Candidate models for bobolink abundance (both sexes) were generated from 8 variables retained for model building: ALF, COV, FORB, HD, HEMI, LIT, ORTH, and SPT. The top model (Table 2), chosen by BIC (lowest APE by 0.05), was HD + HEMI. A strong positive relationship is noted between HD and bobolink abundance (Fig. 2). Female abundance models were created from 10 retained variables: ALF, DIP, HARV, HD, HEMI, HYM, LHL, LIT, ODO, and ORTH. The top model (Table 2) of HD + HEMI was chosen by both BIC and AIC (equal APE) and is the same as the top model for the sexes combined. Male abundance models were generated from a set of 10 retained variables: ALF, COV, DIP, DIPL, FORB, HD, HEMI, LIT, ODO, and SPT. The top model (table 2) was that of a positive relationship with COV and HEMI, and a negative relationship with FORB, ALF, and SPT. This model was selected by AIC (with 0.01 less APE) and differs markedly from the model for females and sexes combined.

Models for the two sparrows species could only be constructed for the sexes combined. The eleven variables of ALF, CHI, COLS, DIP, DIT, HARV, HD, ISO, ORTH, STY and YR were selected for inclusion in the candidate model set for savannah sparrow. The best model (Table 2), chosen with AIC (which had only a marginal reduction of 0.003 APE over BIC) was a positive association with DIP and a negative relationship to HD, CHI, and STY. The strong negative relationship to HD (illustrated in Fig. 2) is in contrast to the positive relationship seen with bobolink abundance. Nelson's sharp-tailed sparrow models were built from the ten retained variables of ALF, ARA, DIT, HARV, HEMI, LIT, ODO, ORTH, SPT, and STY. The top model for abundance (Table 2) was ORTH + DIT, which was selected by BIC (with an APE of 0.0234 less than AIC).

3.3. Reproductive activity models

Candidate models for bobolink reproductive activity were generated from 12 retained variables of ALF, ARA, COV, DIP, DIPL, GR, HD, HEMI, LIT, LUM, ODO, and ORTH. The top model (Table 2), chosen by BIC (lowest APE by 0.017), was HD + ARA + DIP + ODO. Savannah sparrow reproductive activity candidate models were generated from 11 retained variables: ALF, ARA, CHI, COLS, FORB, HPY, LUM, OPIL, ORTH, STY, and YR. The best model (Table 2), chosen with BIC (with an APE 0.052 less than AIC) was OPIL - FORB. Nelson's sharp-tailed sparrow models were built from the 6 retained variables of ALF, ARA, HD, LIT, LUM, and YR. The top model for reproductive activity (Table 2) was HD + ARA, which was selected by BIC (with an APE only 0.001 less than AIC). The positive relationship to ARA is seen as an increased tendency to express high levels of reproductive activity (a reproductive activity index of >2, see *Methods*) as spider abundance increases (Fig. 1).

3.2. Models from independent data sets

Top models for each regional dataset are shown in Table 3. Of the variables that were sampled in common between all three studies, HD (vegetation height-density) was the most important (positive) term in every model for bobolink occupancy and abundance (sexes combined) and was negatively related with savannah sparrow abundance in Iowa prairies and Nova Scotia hayfields, but positively in Wisconsin pastures. This was also retained as a positive term in the top models for savannah sparrow occupancy in Wisconsin and Nova Scotia, but not for the Iowa dataset. Two very different models to predict male bobolink abundance were chosen for Iowa and Nova Scotia (for which Wisconsin data were not available).

FIG. 2. Mean abundance of bobolink (a) and savannah sparrow (b) per point-count plot as a function of vegetation height-density (in dm, determined using method of Robel et al. 1970) in May. Although Poisson regression models were used, least-squares trendline shown to illustrate direction of relationship.

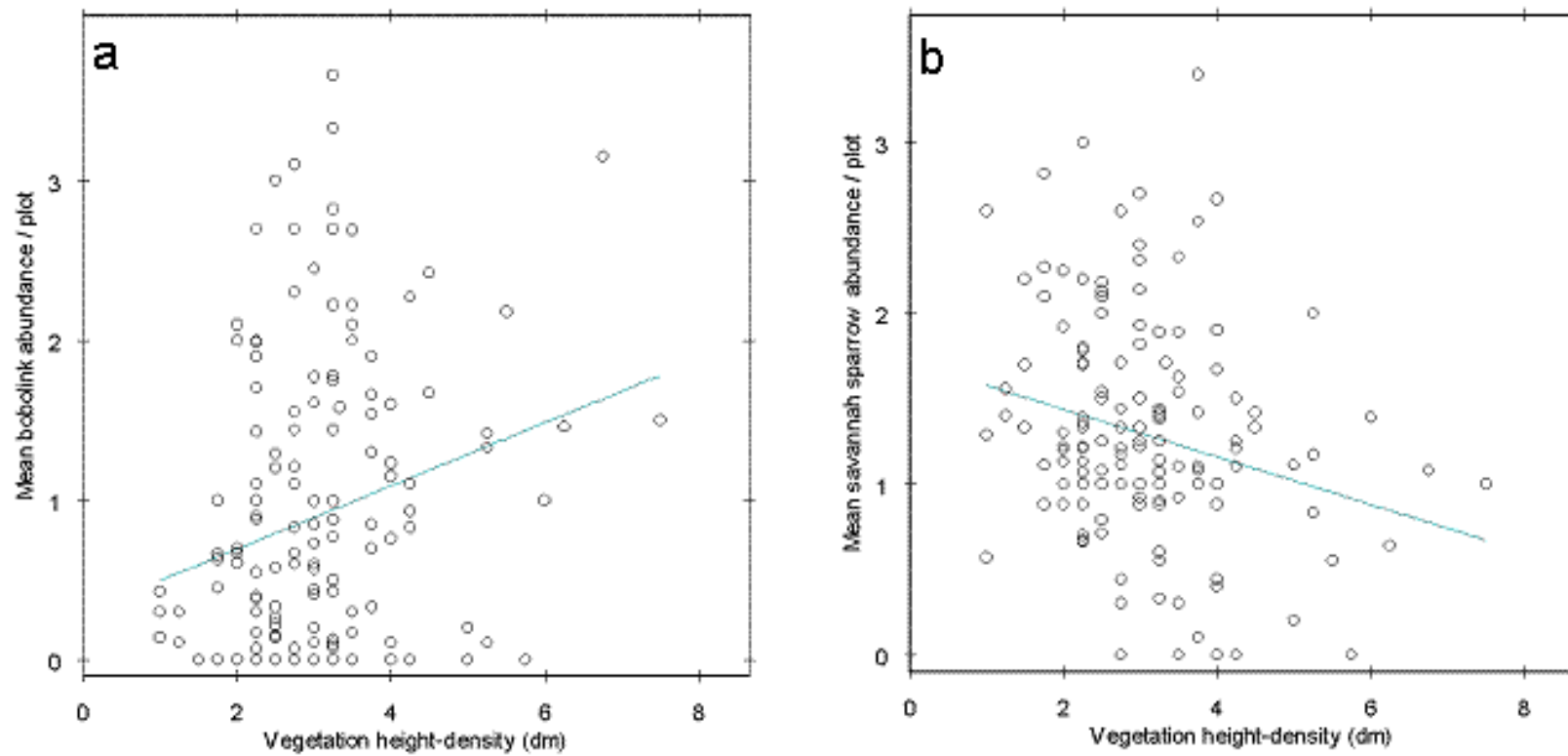


TABLE 3. Top models of vegetative correlates (notation as per Table 1) for presence/absence (occupancy) and abundance of bobolinks and savannah sparrows from three different regions, habitat types and studies: Nova Scotia (hayfields, this study), Wisconsin (pastures, Renfrew 2002), and Iowa (prairies, Fletcher 2003). Only combined-sex bobolink data were available for Wisconsin. Letters in italics represent variables important to Nova Scotia models (see *Results*) not sampled in Wisconsin or Iowa. Poisson generalised linear models were created to model occurrence, and Poisson linear models for abundance. Model selection follows the procedure outlined in *Methods* and de Luna and Skouras (2003).

Top model of:	Region		
	Nova Scotia	Wisconsin	Iowa
Bobolink occupancy	HD ¹	HD ¹	HD + LIT + COV ^{1,3}
Bobolink abundance (male + female)	HD + <i>hemi</i> ¹	HD ¹	HD + LIT + FORB + COV ^{1,3}
Bobolink abundance (males only)	FORB + COV + <i>hemi</i> + <i>alf</i> + <i>spt</i> ²		HD ^{1,3}
Savannah sparrow occupancy	<i>Colp</i> – FORB – HD ¹	HD – COV ^{1,3}	LIT ¹
Savannah sparrow abundance	<i>dip</i> – <i>chil</i> – <i>sty</i> – HD ²	HD + FORB ^{1,3}	– COV – HD ¹

Note: ¹ indicates that a model was selected by Bayesian Information Criterion, ² by Akaike's Information Criterion (AIC), and/or ³ by AIC corrected for small sample size (AIC_c). Variables in bold are shared in top models for all study sites

4. Discussion

The top model for bobolink occupancy showed a positive relationship to vegetation height-density (Table 2). This term was also retained in the top models for bobolink abundance (both sexes; Table 2, Fig. 2) and for female abundance, both of which also included a positive association with the abundance of true bugs (Hemiptera), one of the top four prey groups fed to nestling bobolinks (Wittenberger 1982). The importance of vegetation height-density to bobolinks was also borne out across regions and habitat types; height-density was an important term in all top models from the Iowa and Wisconsin data, which verifies previously reported correlation with bobolink abundance (Herkert 1994, Bollinger 1995). This differs substantially from the more complex model for male abundance with a positive relationship to overall vegetative cover and the abundance of true bugs, but a negative relationship with forb cover and the presence of alfalfa and cordgrass. However, this supports the findings of Bollinger (1988) who attributed these associations to characteristics of older fields. The top model for bobolink reproductive activity showed another positive relationship with vegetation height-density and also to abundance of spiders (Aranea), flies (Diptera) and damselflies (Odonata). Young bobolinks are fed exclusively invertebrates (Martin and Gavin 1995); so it is not surprising that there was a positive association between reproductive activity and the abundance of three arthropod Orders, where both spiders (Aranea) and flies (Diptera) have been documented as part of the juvenile diet.

The top model for savannah sparrow occupancy (Table 2) showed negative relationships with vegetation height-density and forb cover (seen also in the top models for abundance and reproductive activity, respectively). Vegetation height-density was also retained in the top Iowa and Wisconsin (although with a positive relationship) models, again highlighting the ubiquity of this variable's importance. Our top model for occupancy also showed a positive relationship with the abundance of terrestrially captured beetles (primarily Carabidae; COLP, Table 1). This model receives support from that savannah sparrows have been shown to rely heavily on beetle

prey in some years (Miller and McEwen 1995), to exhibit a preference for short or moderate-height dense vegetation (Wiens 1969), and avoid increased forb cover (Sutter and Brigham 1998). The best model of savannah sparrow abundance was a positive association with flies (a known prey item, Wheelwright and Rising 1993) and, again, a negative relationship to vegetation height-density (Fig. 2). The model also contained a negative relationship between savannah sparrow abundance and the abundance of centipedes (Chilopoda) and slugs (Stylommatophora), which may represent avoidance of a latent variable. The best model for savannah sparrow reproductive activity was a negative correlation with forb cover, and a positive association with the abundance of harvestmen (Opiliones), which are likely an important prey item akin to spiders.

The top model for Nelson's sharp-tailed sparrow occupancy was a positive relationship to abundance of caterpillars (the composite of Hymenoptera and Lepidoptera larvae; LHL Table 1) and spiders (Fig. 1), and a positive relationship with the length of ditches. Both of these arthropod groups represent important prey items for adults and nestlings (Greenlaw and Rising 1994; particularly spiders, Montagna 1942). Hayfield ditches likely contain structural cues that Nelson's sharp-tailed sparrows use as a surrogate for more traditional salt-marsh habitat, to fulfill a general requirement for dense, often damp, swards of vegetation (Greenlaw and Rising 1994) which they likely provide. Whereas the top model for Nelson's sharp-tailed sparrow abundance was that of a positive relationship to grasshopper (Orthoptera) abundance (known to be food items for nestlings, Greenlaw and Rising 1994) and another positive relationship to the length of ditches. The top model for Nelson's sharp-tailed sparrow reproductive activity was a positive association with both vegetation height-density and spider abundance (Fig. 1), likely representing the need for dense swards of vegetation with numerous important arthropod prey like spiders.

For species of such conservation concern (particularly bobolink and Nelson's sharp-tailed sparrow), these models form some easily implemented distribution-wide baseline recommendations for management. Although most prey abundance parameters would be difficult to manage for, many structural variables are not. For instance, length of ditch was positively associated with the occupancy and abundance of Nelson's sharp-tailed sparrows. Typically, ditches remain uncut and provide a damp environment with tall coarse vegetation. A simple management action that would benefit this species in agricultural lands during the breeding season would be to ensure that ditches are available that remain uncut (in addition to providing proper drainage); a recommendation of leaving a mandatory uncut buffer around ditches would be beneficial.

Vegetation height-density was retained in many top models. Harvests in late summer are typically of a second or third crop for the year, and in our study region usually occur in early-mid September (Nocera and Milton, unpublished data). Simply ensuring fields are not cut late (e.g. after mid-August) in the preceding year, to allow for some extra growth and height prior to overwintering, should promote the likelihood of increased reproductive activity for Nelson's sharp-tailed sparrow and bobolink, and both bobolink occupancy and abundance (see Fig. 2). This situation is analogous to management suggestions for northern pintail (*Anas acuta*) which show greater reproductive rates in areas with remaining spring crop cover from summer fallow land instead of reduced cover following spring sowing (Podruzny et al. 2002). Conversely, this management prescription would not be appropriate for enhancement of savannah sparrow occupancy and abundance (but, fortunately, this species is faring considerably better with less drastic population declines). Combined with the prescriptions of Nocera et al. (*in press*), the

basic management regimen for bobolinks and Nelson's sharp-tailed sparrow becomes clear: do not harvest too early (e.g. before early July) nor too late (e.g. after mid-August). If the goal is to also manage for savannah sparrows, a staggered harvest in August, with some fields being cut late and others not, is most appropriate.

Our meta-selection procedure for determining which information criterion to use for model selection showed a tendency for choosing models identified by BIC. This tendency reinforces our choice to employ meta-selection and has a statistical basis: our sample size was almost always large enough to not require a correction factor (e.g. AIC_c), and the estimated posterior probabilities of BIC are reliable predictions of accuracy more often than those of AIC (Rust et al. 1995), imparting more consistent model selection and prediction accuracy to BIC. It is not surprising that some of our top models contained relatively few terms and generated the least predictive error; at coarse scales such as that of our study, cover-type models often perform better (Karl et al. 2000).

The conservative nature of our model building and selection, and our assessment of model predictive accuracy, highlights the ubiquitous importance of the correlates retained in top models. An important footnote to our modeling efforts presented here are that we have described the environmental correlates of three population level parameters; we have not modeled habitat selection *per se* (as we have not measured any parameter of choice behavior) and our models would gain significant predictive ability if behavioral processes and spatial constraints were also considered. We predict that such behavioral and consequent spatial processes that more directly accompany true habitat selection, such as conspecific attraction (Stamps 1988), social information use (Danchin et al. 2004), and spatial autocorrelation (Lichstein et al. 2002a, 2002b), would increase model accuracy and provide a valuable avenue for future modeling these and other species of conservation concern.

The models we present provide a geographically robust assessment of the structural cues (*sensu* Smith and Shugart 1987) used during habitat selection and their association with abundance and measures of reproduction. This is an important distinction, because typically models include only one population response parameter of interest, which may be misleading when trying to assess or manage for several aspects of population dynamics (Van Horne 1983). Secondly, the importance of structural variables was assessed across three different regions, under three different habitat types, to help understand the tractability and generality of the models. Few studies have provided this level of generality, and the net benefit derived from any of the management suggestions presented here is likely to be substantial. Such studies that include multiple responses, study sites, and broad habitat assessments are likely to accrue further conservation benefit.

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Compatibility of delayed cutting regime with bird breeding and hay nutritional quality¹

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Abstract

The breeding phenology of three grassland bird species was studied in managed hayfields of Nova Scotia, Canada: bobolink (*Dolichonyx oryzivorus* L.), savannah sparrow (*Passerculus sandwichensis* Gmelin), and Nelson's sharp-tailed sparrow (*Ammodramus nelsoni subvirgatus* Allen), under delayed hay cutting regimes (post 1 July). Weekly changes were monitored in several measures of hay nutritional quality (crude protein (CP), acid detergent fibre (ADF), calcium (Ca) and phosphorus (P)). Timing of peak fledging was variable across years, but generally occurred in the first week of July. Delay of cutting by one week in late June or early July resulted in a small reduction in hay nutritional quality. However, that hay would still meet energy and CP requirements for non-lactating beef cows. Regression models showed that a delay of 1.5 weeks (from 20 June to 1 July) in cutting translated to a mean decrease in CP of 2.1%. Conversely, this delay secured an increase in the rate of fledging, from zero to 20% for bobolink, 56% for savannah sparrow, and 44% for Nelson's sharp-tailed sparrow. Postponing cut by one more week (to a minimum of July 7) gave the benefit of allowing maximum fledging rates for all species, while CP lost 3.5%. While this level of CP is unlikely to support high maintenance periparturient cows and feeder / finisher cattle, it could be made profitable through mineral supplementation. ADF levels were considerably elevated, while Ca and P improved in the same time period. These trends show delayed hay cutting can be a viable option for farmers opting to conserve breeding birds on hayfields. The feasibility of delaying cut varies with a farm's specialization, and to a degree, breed kept. Such practices can be incorporated into a holistic approach to agroecosystem management.

Keywords: Bobolink; Breeding phenology; Crude protein; Fledging rate; Hay cutting; Livestock nutrition; Nelson's sharp-tailed sparrow; Savannah sparrow

1. Introduction

Severe declines in many populations of North American grassland bird species have been detected within the last few decades (Bollinger et al., 1990; Herkert, 1997). Many authors postulate that these declines are caused by a large net loss of hayfields and changes in timing and frequency of hay cutting (Bollinger et al., 1990; Martin and Gavin, 1995; Jobin et al., 1996; Dale et al., 1997; Herkert, 1997). In some areas, it has been estimated that approximately 95% of hayfields that were extant 50 years ago are no longer active (Herkert, 1997). These, and many other, agricultural changes have been detrimental to some wildlife species both in North America and Europe (Green et al., 1997; Krebs et al., 1999; Wakeham-Dawson and Smith, 2000; Hails, 2002). These changes are symptomatic of agricultural intensification, particularly those practices that focus on higher quality nutrition for greater livestock productivity.

Native grasslands have been extensively replaced with agricultural hayfields ("surrogate grasslands"; Sample et al., 2003). The majority of hayfields in North America are planted with

exotic grasses that mature (flower) earlier than native grasses (Giuliano and Daves, 2002). This is particularly true for dairy operations that require early cutting to produce silage. Farms that produce only beef-cattle cut for hay at later dates. Therefore, native grass use often lacks economic incentive, and in some regions of North America has no detectable net benefit for grassland bird breeding (Delisle and Savidge, 1997; McCoy et al., 2001).

Increasing global temperatures and use of early-maturing grasses has led to progressively earlier cutting dates. The median date of hay cutting has increased by 14-21 days in the past 50 years, and now overlaps directly with peak nesting of grassland birds in most regions (Martin and Gavin, 1995; Herkert, 1997). Current hay cutting schedules put grassland bird populations at risk by causing complete reproductive failure through loss of nests, eggs, or flightless young (Bollinger et al., 1990; Dale et al., 1997; Green et al., 1997; Vickery et al., 2001). These activities are also unfavourable to plant and invertebrate diversity (Swash et al., 2000; Vickery et al., 2001).

As most beef-cattle operations continue to use exotic crops for hay in North America and Europe (Giuliano and Daves, 2002), it is of conservation importance to explore methods that reduce risks to wildlife in these field types. Although, it has been shown that delaying the timing and changing the frequency of hay cutting can significantly increase reproduction in grassland birds (Bollinger et al., 1990; Herkert, 1997; Kleijn et al. 2001), impacts to farmers have been overlooked. Potentially unacceptable declines in nutritional quality of hay are a common concern (Vickery et al., 2001) with a delay of first cutting. Further concerns are a potential reduction in the crop's monetary value and creation of extra labor costs for the farmer.

Given these unexamined concerns, our objectives in the present paper are to examine these issues at study sites in Atlantic Canada and a) determine optimum timing of hay cutting to maximize both bird breeding potential and hay nutrition quality for cattle and, b) predict trade-offs between delayed hay cutting for bird conservation and hay nutrition quality as an agricultural concern.

2. Methods

2.1. Study Sites

Three different agricultural sites (centered around 44°45'N, 65°31'W) were studied in the western Annapolis Valley of Nova Scotia, Canada: Belleisle Marsh Wildlife Management Area (hereafter "Belleisle"; 326 ha), Queen Anne (180 ha), and Pea Round (142 ha). Historically, the areas were extensive salt marsh, but dykes built by 17th century settlers and a causeway built in the 1960's, converted and maintains these lands for agriculture production.

Queen Anne and Belleisle support beef-cattle operations and were seeded (in the late 1980's, early 1990's) to large swards of mixtures of timothy (*Phleum pratense* L.), meadow fox-tail (*Alopecurus pratensis* L.), various bluegrass species (*Poa* spp.), and reed canary grass (*Phalaris arundinacea* L.). Fertility management is accomplished by periodic (ca. every 10 years) applications of lime, at approximately 270 kg/ha per field. Except for a small amount (3.7 ha) of early-cutting at Queen Anne, the cutting at these two sites was almost wholly in the form of late-cut hay. Date of first cut at both these sites was after 1 July, except for the small field cut for silage at Queen Anne. Pea Round was cultivated solely to support dairy operations, and most of the cutting was for silage; first-cut began relatively early (pre 15 June). The same mixtures of grasses are planted at this site, with the addition of several homogenous swards of alfalfa (*Medicago sativa* L.). None of fields at the three sites were grazed during the study.

The Queen Anne and Pea Round sites are privately owned and managed exclusively by the landowners. The predominantly government-owned Belleisle is managed for both wildlife and agricultural benefits in a multifaceted approach integrating wildlife habitat and human land use. Agricultural areas in Belleisle are licensed to farmers through a periodic tender system, but licensees are required to adhere to a management strategy that includes delayed hay cutting (currently post 1 July) and pesticide restrictions. No pesticides were applied during the period of this study. The mandatory delayed cutting date was created to mitigate risk of nestling mortality and enhance fledging (for passerines and waterfowl).

2.2. Breeding Bird Phenology

Breeding phenology was monitored for the three most common birds breeding regionally in hayfields: bobolink (*Dolichonyx oryzivorus* L.), savannah sparrow (*Passerculus sandwichensis* Gmelin), and Nelson's sharp-tailed sparrow (*Ammodramus nelsoni*; Acadian race *subvirgatus* Allen). Bobolinks are visibly sexually dimorphic and were the only species identifiable to sex. All individuals encountered were visually aged as fledgling (hatch year) or adult. During all observations individuals were closely followed, to limit double-counting and arrive at the maximum number of individuals observed per unit ($n = 13$ in 2000 and 2001, $n = 52$ in 2002 and 2003). We defined peak fledging as the date with the greatest mean number of fledglings observed per adult. Summarising count data this way accounted for the effect of switching count methods (described below) and reduced (but not eliminate) the inflation effect of floaters and non-residents on counts of adults.

In 2000 and 2001, these species were monitored at the Belleisle site only, along two fixed-route census paths (2.9 and 1.7 km) that were divided into 13 portions of approximately equal length. Between 7 June and 12 July, all study species were counted (visually and by song) within ~100m on each side of the transect line. Each census began within one hour after sunrise and was conducted at least twice weekly. Total area surveyed (4,521 m transect length x 200 m width) was 0.9 km².

The remaining two study sites were included in 2002 and 2003. To accommodate this expansion, monitoring methods were changed to fixed-radius point counts. From 29 May - 8 August, five-minute counts were conducted 10-12 times, across each of 52 plots with 50m radii. Counts were conducted between 30 min post-sunrise and 1000 AST (weather permitting: wind <25kph, no precipitation). As with the fixed-route census, all individuals were counted visually and by song.

2.3. Hay Nutritional Quality

Vegetation nutrition quality samples were randomly collected from study hayfields in 2001-2003, weekly between 9 June and 24 July, until a sample hayfield was cut. The vegetation samples from Pea Round, because of the early cut date, are therefore incomplete across the season. The other two study sites did have plots that were not cut until after 24 July, allowing a full sampling season. In 2001, these samples were collected from three different areas (~2 ha each) along the fixed-route census (in Belleisle only). In each of these three areas, at least two random non-linear cross-sections were traversed and at every fifth step 5-10 stems of vegetation were clipped at a height of 8-10 cm (to approximate the height of an actual hay cut). The same protocol was used for vegetation sampling within the fixed-radius point count plots in 2002 and 2003, within 13 plots randomly selected from the 52 point-count plots. Eight of these plots were located in Belleisle, three in Queen Anne and two in Pea Round; all of these plots were typical of

the field composition for each site described in Study Sites. The typical sample from a plot in all years weighed approximately 200g each.

Crude protein (CP; a measure of grass nitrogen content) and acid detergent fibre (ADF), which is an estimate of indigestible lignin-bound carbohydrates (lignification reduces cell wall degradability and diminishes assimilation of forage gross energy) were measured. The mineral contents of grass for calcium (Ca) and phosphorus (P) were also measured. However, parameters of CP quality (i.e. degradability and digestible undegraded protein) were not evaluated.

Nutritional analysis was conducted by the Nova Scotia Department of Agriculture and Fisheries- Feed Quality Evaluation Division. Samples were dried (65°C for 48 h), ground (Wiley mill, 1mm sieve) and then tested individually. ADF was determined for each sample from the cellulose and lignin remaining after boiling the sample in acidified detergent solution (to solubilize digestible nutrients). Remaining solids were filtered through a fritted glass filter and weighed (AOAC 1996). CP was sampled through nitrogen combustion (Leco FP528 Nitrogen Determiner with interfaced balance and autosampler). Calcium and phosphorus concentrations were determined using inductively coupled argon spectrometry.

2.4 Statistical Analyses

All statistical tests were conducted using *R* version 1.8.1 (R Development Core Team 2003). The first goal was to determine if there were differences in bird breeding phenology or vegetative nutrition quality between each dyad of years (sites combined). Concordance in distribution shape of the frequency of incremental fledgling:adult ratios observed (steps of 0.1) and CP in vegetation (based on quartiles) was analysed with two-sample Kolmogorov-Smirnov tests (Sokal and Rohlf, 1997). A change in the shape of the distribution would imply a stochastic event had occurred to unduly influence phenology or forage quality.

To determine if there were significant changes in peak observed fledging rates, for dates with multiple observations across years, Kendall's rank correlation was used, calculating $\tau\text{-}b$ (which corrects for tied samples; Kendall, 1970). This analysis was not conducted for nutrition quality data, as the peak (in CP) always occurs in the first sample.

Trends in the weekly means (from all years combined) of crude protein in vegetation and fledging rate for all species were modelled with least-square linear regression (Sokal and Rohlf, 1997) using a binomial error term. As fledging phenology data lack within-subject error (which would lead to problems with pseudo-replication), repeated measures tests were not applied. To avoid over-fitting and to exclude the periods of pre-fledging and post-peak fledging when dispersal has likely started, a linear model was fit instead of a logistic response curve. Residuals were graphically assessed for departures from linearity, and regression equations are presented to estimate trajectory, quoting the R^2 statistic to describe regression line fit.

3. Results

3.1. Breeding Bird Phenology

The average peak fledging dates for each study species (Table 1) fell within the first week of July. However, numbers of confirmed sightings of Nelson's sharp-tailed sparrow fledglings were low in most years, allowing only cautious interpretation and no statistical analyses. Savannah sparrows are the only one of these three species that predictably double-brooded at the study sites, with a second (usually much smaller) peak in fledging during the first week of August. This bimodal distribution, monitored in 2002 and 2003, identified the second peak

fledge dates as 2 and 3 August, respectively. These dates are well ahead of second cuts at the study sites that occur in September, so there was adequate cover to double-brood.

Table 1

Dates of peak fledging for bobolink, savannah sparrow, and Nelson's sharp-tailed sparrow. Values for 2000 and 2001 were determined from 13 legs of 2 transects, and for 2002 and 2003 from 52 point count plots

Year	bobolink		savannah sparrow		Nelson's sharp-tailed sparrow ^a	
	peak	mean \pm s.d.	peak	mean \pm s.d.	peak	mean \pm s.d.
2000	4 July	6 July \pm 4.7	30 June	1 July \pm 9.8	3 July	4 July \pm 6.6
2001	6 July	11 July \pm 6.1	6 July	7 July \pm 8.2	6 July	7 July \pm 8.2
2002	3 July	8 July \pm 9.1	29 June	9 July \pm 14.3	7 July	10 July \pm 4.2
2003	1 July	3 July \pm 2.6	1 July	30 June \pm 3.3	10 July	9 July \pm 5.0
All Years	4 July ^b	-	2 July ^b	-	7 July ^b	-

^a Dates for Nelson's sharp-tailed sparrow should be interpreted with caution as they are determined from few dates (n<5) with clear fledgling observations.

^b Calculated as rounded mean of peak fledging dates (in Julian-annual days)

Two-sample Kolmogorov-Smirnov tests showed that the non-normal (right-skewed) distribution of fledging observations across years for bobolink and savannah sparrow did not change. However, the timing of fledging did significantly differ between 2000-2001 for bobolink and between 2001-2003 for bobolink and savannah sparrow, which represents one-third of all possible dyads. Within the remaining dyad comparisons for bobolink, some showed relatively high τ -b statistics (>0.30).

Although fledging rate over the entire season showed a non-normal distribution (with no fledging occurring in the pre-fledging period), the trajectory of the fledging pattern *after* initiation, to the annual peak was linear (e.g. Figure 1 for cumulative rates of bobolink) verified from a visual assessment of residuals. However, all fledging rates, after experiencing such a sharp linear increase in the early stages, do plateau and drop (likely because dispersal had started) as fledging rate slowed (e.g. Figure 1). The following models, using a binomial error term, describe this linear relationship (compare to CP; Figure 1) from the onset of fledging (last date that no fledglings were recorded) to peak fledging approximately three weeks later:

$$\text{Bobolink: } y = 0.0668x - 0.0762 \text{ (R}^2 = 0.9855\text{)}$$

$$\text{Savannah sparrow: } y = 0.0547x - 0.0741 \text{ (R}^2 = 0.9225\text{)}$$

$$\text{Nelson's sharp-tailed sparrow: } y = 0.315x - 0.3267 \text{ (R}^2 = 0.9959\text{)}$$

3.2. Nutritional Quality

The distribution of crude protein measurements did not change shape across years ($D = 0.25$, $p \sim 1.00$ for each dyad of years). This implies that no unexpected event occurred in any sampling year to unduly influence measurements.

Results of nutritional quality measurements are presented in Table 2 (mean trend in CP in Figure 1). Table 2 provides no evidence for a reduction in CP during the first week in July of 2001 and 2003, indicating nutritional quality was not significantly reduced by a cut delay in this

period. CP content remained at a level suitable for dry, late-lactation or non-pregnant cows, particularly small breeds (National Research Council (NRC), 1996), until well after peak fledging dates for all species (Table 1) in 2002 and 2003 (pre 15 and 7 July, respectively; Table 2). The first sampling in 2001 (19 June) was already below this level, with expected declines into July (Table 2). However, CP sample content declined below necessary limits for calves and pregnant females (>11%; NRC, 1996) much earlier (pre 23 June in 2002, and 22 June in 2003), and well before peak fledging of birds at those sites.

Table 2

Mean forage quality measurements (\pm s.d.) from all samples across study sites for each sampling date

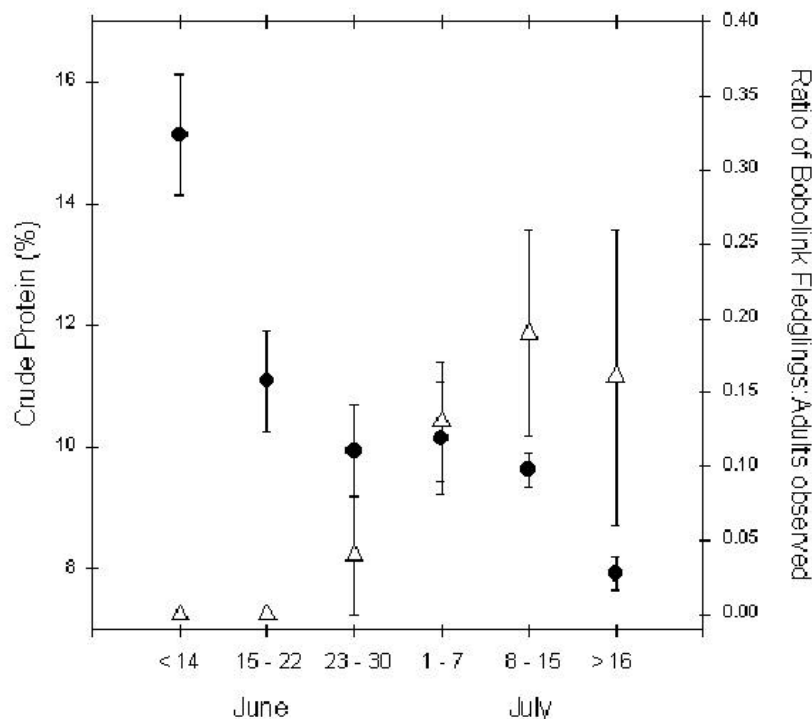
Day	Year	Crude Protein (% \pm s.d.)	Acid Detergent Fibre (% \pm s.d.)	Calcium (% \pm s.d.)	Phosphorus (% \pm s.d.)	Calcium: Phosphorus Ratio
19 June	2001	9.53 \pm 0.76	40.50 \pm 1.12	0.10 \pm 0.02	0.20 \pm 0.02	0.50
26 June	2001	9.17 \pm 0.70	42.06 \pm 1.78	0.13 \pm 0.04	0.20 \pm 0.02	0.65
3 July	2001	8.32 \pm 0.74	41.59 \pm 1.60	0.12 \pm 0.03	0.18 \pm 0	0.67
10 July	2001	8.98 \pm 0.11	40.29 \pm 0.46	0.23 \pm 0.03	0.17 \pm 0.01	1.35
17 July	2001	7.65 \pm 2.46	43.04 \pm 3.20	0.16 \pm 0.02	0.16 \pm 0.01	1
24 June	2002	11.47 \pm 1.60	37.53 \pm 2.04	0.13 \pm 0.05	0.20 \pm 0.03	0.65
2 July	2002	10.77 \pm 1.57	38.50 \pm 1.68	0.13 \pm 0.03	0.18 \pm 0.03	0.72
8 July	2002	10.18 \pm 1.08	38.46 \pm 1.24	0.15 \pm 0.04	0.17 \pm 0.03	0.88
15 July	2002	10.05 \pm 2.35	37.61 \pm 2.87	0.22 \pm 0.07	0.18 \pm 0.03	1.22
24 July	2002	8.19 \pm 1.60	39.60 \pm 2.04	0.15 \pm 0.02	0.14 \pm 0.02	1.07
9 June	2003	16.13 \pm 2.09	31.01 \pm 1.54	0.19 \pm 0.05	0.31 \pm 0.03	0.61
16 June	2003	14.16 \pm 1.38	33.85 \pm 2.27	0.19 \pm 0.05	0.26 \pm 0.04	0.73
23 June	2003	12.27 \pm 1.93	36.13 \pm 1.98	0.16 \pm 0.05	0.22 \pm 0.04	0.73
30 June	2003	10.69 \pm 1.13	38.00 \pm 1.43	0.14 \pm 0.03	0.19 \pm 0.03	0.74
7 July	2003	11.37 \pm 0.85	37.64 \pm 1.14	0.17 \pm 0.05	0.20 \pm 0.04	0.85
14 July	2003	9.32 \pm 1.22	40.19 \pm 1.47	0.16 \pm 0.05	0.16 \pm 0.02	1

Acceptable ADF levels for all types of cattle are below 34-35% (Rayburn, 1994; NRC, 1996). Above these levels vegetation becomes increasingly fibrous and indigestible. In all years, except for the two earliest sampling dates in 2003, ADF was above these levels, yet had sufficient levels of CP (Table 2). Concentration of ADF generally increased as cutting was delayed.

Calcium concentration of vegetation is generally low, but Ca and P concentrations observed in the delayed cut samples were too low (Table 2) to support extra-maintenance functions of cattle. The Ca:P ratio was also too low (ideally, the ratio should be > 1; NRC, 1996), suggesting that a supplement containing Ca at least would be required for cattle of all physiological states.

Figure 1

Annual mean measurements (\pm SE) of % crude protein (circles) in forage samples and cumulative bobolink fledging rate (# fledglings / # adults observed; triangles) per weekly time period. Least squares linear regression equation for crude protein: $y = -1.3994x + 15.965$ ($R^2 = 0.865$); see text for fledging rate equation



4. Discussion

For all three species, peak fledging periods occurred during the first week of July, which closely matches dates reported for other sites in eastern Canada (e.g. fledging dates as in Welsh, 1975; other temporal patterns as in Bédard and LaPointe, 1984; Boutin et al., 1999) and is 1-2 weeks later than some southern/western populations (e.g. citations in Wheelwright and Rising, 1993; Martin and Gavin, 1995; Dale et al., 1997). A savannah sparrow population on Kent Island, New Brunswick, 100 km west of the sites in this study, typically sees peak fledging in late June (one week prior to this study; Wheelwright and Rising, 1993). Variability between years at the sites, and between regions, was expected as breeding phenology is known to vary (especially under such influences as temperature, weather, and food availability; Winkel and Hudde, 1996; Przybylo et al., 2000). Savannah sparrow was the only species to regularly show double-brooding behaviour (Wheelwright and Rising, 1993).

An indicator of overall vegetation quality, and a variable of high importance to cattle nutrition is CP %, which accounts for all nitrogen components of the vegetation (Rayburn, 1994; NRC, 1996; Ortega et al., 1997). Cattle convert these nitrogenous compounds into amino acids, and require a minimum ~10% CP for maintenance and growth (Rayburn, 1994; NRC, 1996). Crude protein concentration of unfertilized swards reflects its energy content insofar as it is associated with legume and leaf. Thus, during the peak fledging period for grassland birds, nutritional quality at these sites did not decline below requirements for feeding growing steers in

beef-cattle operations. This assessment is particularly true if those farms are using cattle breeds that maximize nutrient intake, such as Herefords and other English varieties. However, the same vegetation may be considered of poorer quality for larger and more energetically demanding breeds such as Simmental, or those requiring additional quality such as dairy cattle, calves, and pregnant females.

In the present study, the effects of delaying hay cutting in terms of both CP and numbers of fledglings produced were calculated. Whereas many fields outside of our study sites are completely cut by June 20 each year (Nocera, Parsons, and Milton *unpublished data*), a delay of an additional 1.5 weeks (to 1 July) in our study site translated to a mean decrease in %CP of 2.1 (to 11.57%; see Figure 1 equation). Conversely, this delay secured an increase in the rate of fledgling, from zero to 20% for bobolink, 56% for savannah sparrow, and 44% for Nelson's sharp-tailed sparrow. Postponing cut one more week (to a minimum of July 7) gave the benefit of allowing peak fledging rates to be achieved for all species. However, %CP exhibited a loss of 3.5, reducing quality even for energetically conservative breeds of growing steers (to 10.17%; NRC, 1996). A total decline in %CP level was observed from beginning to end of the season in 2001, 2002 and 2003 of 1.88, 3.28 and 6.81, respectively. In context, these declines are comparable to those observed in a naturalized dairy pasture containing white clover, but receiving no N fertilizer, where an increase in %CP of 2.7 was observed one year, while a decline of 14.3 was observed over the same period, the next (Fredeen et al., 2002). Additionally, similar values to those observed have been seen previously in stockpiled forage, a strategy used in the region's beef and sheep industries to provide pasture during the season's dry periods (Benedict, 1999).

Peak fledging dates are subject to mortality and human-influenced fluctuations. Bollinger et al. (1990) observed that if cuts occurred early in the season (before 20 June), bobolinks renested and were able to improve overall fledgling productivity. These early cuts resulted in almost 94% overall nest/nestling mortality (Bollinger et al., 1990). A mortality event of this magnitude that allowed time for renesting (provided non-cut habitat was available; Green et al., 1997) would surely delay peak fledging beyond any dates observed in this study. We suspect the ratio of fledglings to adults observed for bobolinks at peak fledging over the period of the study is indicative of a fledging rate at, or near, a level that could sustain a population if adult survivorship were high (e.g. >70%; Bollinger et al., 1990). There is little information on population vital rates for either Nelson's sharp-tailed sparrow (Greenlaw and Rising, 1994) or savannah sparrow, although there are estimates that adults can experience >95% annual survivorship (Wheelwright and Rising, 1993). Fledging ratios we observed for these two species are likely adequate for population maintenance and that such high annual adult survivorship does not indicate a need to maximise reproduction for population maintenance (as in Green et al., 1997).

Some farmers (particularly in our study region) tend to emphasize quantity over quality, or try to simultaneously maximize yield, quality and stand persistence (Kallenbach et al., 2002), which further reduces emphasis on optimal quality. This contrasts with a common emphasis on quality over quantity observed in the United Kingdom (Vickery et al., 2001). Delayed hay cutting allows field curing conditions to improve as summer progresses (Kunelius et al., 2000) and significantly increases total annual yields in one-cut systems (Mason and Lachance, 1983). Thus, delayed cutting can be a viable option for farmers that wish to conserve breeding birds on hayfields. The feasibility of this approach will depend on the breed of cattle kept, the use of those cattle (dairy vs. beef production), and herd requirements (fattening vs. maintenance).

Overall, the strategy tested in this study, to improve survival rates and reproduction of grassland birds by delaying hay cutting, is most viable for beef farms utilizing small frame breeds in cow-calf systems. Nutritional value of delayed cut vegetation would likely meet requirements for energy and protein of maintenance as well as mid- and late- lactation (Rayburn, 1994; NRC, 1996, Ortega et al., 1997). Mineral concentration however, appeared low for cattle. Other advantages of delaying cutting include cost reduction and lower risk of rain to preclude or damage harvest.

These results provide clear evidence that quality declines in vegetation nutrition are acceptable under certain agricultural conditions, when the objective is to increase/provide adequate conservation of breeding grassland birds in hayfields. The practice needs to be incorporated into a more holistic approach to sympathetic agroecosystem management. Such attributes as farmland-landscape and vegetative heterogeneity (Benton et al., 2003), grazing intensity (Lapointe et al., 2000), management of field edges and margins (Jobin et al., 2001; Vickery et al., 2002), and fertilisation (Vickery et al., 2001) are all examples of items that need to be addressed at local (farm-level) and broad scales.

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