The use of a small scale study and regional data sources to understand grassland bird habitat relationships

by

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Abstract

Habitat loss and degradation, among other factors, contributed to a steady decline in grassland bird populations across the U.S. Many large scale management efforts are in place to stabilize and increase grassland bird populations through habitat restoration and protection. To inform this effort, large scale habitat associations of birds can help predict where best to put habitat and the benefit to grassland bird populations. We developed a directed dynamic occupancy study and utilized avian database information from the North American Breeding Bird Survey to understand occupancy-habitat associations of bobwhite (*Colinus virginianus*), eastern meadowlark (*Sturnella magna*) and dickcissel (*Spiza americana*) in the Black Belt Region of the Upper East Gulf Coastal Plain Joint Venture to inform regional conservation planning. Our results indicate grassland connectivity and landscape composition are important habitat factors to consider on multiple scales for multi-species conservation. Also, the use of avian database sources is variable and prior considerations should be considered before applying data to occupancy modeling techniques.

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Table of Contents

Abstract ii

Acknowledgments iii

List of Tables vi

List of Figures xi

Chapter 1: General Introduction 1

- Thesis Organization 3
- Literature Cited 4

Chapter 2: Habitat associations of grassland birds in the Upper East Gulf Coastal Plain. 6

- Abstract 6
- Introduction 7
- Study Area 10
- Methods 11
  - Field Methods 11
  - Landscape Analysis 12
  - Statistical Analysis 15
- Results 19
  - Occupancy Probability 19
  - Habitat Composition 20
  - Habitat Patch Size 20
  - Habitat Scale 20
  - Grassland Connectivity 21
- Discussion 22

Usage of NLCD for Habitat Covariates 28

Conclusions 30

Literature Cited 31

Chapter 3: The utility of the North American Breeding Bird Survey to predict habitat relationships of grassland birds using prior knowledge from a small scale study 54

Abstract 54

Introduction 55

Study Area 58

Methods 60

BBS Data Acquisition 60

Route Stop Sampling Procedures 61

Statistical Analysis 62

Results 65

Discussion 66

Literature Cited 73

List of Tables

Table 2.1. Occupancy (ψ) survey site selection based on agriculture and hay/pasture percentage composition within 200 m of survey location in the Black Belt Prairie Region of the Upper East Gulf Coastal Plain Joint Venture in 2013 and 2014. Each “x” represents a secondary class from which 16 sites were selected for point count survey... 41

Table 2.2. Initial occupancy habitat covariates used in analysis of grassland bird dynamic occupancy in the Black Belt Prairie region of the Upper East Gulf Coastal Plan Joint Venture, USA in spring 2013 and 2014. Covariates were incorporated at the site and landscape extent indicated by specific scales in model selection results 42

Table 2.3. Models sets for single season analysis of bobwhite (*Colinus virginianus*) occupancy (ψ) in the Black Belt Prairie region of the Upper East Gulf Coastal Plain Joint Venture in spring 2013 and 2014. Models were run in R-program Unmarked to identify best (AICc ≤ 2.0) occupancy models in 2013 and 2014 to transition to a Bayesian multi-season occupancy model. Model 20 represents the null occupancy model... 43

Table 2.4. Models sets for single season analysis of eastern meadowlark (*Sturnella magna*) and dickcissel (*Spiza americana*) occupancy (ψ) in the Black Belt Prairie region of the Upper East Gulf Coastal Plain Joint Venture in spring 2013 and 2014. Models were run in R-program Unmarked to identify best (AICc ≤ 2.0) occupancy models in 2013 and 2014 to transition to a Bayesian multi-season occupancy model. Model 18 represents the null occupancy model.. 44

Table 2.5. Detection (p) model sets with covariate description (Covariate) and name (Model) for grassland bird occupancy (ψ) modeling using road side presence-absence surveys in the Black Belt Prairie region of the Upper East Gulf Coastal Plain Joint Venture, USA in 2013 and 2014 based on detection model type (Type).. 45

Table 2.6. Summary statistics of site habitat covariates (Covariate (ψ)) included in the best dynamic multi-season occupancy (ψ) models of prevalent grassland birds in the Black Belt Prairie region of the Upper East Gulf Coastal Plain Joint Venture, USA in 2013 and 2014. Average (Mean), standard deviation (SD), minimum value (Min), and maximum value (Max) were calculated for each covariate.....46

Table 2.7. Estimated number of occupied sites (n=102) resulting from best occupancy (ψ) and detection (p) models (ΔDIC ≤ 2.0) of prevalent grassland birds in the Black Belt Prairie region of the Upper East Gulf Coastal Plain Joint Venture, USA in 2013 and 2014. Parentheses indicate 95% credibility intervals........................ 47

Table 2.8. DIC (Deviance Information Criterion) results of dynamic multi-season occupancy (ψ) model selection for dickcissels (*Spiza americana*), eastern meadowlark (*Sturnella magna)* and northern bobwhite (*Colinus virginianus*) at 102 study sites in 2013 and 2014 in the Black Belt Prairie region of the Upper East Gulf Coastal Plain Joint Venture, USA. Models include covariates for detection (p) and occupancy (ψ) components and are reported with Deviance information Criterion (DIC), difference of model DIC to best model (ΔDIC), and model weight (W_i)... 48

Table 3.1. North American Breeding Bird Survey routes in the Black Belt Prairie Region of the Upper East Gulf Coastal Plain Joint Venture including several additional counties in Tennessee... 80

Table 3.2. Occupancy (ψ) route stop sampling procedure (n = 121) based on agriculture and hay/pasture percentage composition within 400 m of route stop on BBS routes in the Black Belt Prairie Region of the Upper East Gulf Coastal Plain Joint Venture in 2009 to 2013. Each “x” represents a secondary class from which 30 route stops were potentially selected for dynamic occupancy estimation... 81

Table 3.3. Models sets for dynamic occupancy (ψ) analysis of bobwhite (*Colinus virginianus*), eastern meadowlark (*Sturnella magna*) and dickcissel (*Spiza americana*) occupancy in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA using North America Breeding Bird Survey Data for 2009 to 2013. Models were run in Program R and WinBUGS........................ 82

Table 3.4. Dynamic occupancy habitat covariates used in analysis of grassland bird dynamic occupancy in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA using North America Breeding Bird Survey Data for

2009 to 2013. Covariates were incorporated at the site and landscape extent indicated by specific scales within the model covariates column...................... 83

Table 3.5. Number of detections at BBS route stops in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region from 2009 to 2013. Parentheses indicate the number of route stops surveyed each year based on BBS route completion. 84

Table 3.6. Standardized effect sizes of bobwhite (*Colinus virginianus*) dynamic occupancy model covariates using BBS route stops counts from 2009 to 2013 in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA utilizing 6 different sampling/modeling procedures. Sampling procedures progress in habitat suitability from top to bottom (best). Parentheses indicate 95% credibility intervals and bolded values indicate effect sizes whose credibility interval does not span zero... 86

Table 3.7. Standardized effect sizes of eastern meadowlark (*Sturnella magna*) dynamic occupancy model covariates using BBS route stops counts from 2009 to 2013 in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA utilizing 6 different sampling/modeling procedures. Sampling procedures increase in habitat suitability from top to bottom. Parentheses indicate 95% credibility intervals and bolded values indicate effect sizes whose credibility interval does not span zero... 87

Table 3.8. Standardized effect sizes of dickcissel (Spiza americana) dynamic occupancy model covariates using BBS route stops counts from 2009 to 2013 in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA region utilizing 6 different sampling/modeling procedures. Sampling procedures increase in habitat suitability from top to bottom. Parentheses indicate 95% credibility intervals and bolded values indicate effect sizes whose credibility interval does not span zero... 88

Table 3.9. Deviance Information Criterion (DIC) results of dynamic multi-season occupancy (ψ) models for dickcissels (Spiza americana), eastern meadowlark (Sturnella magna) and northern bobwhite (Colinus virginianus) at North American Breeding Bird Survey route stops in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA in 2009 to 2013. Null occupancy models are indicated as NULL... 89

Table 3.10. Predicted yearly occupancy probabilities of BBS route stops in the East gulf Coastal Plain Joint Venture Black Belt Prairie region, USA utilizing habitat relationships of best models from chapter 1 standardized mean posterior distribution effect sizes for bobwhite, eastern meadowlark, and dickcissel from

2009 to 2013. "a" refers to occupancy models including 3 km grassland network size for bobwhite and 1 km hay/pasture, grassland, and agriculture including 3km grassland network size for dickcissel and 400 m hay/pasture, grassland, and agriculture including 1 km grassland network size for eastern meadowlark. "b" refers to occupancy models including average 2 km agriculture composition and agriculture patch size for bobwhite and 1 km hay/pasture, grassland, and agriculture composition... 91

Table 3.11. Posterior distribution standardized effect sizes of bobwhite (*Colinus virginianus*), eastern meadowlark (*Sturnella magna*) and dickcissel (*Spiza americana*) dynamic occupancy model covariates using BBS route stops counts from 2009 to 2013 in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA displaying the sampling procedure with 150 route stops with uninformed and informed priors. Parentheses indicate 95% credibility intervals.. 92

Table 3.12. Posterior distributions of bobwhite (*Colinus virginianus*), eastern meadowlark (*Sturnella magna*) and dickcissel (*Spiza americana*) yearly dynamic occupancy estimates using BBS route stop counts from 2009 to 2013 in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA displaying the sampling procedure with 150 route stops with uninformed and informed priors. Parentheses indicate 95% credibility intervals....................... 94

Table 3.13. Posterior distributions of bobwhite (*Colinus virginianus*) dynamic occupancy estimates using BBS route stop counts from 2009 to 2013 in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie, USA utilizing 6 different sampling/modeling procedures. Sampling procedures increase in habitat suitability from top to bottom. Parentheses indicate 95% credibility intervals. 96

Table 3.14. Posterior distributions of eastern meadowlark (*Sturnella magna*) dynamic occupancy estimates using BBS route stop counts from 2009 to 2013 in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie, USA utilizing 6 different sampling/modeling procedures. Sampling procedures increase in habitat suitability from top to bottom. Parentheses indicate 95% credibility intervals.. 98

Table 3.15. Posterior distributions of dickcissel (*Spiza americana*) dynamic occupancy estimates using BBS route stop counts from 2009 to 2013 in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie, USA utilizing 6 different sampling/modeling procedures. Sampling procedures increase in habitat

suitability from top to bottom. Parentheses indicate 95% credibility intervals. 99

List of Figures

Figure 2.1. The boundary of East Gulf Coastal Plain Joint Venture includes five states within the USA and encompasses large portions of Mississippi and Alabama. One hundred and two survey sites were selected within 6 counties of interest throughout the Upper East Gulf Coastal Plain Joint Venture. Sampling counties in Mississippi and Alabama were part of the historic Black Belt Prairie region. 50

Figure 2.2. Independent relationships of expected occupancy probability of eastern meadowlark (*Sturnella magna*) in response to percentage of hay/pasture or agriculture land cover at a site in the Black Belt Prairie region of the Upper East Gulf Coastal Plain Joint Venture, USA in 2013 and 2014................................ 51

Figure 2.3. Independent relationships of expected Dickcissel (*Spiza americana*) occupancy probability to percentage of agriculture, hay/pasture and grasslands within 1 km in the Black Belt Prairie region of the East Gulf Coastal Plain Joint Venture, USA in 2013 and 2014.. 52

Figure 2.4. Relationship of expected occupancy probability of northern bobwhite (*Colinus virginianus*) and Dickcissel (*Spiza americana*) to 3 km grassland network size in the Black Belt Prairie Region of the Upper East Gulf Coastal Plain Joint Venture, USA in 2013 and 2014... 53

Figure 3.1. North American Breeding Bird Survey (NABBS) routes of the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA. A total of 21 routes were used in dynamic occupancy modeling of route stops to assess occupancy-habitat relationships of prominent grassland birds in the region. 101

Figure 3.2. Mean posterior distribution of standardized covariate effects of hay/pasture composition within 400 m on eastern meadowlark (*Sturnella magna*) occupancy probability (ψ) along North American Breeding Bird Survey (BBS) route stops in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA in 2009 to 2013. Relationships are presented for the six different BBS sampling/modeling procedures... 102

Figure 3.3. Mean posterior distribution of standardized covariate effects of agriculture composition within 400 m on eastern meadowlark (*Sturnella magna*) occupancy

probability (ψ) along North American Breeding Bird Survey (BBS) route stops in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA in 2009 to 2013. Relationships are presented for the six different BBS sampling/modeling procedures.. 103

Chapter 1:
General Introduction

Grassland bird populations have declined throughout North America for several decades and are considered the continent's most imperiled group of birds (Peterjohn and Sauer 1999). For example, northern bobwhite (*Colinus virginianus,* hereafter, bobwhite) abundance has recently been estimated to be declining 4.2 percent annually range-wide and other prominent grassland birds in decline include the eastern meadowlark (*Sturnella magna*) and dickcissel (*Spiza americana*) (Sauer et al. 2013) . Population declines are attributed to several factors. Habitat loss and degradation is a commonality across the continent (Herkert 1994). Modern, efficient agricultural production has further degraded the utility of near-grassland habitats by providing less cover and food sources to grassland birds than past techniques (Martin and Finch 1995). Successional changes have also contributed to grassland habitat declines. Whether being taken out of agricultural production or due to fire suppression, conversion and successional change of open areas to closed canopy forest has had negative impacts on grassland bird habitat availability (Noss 2012).

Especially in the Black Belt Prairie region of the Southeastern United States, fire suppression and other factors have decreased the value of historic prairies and forested systems. Conversion of natural grasslands and prairies to hay production, pastures and agricultural has greatly reduced the amount natural habitat for birds (Noss et al. 1995). In the Black Belt Prairie region, only a few prairie remnants are left, with a vast majority of historic prairie converted to agriculture (DeSelm and Murdock 1993). Woody encroachment due to fire suppression on prairie remnants has greatly diminished their quality for some grassland species. Pine savannas are also important systems in this region and contain herbaceous understories, which is important for many grassland associated birds (Van Lear et al. 2005). However, many of these systems now contain woody understories and higher canopy cover because of fire suppression (Noss et al. 1995).

Habitat losses and population declines have led to many habitat relationship studies of grassland birds. Key habitat features have been identified for grassland bird conservation. Area-sensitivity has been found in many grassland bird species and these relationships have been found to vary across regions (Ribic et al. 2009). Habitat patch shape has also been reported to influence species use an area (Helzer and Jelinski 1999). Moreover, the composition of the landscape around an area has been reported to influence both occupancy and abundance of grassland birds (Twedt et al. 2007). Current knowledge of habitat responses provides substantial information for grassland birds at local and landscape scales (Herkert 1994, Thogmartin et al. 2006b).

Many of these habitat-relationships have been developed in the Great Plains and Midwest. Unique ecosystems and land use patterns of the Black Belt Prairie region have not been extensively studied. In response, I developed directed studies to understand these habitat relationships in the Black Belt Prairie region to be used in conservation planning.

I studied the influences of local and landscape habitat features on occupancy of grassland birds in the Black Belt Prairie region of the Upper East Gulf Coastal Plain Joint

Venture. The Black Belt Prairie is an area of the Southeastern United States containing a network of grassland patches in Alabama and Mississippi, which are situated among many agricultural land uses. I sought to understand unique, species-specific grassland bird relationships to area sensitivity, patch shape, habitat composition and grassland connectivity, along with the spatial scales at which these occur. I developed and executed a grassland bird point count study in the Black Belt Prairie region in 2013 and 2014 to understand these occupancy-habitat relationships. Based on results of this effort, I then used North American Breeding Bird Survey (BBS) data to demonstrate the utility of BBS to predict habitat relationships for conservation planning. Additionally, I wanted to understand the ability of a grassland bird directed study to inform occupancy modeling efforts with bird database information.

This study provides 2 different insights for grassland birds. One, the occupancy-habitat relationships of grassland birds in the Black Belt Prairie region of the EGCPJV, which represents a historic area of grassland communities within the JV. These relationships will provide empirical information for grassland bird management to aide land acquisition efforts for protect and habitat restoration. Second, the BBS analysis and results provide an example of a directed grassland bird study informing population modeling of BBS data and BBS results will further contribute empirical occupancy-habitat relationships using a database source for conservation actions in the EGCPJV.

THESIS ORGANIZATION

This thesis contains three chapters, including two chapters written as manuscripts for peer-reviewed publications. Authorship on these chapters includes me, my committee, who contributed procedural knowledge and guidance, and Dr. Wayne Thogmatin, who provided much technical assistance on both chapters. Chapter 1 provides a general introduction to the thesis topics. Chapter 2 explores the occupancy-habitat relationships of grassland birds using occupancy data from a directed survey method. Chapter 3 utilizes prior information from chapter 1 and BBS data to develop occupancy-habitat relationships utilizing database sources with informed priors.

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Chapter 2:
Habitat Associations of Grassland Birds in the Upper East Gulf Coastal Plain

ABSTRACT

Grassland birds are among the most imperiled groups of avian species in North America and declining population trends have been observed in the Southeastern United States. Important local and landscape scale habitat associations important for grassland birds in this region are unknown and these may be important issues for conserving these declining populations. We conducted roadside point count surveys at 102 sites in Alabama, Mississippi and Tennessee to estimate the relationship between occupancy and land cover habitat metrics for northern bobwhite (*Colinus virginianus*), eastern meadowlark (*Sturnella magna*) and dickcissel (*Spiza americana*) within the upper East Gulf Coastal Plain Joint Venture region. Using Bayesian multi-season occupancy modeling, we found agricultural patch size (ha) had a positive effect on bobwhite occupancy. The extent of agricultural, hay and pasture land cover (%) had a positive effect on eastern meadowlark occupancy. The extent of agriculture, grasslands, hay, and pasture land covers (%) showed positive effects on dickcissel occupancy. Grassland connectivity was found to be important for all species. Our findings suggest that managing the landscape configuration and composition of agriculture, hay, pasture, and grassland land cover types can benefit grassland bird populations in the Southeastern U.S. Additionally, conservation actions should focus on local and landscape scale habitat features and the spatial distance between grassland patches to benefit grassland birds.

INTRODUCTION

Grassland bird populations have declined more than any other bird group of North American since the 1960's, raising concerns regarding habitat availability and quality for grassland dependent species (Herkert 1994, Samson and Knopf 1994, Askins 1999, Peterjohn and Sauer 1999). Modern, efficient agricultural techniques (Martin and Finch 1995), range management (Vickery et al. 1999), habitat loss/fragmentation, and habitat simplification (Martin and Finch 1995) have all contributed to the decline of grassland bird habitat and populations. Grassland habitats now occur in a highly fragmented patchwork with great variation in quality, size and isolation, especially in the Southeast United States (Barone 2005).

In response to habitat and population declines, researchers have sought to understand grassland bird habitat relationships. Patch size (Herkert 1994, Helzer and Jelinski 1999, Renfrew and Ribic 2008), and landscape composition (Murphy 1996, Twedt et al. 2007) have been associated with grassland bird occupancy or abundance. In addition to local habitat characteristics, landscape-scale characteristics of habitat composition and connectivity have been recognized as important considerations for grassland birds (Ribic et al. 2009). Identification of these and other habitat and landscape relationships have increased our understanding of population declines.

Unfortunately, few studies of habitat association of grassland birds were of regional scope (Thogmartin et al. 2004b) and many failed to incorporate detectability of species in occupancy and abundance studies (Herkert 1994, Vickery et al. 1994, Bakker et al. 2002). Occupancy is the probability a species is present at a site during a season (MacKenzie et al. 2002). Detectability is the probability a species is detected at a site given its presence at that site (MacKenzie et al. 2002) and has become a critical component of occupancy estimation in wildlife studies (MacKenzie 2006). Not incorporating detectability can bias and even misidentify occupancy and abundance habitat associations (Gu and Swihart 2004).

In this paper, we used occupancy estimation techniques to evaluate how grassland birds use the available land cover in the southeastern region of the United States. Very few large scale grassland bird studies focused on the southeastern United States and even fewer account for detectability. We estimated detectability and occurrence of grassland birds in the Black Belt region of the Upper East Gulf Coastal Plain Joint Venture (EGCPJV). Joint Ventures are collaborative partnerships of diverse groups to conserve habitat for priority bird species as defined by the Fish and Wildlife Service Director's Order No. 146. The East Gulf Coastal Plain Joint Venture (EGCPJV) was created in 2006 and serves as a habitat-based region east of the Mississippi River. In the EGCPJV, forming and implementing a landscape-scale grassland conservation strategy is a primary objective for bird conservation of the region. The land cover composition of the EGCPJV based on National Land Cover Data (NLCD) (Fry et al. 2011) is forest (25%), shrub (21%), agriculture (16%), herbaceous grassland (14%), hay/pasture (7%), water (6%), wetland (6%) and developed (5%); the region is dominated by a mosaic of agriculture, pasture, grassland and forest patches.

For this study, we focused specifically on northern bobwhite (*Colinus virginianus*, here after bobwhite), eastern meadowlark (*Sturnella magna*) and dickcissel (*Spiza americana*). Bobwhite was chosen based on economic and ecological value as a game species and generalist grassland bird (Brennan 1999) in the EGCPJV. Eastern meadowlark (Jaster et al. 2012) and dickcissel (Temple 2002) present two of the most prominent grassland specialist birds in the EGCPJV. Furthermore, these three species exhibit differential migratory strategies, i.e., bobwhites are non-migratory resident birds, meadowlarks are partial and short distance migrants and dickcissels are long distance, intercontinental migrants. Each migratory strategy may result in different patterns of landscape-scale habitat associations.

Our research effort was focused on evaluating four core hypotheses related to the management and conservation of grassland birds. First, occupancy by grassland birds will have a positive relationship with the percentage of grassland habitat at the site level, which is defined as a 200m or 500m radius around point count locations. Grassland composition has been reported as an important covariate for grassland birds and we believe these patterns will be reflected in our study area (Twedt et al. 2007, Renfrew and Ribic 2008). Second, occupancy by specialist grassland birds will be positively related with the area of grassland patches at a landscape scale. Area sensitivity is well documented for grassland birds (Johnson and Igl 2001, Ribic et al. 2009). Grassland habitat size and shape is known to influence specialist species usage of habitat far more than generalist species (Vickery et al. 1994). Third, grassland birds will respond to habitat features at the site level but also at landscape levels. Both levels have been identified as important for grassland birds (Murray et al. 2008, Robles 2010) and represent an avian hierarchical decision making process to use a specific area (Hutto 1985). We included habitat covariates at multiple scales to understand this hypothesis. Finally, connectivity of suitable habitat patches will be important for all grassland birds. Bobwhite and dickcissel have been reported to respond positively to grassland connectivity (Winter 1998, Duren et al. 2011). However, stronger association to connectivity will be exhibited by resident species compared to migrating species due to decreased dispersal mobility and inter-annual movement of individuals as part of a life history strategy. Understanding these four hypotheses will enable managers to plan management at the landscape scale (e.g., habitat acquisition decisions, conservation easement programs) to best benefit grassland birds with varying life history and habitat requirements.

STUDY AREA

Our study specifically focused on the Black Belt Prairie region in the upper EGCPJV in Alabama, Mississippi and Tennessee (Figure 2.1). Fertile, dark soils distinguish the Black Belt Prairie where natural vegetation was once mostly composed of bluestem (*Andropogon spp.*) prairie and sweetgum (*Liquidambar styraciflua*), post oak (*Quercus stellata*), and red cedar (*Juniperus virginiana*)-dominated forests (Omernik and Griffith 2012). This prairie region forms the shape of an arc spanning approximately 500 km long and 40 km wide from central Alabama to northern Mississippi. Using information from 1830s General Land Office surveys, an estimated 144,000 ha of natural prairie were spread across the Black Belt region (Barone 2005). Land cover conversions and fire suppression have altered much of the natural habitat leaving remnant natural grasslands in a network of habitat patches (Noss et al. 1995). Most habitats for grassland birds now consist of working landscapes including agriculture, hay and pasture land cover types.

METHODS

Field Methods

We conducted point counts for birds at stratified random points in the target region (Figure 2.1). We restricted county and site selection in Alabama, Mississippi, and Tennessee to the Black Belt Prairie region. We generated potential survey sites in ArcMap software (ArcGIS Desktop: Release 10.2. Environmental Systems Research Institute, Inc., Redlands, CA) every 400 m along secondary state highways, county highways, and other local public road types using the U.S. Census Bureau's TIGER/Line road information. We estimated the proportion of agriculture and hay/pasture land cover within 200 m of each potential site based on most recent spatial information available from CropScape (Han et al. 2012). Agriculture, hay, and pasture land cover types may represent usable habitat for some grassland birds and comprise an overwhelming majority of potential grassland bird habitat in the region. We classified each site into one of 3 primary classes based on the percentage of hay/pasture or agriculture (0-33%, 33-67%, 67-100%), then created 6 secondary classes using all possible combinations of agriculture and hay/pasture sites within each class (Table 2.1). For example, one class of sites had 0-33% hay/pasture and 67-100% agriculture. We selected 16 sites at random from each of the six secondary classes totaling 96 sites.

We then chose 14 additional sites in Alabama to represent locations with varying proportions of historic prairie using a database of historic prairie sites provided by the Alabama Department of Conservation and Natural Resources (Schotz and Barbour 2009). The historic prairie sites were placed into the above categories according to percentage of site area for agriculture and hay/pasture. We choose 5 sites containing of 0-33% prairie composition and 5 sites containing 0-66% prairie composition and 4 sites containing 66-100% prairie composition.

We conducted point counts at each site from one half-hour before sunrise to 5 hours after sunrise between 15 May and 15 June in 2013 and 2014, similar to North American Breeding Bird Survey procedures (Robbins et al. 1996). We recorded additional information at each point count including start and end time of survey, coordinates (UTM), wind speed (wind) based on the Beaufort scale of wind speed indicators, and sky conditions (sky) using Weather Bureau sky condition indicator codes, number of passing cars (cars), and distance from road to nearest herbaceous patch. Counts were not conducted if inclement weather (e.g., steady rain, wind speed exceeding 12mph) occurred that could severely hinder detectability of birds at sites. Surveys began after a rest period of 3 minutes after arrival by automobile. During this period, we visually compared major habitat types to recent satellite imagery for accuracy assessment. We estimated vegetation heights of crop and grass habitat types as part of this habitat assessment. Each site was visited one time during the breeding season, constituting the primary sampling period. Within the primary period a secondary sampling period consisted of 3, 5-minute point counts at each site completed during the single visit to each site. Based on point count data, we recorded presence/absence of target species at each site.

Landscape Analysis

We incorporated landscape-scale habitat data as covariates in our bird occupancy analyses. The National Land Cover Database (NLCD) 2011 (Jin et al. 2013) represents the most recent, usable country-wide spatial dataset consisting of dominant land covers observed in the United States. The NLCD provides a distinct advantage over small scale, study-specific habitat covariates sources in that we could use it to predict occupancy probabilities across our region of inference. To conduct a similar habitat investigation without large scale remote sensing abilities, the time and resource investment could far exceed that used for our study. NLCD is a national database and provides habitat covariate information beyond our survey sites. Few national habitat databases exist and the NLCD provides potential for further investigations of large scale habitat association. Most importantly, we can evaluate landscape quality and predict the value of changing habitat composition and configuration on species distribution to inform habitat management decisions at a large scale. Sillett et al. (2012) employed similar techniques for large scale habitat information to assess habitat quality over a large spatial scale for island scrub-jay (*Aphelocoma insularis*). Some early studies of grassland birds only focused on local scale and microhabitat features (Herkert 1993, Vickery et al. 1994, Askins et al. 2007, Robles 2010), but a shift in research focus to landscape level habitat has greatly improved our abilities to predict grassland bird population dynamics and conservation planning efforts (Thogmartin et al. 2006, Thogmartin and Knutson 2007, Thogmartin et al. 2014). The NLCD and similar land cover products provide the ability to inform large scale predictive models for grassland birds.

We utilized several major classes of land cover types in our occupancy analysis to evaluate grassland bird habitat relationships, including: forest, agriculture, herbaceous, hay/pasture and shrub. For our study, forest consisted of a combined class of the evergreen forest, mixed forest, and deciduous forest NLCD classifications; agriculture consisted of the cultivated crops NLCD classification; grassland consisted of the herbaceous NLCD classification; hay/pasture consisted of the hay/pasture NLCD classification and shrub consisted of the shrub/scrub NLCD classification. Major land cover classification allowed us to identify composition (percentage of area) and configuration (patch area) of identified land cover types to generate habitat characteristics of survey sites. Based on reclassified raster land cover data, we created a vector land cover data file which aggregated adjacent raster cells of the same cover type creating cohesive habitat patches to use for patch area assessment.

We utilized several habitat characteristics based on major land cover types derived from the NLCD 2011 as covariates for occupancy modeling. Proportion of area, average patch size and average patch perimeter to area ratio were calculated for each survey location at the site and landscape scale for important land cover types (Table 2.2). Proportion of area was calculated by dividing the number of raster cells of a certain land cover type, within multiple radii of a site location, by the total number of raster cells in the extent. Average patch size and average patch perimeter to area ratios were calculated by aggregating raster cells and converting the raster layer to smoothed polygons in ArcMap 10.2. All patches at least partially within specified radii of a site were identified and patch area (m^2) was calculated. An average patch size was then calculated for each land cover type for each site. Patch area was utilized additionally, along with patch perimeter (m), to calculate perimeter to area ratios of each habitat patch within multiple radii of each site. Average perimeter to area ratio was calculated similar to average patch size.

Additionally, we calculated grassland connectivity based on grassland network size. We followed a 4 step process to generate grassland network sizes. First, we converted NLCD grassland raster cells into polygons in ArcMap 10.2. Second, we then identified patches of a threshold size of 1 ha and removed all patches under the threshold. Third, we calculated centroid distances from each patch to all other grassland patches. We defined a grassland patch as a continuous collection of NLCD-derived grassland pixels equal to one hectare in size. We used MATLAB (Grant et al. 2008) to identify grassland patches on the landscape and calculate Euclidean distances to other patches. We then calculated the size of grassland networks by estimating the number of grassland patches available to a species from any given grassland patch, given its movement ability. Grassland network sizes incorporated into occupancy models were calculated with movement distances of 1 km and 3 km. We chose these specific distances to reflected the movement of bobwhite reported in past studies (Townsend et al. 2003, Fies et al. 2002, Cook et al. 2006, Liberati 2013) and limited our spatial extent to grassland patches within 100 km of survey sites due to computational requirements and regional habitat characteristics. We utilized same grassland network sizes for all species.

Statistical Analysis

We developed species-specific occupancy model sets with habitat covariates based on species-habitat relationship knowledge (Table 2.3 and 2.4). Roadside point count locations were not located within a specific habitat patch, but were near one or more habitat patches. We averaged patch size and perimeter to area ratio at each point to account for all patches fully or partially included in our site definition. For all species, we included grassland connectivity based on grassland network size and landscape composition at the site and landscape scale. We also incorporated effects of habitat edge and combined land cover type patch size for bobwhite.

For all species, except bobwhite, we defined a site as the area within a 200 m radius of the survey point and landscape as the area within a 1 km radius of the survey point. For bobwhites we defined use as 500 m radius for sites and a 2 km radius for landscapes due to this species' greater detection ranges (Wellendorf and Palmer 2005) and within-season movement (Fies et al. 2002, Townsend et al. 2003). Site sampling protocol was initialized with a 200 m site definition and sites were at least 400 m apart. We eliminated 4 sites for bobwhite occupancy modeling due to overlapping site extents based on the 500 m site definition.

Covariate incorporation and candidate models for detection probabilities were more general than occupancy procedures. A general set of covariates affecting detection was generated based on past studies and was applied to each species (Table 2.5). Three detection model categories were generated based on a priori hypotheses regarding the effects of weather, time of day, and disturbance. Weather models included sky conditions and temperature (°C). We hypothesized deteriorating sky conditions based on United States Weather Bureau Sky condition codes, utilized in the North American Breeding Bird Survey (Pardieck et al. 2014), and increasing temperatures would have a negative effect on detection rates of grassland birds. Temporal models included time of day and Julian date because earlier time of day (Duren et al. 2011, Robbins et al. 1986) and date of survey (Lele et al. 2012) are expected to have positive effects on detection probability. Disturbance models included wind speed and number of passing cars; we hypothesized that increasing wind speeds and more passing cars would lessen the ability to hear calling birds (Pacifici et al. 2008). We combined detection and species-specific occupancy models to evaluate important covariates for each species and estimate their effect sizes.

We used a Bayesian adaptation (Royle and Kéry 2007) of the maximum likelihood multi-season occupancy model (MacKenzie et al. 2003) to estimate effect sizes of detection and occupancy covariates for each species in 2013 and 2014. In this model, occupancy is a Bernoulli random variable only dependent on the probable occupancy state of the site. Occupancy was defined as the probability a species occupies a given site within a year. So, occupancy is the probability a species occupies a given site in 2013 and 2014. A Bayesian dynamic multi-season occupancy model incorporates two components: the state model and the observation model (Royle and Kéry 2007). The state model utilizes yearly site occupancy in 2013 and 2014. Multi-season occupancy models assume closure of sites within a season, but occupancy can change between seasons, thus site occupancy can change over time. We directly estimated occupancy each year to understand habitat relationships for each species in a multi-year structure following the alternative parameterization outlined in MacKenzie (2006). This alternative parameterization directly estimates occupancy probabilities each year and derives colonization and extinction rates, which is similar to combining multiple single-season occupancy models ((MacKenzie 2006)

Bayesian techniques have inherent flexibility to directly estimate parameters of interest given a small number of sites, providing an advantage over maximum likelihood techniques (McCarthy 2007). To best determine explanatory models for detection and occupancy in a Bayesian framework, we limited the number of competing models (Link and Barker 2010, Kéry and Schaub 2012). We employed a sequential process, similar to (Keever 2014), (McGowan et al. 2011), and (Franklin et al. 2004), for detection and occupancy candidate model reduction because of the complexity of Bayesian hierarchical model selection and lack of consensus of preferred methods (Link and Barker 2006, Tenan et al. 2014). This approach allowed us to strategically incorporate a smaller set of candidate models into a Bayesian occupancy modeling framework, which is best utilized with a small number of candidate models (McCarthy 2007). We first used a model selection analysis (Burnham and Anderson 2002) of single-season occupancy data, keeping occupancy as a constant parameter, to set the covariate structure of detection models in the UNMARKED package in program R (Fiske and Chandler 2011, R Core Development Team 2011). Second, we compared models of single-season occupancy incorporating detection models ≤2.0 Δ Akaike's Information Criterion adjusted for small sample size (AICc) of the best model to set the covariate structure of occupancy (Burnham and Anderson 2002). Covariates were incorporated in models using a logit-link function (MacKenzie et al. 2002). To avoid covariate co-linearity we discarded any occupancy models with covariates correlated r-squared ≥ 0.5. Using detection and occupancy models ≤2.0 ΔAICc of the best model in each previous model selection step, we combined the yearly observations. We identified 3 detection and 2 occupancy models for dickcissel, 4 detection and 2 occupancy models for eastern meadowlark and 3 detection and 3 occupancy models for bobwhite as being the best models to utilize in multi-season analysis. We then generated summary statistics of occupancy covariates included in best occupancy models (Table 2.6). Once we established single-season occupancy and detection models, we then transitioned the analysis to a Bayesian dynamic multi-season occupancy framework.

We implemented competing Bayesian dynamic multi-season occupancy models in WinBUGS 1.4 (Gilks et al. 1994) using statistical program R (The R Foundation for Statistical Computing, 2013, version 3.0.2) through package R2WinBUGS (Sturtz et al. 2005). WinBUGS utilizes Markov chain Monte Carlo (MCMC) implementation based on Gibbs Sampling (Geman and Geman 1984).   Posterior probability distributions were based on 100,000 iterations with 20,000 iterations discarded as burn-in. A total of 3 MCMC chains were run for each model with a chain thinning rate of 3. Models were then compared to each other using Deviance Information Criterion (DIC) to assess model quality. The DIC provides an alternative to AIC which incorporates the deviance of the mean of a parameter posterior distribution added to the effective number of estimated parameters (McCarthy 2007). We reported important covariates and effects of models with ≤ 2.0 ΔDIC with the posterior distribution means and 95% credibility intervals for each species due to highly debated multi-model inference abilities of Bayesian model selection (Link and Barker 2010). Nagelkerke's R^2 was not calculated due to inability to determine effective sample size.

RESULTS

Occupancy Probability

One hundred four sites were surveyed in 2013 and 102 sites were surveyed in 2014. Eastern meadowlark had the highest posterior mean distribution of occupancy probability compared to bobwhite and dickcissel, which had the lowest posterior mean distribution of occupancy probability (Table 2.7). Estimated occupancy rates were similar for all species in 2013 and 2014.

Habitat Composition

Occupancy of grassland birds was not associated with the percentage of grassland habitat at the site level. Eastern meadowlark was the only species to have best occupancy models containing positive site level habitat composition relationships. Models that included percent grassland at sites as a covariate for dynamic occupancy did not converge; therefore that covariate was discarded from analysis. Meadowlarks were 1.047 (95% CI: 1.031–1.065) times as likely to use sites for every 1% increase in hay/pasture land cover and 1.042 (95% CI: 1.024–1.061) times as likely to use them with a 1% increase in agriculture (Figure 2.2).

Habitat Patch Size

Occupancy of specialist grassland birds was not associated with size of grassland patches. However, generalist grassland bird occupancy was associated with size of agricultural patches. In the 2 top models for bobwhite, a 1 ha increase in mean agriculture patch size within 2 km corresponded to 1.06 fold (95% CI: 1.01–1.13) and 1.08 fold (95% CI: 1.01–1.14) increases in the odds of occupancy (Figure 2.3).

Habitat Scale

Grassland bird occupancy corresponded with habitat composition at the site and landscape scale. Eastern meadowlark was the only species that responded to site level (within 200m) habitat covariates but dickcissel and bobwhite responded to landscape covariates in our analyses. Based on results of one top dickcissel model, sites were 1.096 (95% CI: 1.060–1.138) times more likely to be occupied for each 1% increase in hay/pasture. Similarly, sites were 1.109 (95% CI: 1.089-1.878) times more likely to be occupied by dickcissel for each 1% increase in agriculture and 1.405 (95% CI: 1.061–1.878) times more likely to be occupied for each 1% increase in grassland (Figure 2.4).

Grassland Connectivity

In our study, grassland connectivity was important for birds with all migratory strategies. A positive association to 3 km grassland network size was exhibited by bobwhite and dickcissel. In 2 of the top models for bobwhite, for each 100 grassland habitat patches added to a 3 km dispersal ability grassland network size, bobwhite were 1.128 (95% CI: 1.060–1.202) and 1.128 (95% CI: 1.060–1.203) times as likely to occupy a site (Figure 2.5). For each 100 grassland habitat patches added to a 3 km grassland network size, dickcissel were 1.276 (95% CI: 1.097–1.521) times as likely to occupy a site (Figure 2.5). Grassland connectivity at 1 km was incorporated in the top model for eastern meadowlark but the 95% credibility interval includes zero. For each grassland habitat patch added to a 1 km grassland network, meadowlarks were 1.022 (95% CI: 0.943–1.103) times as likely to occupy a site.

DISCUSSION

We did not observe dynamic occupancy of any species to be associated with the amount of grassland at a site or landscape. Specialist species occupancy was not associated with patch area but generalist, resident occupancy was associated with agricultural patch size. Site and landscape scale habitat features were important for grassland bird species. Grassland network size was included in the best occupancy models for all migration strategies and grassland associations.

We did not find site-level grassland composition to be important for any species when modeling dynamic occupancy. We found models including grassland composition at the site level to be important for eastern meadowlark single season occupancy, which has been observed in previous studies (Ribic and Sample 2001, Renfrew and Ribic 2008). However, we were unable to estimate their effects because multi-season models with grassland composition did not converge. Convergence was most likely not achieved due to low variability of grassland composition at the site level. Average grassland site composition was 0.002, with a stand deviation of 0.015; whereas average composition of agricultural was 0.220, with a standard deviation of 0.253 and hay/pasture was 0.344 with a standard deviation of 0.285. We could have improved the performance of dynamic models by incorporating grassland composition in site selection procedures following the same protocol illustrated for hay/pasture and agricultural land cover types.

Composition of other land cover types at the site level was important for our specialist, eastern meadowlark. Occupancy of eastern meadowlark was best explained by percent hay/pasture and percent agriculture at a site. Such findings suggest meadowlark occupancy is dependent on local habitat composition more so than landscape composition. The local grassland composition has been found to be important for grassland bird site abundance, especially in isolated areas (Renfrew and Ribic 2008). Robles (2010) reported a negative relationship between occupancy and percent forest cover at 300 m and 800 m spatial extents in Iowa. Negative relationships to forested land cover in Robles (2010) may be analogous to the positive association of site level open habitat composition to occupancy probability of eastern meadowlarks due to the negative correlation observed of percent forest cover and open habitat cover in a landscape.

Dickcissel occupancy estimates were the lowest of the three species we surveyed. Low estimated occupancy probability was most likely due in part to geographic range limits. The Black Belt Prairie region constitutes the dynamic, eastern edge of dickcissel breeding range (Sauer et al. 2014). We observed dickcissel occupancy to be best explained by percent cover of open habitat types within 1km of a point count survey location, suggesting the amount of open habitat in the landscape is more important than how it is distributed. Dickcissel occupancy may have been greater if our study focused in the western portion of the Joint Venture region as opposed to the Black Belt region, which coincides with areas in closer proximity to core range of species distribution and higher predicted relative abundance (Sauer et al. 1995). Our results support this conclusion because AICc and DIC model selection results gave higher weight to models incorporating percent land cover types for occupancy than models with patch size characteristics.

We did not find our specialist species eastern meadowlark and dickcissel to be area-sensitive based on model selection results even though several other studies found patch area or area sensitivity to be important in other regions of dickcissel and eastern meadowlark distributions and the patterns are well established (Herkert 1991, Herkert 1993, Herkert 1994, Vickery et al. 1994, Helzer and Jelinski 1999, Winter and Faaborg 1999, and Renfrew 2002, Ribic et al. 2009, Robles 2010). We expected to observe area sensitivity due to our variability in average site patch size for open habitats which include 0 to 497 ha for agriculture, 0 to 891 ha for hay/pasture, and 0 to 1.4 ha for grassland patch areas. The importance and trend of area sensitivity effects may also depend on the surrounding landscape composition as noted in Renfrew and Ribic (2008) and Horn and Koford (2004). Sites surveyed contained a wide variability of patch sizes were Surrounding open landscape in our study may have increased the suitability of habitat patches at sites regardless of patch size, decreasing the importance of area sensitivity at the survey sites in our study.

Area sensitivity of specialist grassland birds may not have been observed in our study for other reasons as well. Our site sampling procedures did not incorporate patch area characteristics so variability among sites may be too low to observe an effect of patch area on occupancy probability. Specifically selecting sites with wider patch size variability and conducting surveys in distinct habitat patches could increase the ability to observe area-sensitivity. Regional differences in habitat relationships could also account for patch sensitivity differences. Southeast United States studies of grassland birds are few and much grassland bird habitat knowledge is from other areas of the U.S, especially the Midwest and Northeast (Ribic et al. 2009). Specialist grassland bird occupancy in the Black Belt region may be indicated better by composition than patch area characteristics (Fahrig 2001, 2002). Furthermore, area sensitivity patterns were somewhat different for specialists and generalists in our study.

We did observe area sensitivity for our resident, generalist species, bobwhite. Occupancy of bobwhite was, in part, best explained by models including average agricultural patch size within 2 km of sites. Agricultural areas are known to provide good quality habitat but generally at small patch sizes (Brennan 1999). We found that increases in patch size increased occupancy of bobwhite. Within patch habitat quality variability of agricultural land cover type may have increased its importance. Agricultural patches at survey sites were observed in various stages of habitat quality ranging from recently planted with little vegetation to fallow fields with higher quality vegetation. Agricultural areas sampled may have over-represented higher quality patches within the landscape distribution of the region. However, agricultural production occurs widely in historic Black Belt Prairie, which presented a small but distinct network of habitat (Barone 2005). Agricultural habitat patches in the Black Belt Prairie may be smaller and possess more valuable habitat than patches in other areas of bobwhite distribution.

Between the three species we analyzed with occupancy estimation models, site and landscape-level covariates were important for explain patterns at sites. We observed a positive relationship of meadowlark occupancy to site level habitat composition and include 1 km grassland network sizes in the best occupancy models. Contrarily, landscape-level relationships were observed for both dickcissel and bobwhite. The scale of important habitat features may follow a hierarchical decision process for habitat selection (Wiens 1973, Hutto 1985, Fisher and Davis 2010). Even with vastly different life history strategies, bobwhite and dickcissel occupancy responded to similar landscape covariates. Even if physical perspectives of habitat are different for these two species, they may perceive and select habitat features at similar landscape scales. Additionally, we found evidence that multiple spatial scales were important to each species when incorporating grassland connectivity.

Bobwhite occupancy was best explained by models with 3 km grassland network size. Bobwhite have less potential movement or dispersal than meadowlarks and dickcissel (Brennan 1999) due to their movement behavior and non-migratory nature. As a resident species, habitat connectivity is thought to be an important predictor of population measures (Duren et al. 2011). Limited dispersal abilities could explain why bobwhite did not respond to landscape composition like dickcissel, which migrate after the breeding season (Townsend et al. 2003). Bobwhite may also have less ability to move through hostile land cover and occupy more isolated habitats compared to migratory species. Duren et al. (2011) found early successional habitat cohesion at 2 km to be one of the best predictors of bobwhite occupancy, suggesting cohesion and connectivity could be an important predictor of bobwhite occupancy in different geographic regions. We chose a 1 km and 3 km dispersal ability to test a short and long distance hypotheses based on reported bobwhite movement abilities. A dispersal ability of 3km falls in the upper range of average dispersal ability or annual movement reported by previous studies (Dimmick 1992, Fies et al. 2002, Townsend et al. 2003, Cook et al. 2006, Liberati 2013).

Interestingly, our migrating and potentially migrating specialist species dickcissel and eastern meadowlark also had top models that incorporated grassland connectivity. Winter (1998) reported that dickcissel density increased with decreasing distances between grassland patches in southwestern Missouri. This suggests that increasing grassland connectivity can have a positive impact on dickcissel populations. Our results complement this finding, suggesting a positive relationship of connectivity of grassland patches to occupancy. The calculated per unit increase of occupancy to grassland connectivity is larger for dickcissel than bobwhite, but bobwhite had higher occupancy rates at sites with small grassland network sizes, which may be due to the open habitat generalist abilities of bobwhite to use less connected grasslands.

Spatial relationships of grassland patches on the landscape may be beneficial for grassland birds and represent key habitats in highly fragmented landscapes. Prior to landscape conversion to agricultural production in the region, prairie sites were seen as a distinct, but small, isolated features on the landscape (Barone 2005). Since Black Belt Prairie remnants and grassland patches are considered isolated in the past and present (Noss 2012), patch networks may be an important consideration for occupancy of migratory and non-migratory grassland birds in the Black Belt region. This suggests that small but high quality landscape features should be considered as important influences of occupancy.

Even though inter-annual movement strategies are very different for bobwhite, eastern meadowlark and dickcissel, our results may support similar views of suitable breeding habitat between species. Casual study of life history strategies for bobwhite (Brennan 1999) and dickcissel (Temple 2002) might conclude that hierarchies of breeding habitat selection would be different. Dickcissel are long-distance Neotropical migrants and completely vacate their North American breeding grounds to winter in Central and South America (Temple 2002). Meadowlarks are resident and short distance migrants (Lanyon 1995). Bobwhite are resident birds with very restricted movements, even compared to other galliformes (Townsend et al. 2003), generally living within 1 km of their hatching site (Taylor et al. 1999). Even with these wide discrepancies in migratory strategy and movement, breeding season occupancy was associated with landscape scale patch connectivity metrics. This suggests they perceive some aspects of grassland habitat in the same way, and have similar patterns for occupying a fragmented landscape. Focusing on grassland connectivity using NLCD datasets could provide habitat improvements for these and other grassland dependent species that have similar inter-annual settlement patterns.

Usage of NLCD for Habitat Covariates

While the NLCD datasets provide several benefits, there are numerous drawbacks worth noting. The temporal delay of remote imagery for large scale land cover datasets increases the probability that land cover classifications are currently different than when originally surveyed. Such uncertainty is more prominent for successional stages that succeed at faster rates than others (LeBrun et al. 2012). For example, early successional habitats such as grasslands may not be disturbed from time of remote imagery in 2011 to when we surveyed grassland bird occupancy in 2013 and 2014 (Veran et al. 2012). Woody encroachment could have converted these areas into shrub-land cover types or even young forests and created bias effect sizes of land cover derived covariates. Forestry activities, successional disturbance, and changing agricultural regimes after remote imagery timing could lead to inaccuracies for grassland bird survey covariates (Duren et al. 2011) and therefore lead to inaccurate model selection analyses. Classification errors associated with NLCD land cover types could also contribute to uncertainty of land cover dataset accuracy (Thogmartin et al. 2004). Extensive accuracy assessments are not yet available for NLCD 2011, but the NLCD 2006 dataset was collected in a similar manner and offers accuracy trends reflecting NLCD 2011 datasets (Bakker et al. 2002). Herbaceous dominated land cover classifications have a lower accuracy than other classification types (Wickham et al. 2013). Kleiner (2007) reported a user accuracy of herbaceous land cover in the Black Belt Prairie region of 9.0% and a producer accuracy of 30%. Such accuracies are much lower compared to later successional land cover types including forested (user 71%; producer 60%) black belt land cover. The NLCD classification system has difficulty distinguishing among different grass-dominated classifications including hay/pasture and herbaceous cover types (Thogmartin et al. 2004). Additionally, other land cover types such as developed open space have the potential to be mislabeled as grasslands (Wickham et al. 2013) as well. Current work to find commonality between NLCD (Fry et al. 2012) and USDA-NASS Cropland Data Layer (Johnson and Mueller 2010) could improve herbaceous cover dominated classification accuracy. Such drawbacks in the NLCD datasets could lead to misidentification of important habitat variables or biased effects sizes in grassland bird habitat relationship assessment.

Improvements are needed for habitat data resources to provide more comprehensive use for grassland bird population assessments. Since herbaceous-dominated land cover classification accuracy is relatively low in NLCD, combining similar classes (e.g., hay/pasture and agriculture) could improve ability of habitat relationship inference. Past studies have combined grassland and pasture/hay NLCD classes to minimize classification errors of grass dominated cover types (Thogmartin et al. 2004a). Ground based assessment of survey areas could also improve land cover accuracy by direct observation or use of finer scale satellite imagery (Bakker et al. 2002).

Such investigations could provide more accurate, detailed habitat metrics at survey locations for grassland bird studies in light of large scale land cover data limitations. Another way to improve usage of NLCD is to address the inherent variability within classifications. Consider two hypothetical fields that are classified as pasture/hay in NLCD 2011, but one had an average vegetation height of 1 m and the other just 0.25 m. These two fields may have different value for breeding grassland birds (Bollinger et al. 1990). Additionally, simulation studies could be used to assess the sensitivity of model selection and occupancy estimates to varying error rates in land cover classification. Further research is needed to integrate within land cover class variability and landscape level predictions based on habitat relationships of grassland birds.

CONCLUSION

Evaluating grassland bird occupancy using land cover datasets could be useful for studying grassland bird habitat relationships and informing habitat management decisions at large spatial scales. A great strength of using continent-wide habitat datasets is the ability to predict the value of the landscape beyond sites surveyed. Large spatial scale studies can inform landscape scale management of birds and other wildlife populations over large areas. Identification of important landscape habitat features and effect sizes of features can help predict the value of habitat patches relative to other patches for wildlife populations both reactively and proactively for state and federal land acquisition programs. Reactively, proposed properties for programs can be evaluated a property based on how implementing habitat restoration will benefit regional grassland bird populations. Proactively, identification of potential properties to enroll in programs (e.g., CRP, Section 6 of the ESA) for greatest benefit of grassland bird populations is possible. If connectivity or important habitat covariates are known, proposed conservation projects could be compared and ranked based on their relative predicted benefit to grassland bird occupancy Such actions can maximize benefit for grassland bird populations while minimizing efforts and costs of program implementation (Polasky and Solow 2001). Integrating large scale grassland bird habitat studies with restoration efforts could further bolster the success of grassland habitat restoration in North America for the benefit of dependent bird species.

Additionally, we identified several important habitat relationships that could be considered in conservation planning for grassland birds. Increasing composition of grassland and other suitable habitats types could have benefits for grassland birds without the consideration of patch size. Also, improving grassland connectivity could have a positive impact on birds with very different life history strategies suggesting landscape-level habitat connectivity restoration efforts could benefit a wide range of grassland birds in the southeast United States.

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TABLES AND FIGURES

Table 2.1. Occupancy (ψ) survey site selection based on agriculture and hay/pasture percentage composition within 200 m of survey location in the Black Belt Prairie Region of the Upper East Gulf Coastal Plain Joint Venture in 2013 and 2014. Each "x" represents a secondary class from which 16 sites were selected for point count surveys.

	Agriculture		
Hay Pasture	0 – 33%	33 – 67%	67 – 100%
0 – 33%	X	X	X
33 – 67%	X	X	
67 – 100%	X		

Table 2.2. Initial occupancy habitat covariates used in analysis of grassland bird dynamic occupancy in the Black Belt Prairie region of the Upper East Gulf Coastal Plan Joint Venture, USA in spring 2013 and 2014. Covariates were incorporated at the site and landscape extent indicated by specific scales in model selection results.

Covariate	Land Cover Type	model covariate
Proportion of Habitat	Grassland	prop_hb
	Hay/pasture	prop_hp
	Agriculture	prop_ag
	Shrub	prop_ls
Mean Habitat Patch Size	Grassland	hb_mean_area
	Hay/pasture	hp_mean_area
	Agriculture	ag_mean_area
	Shrub	ls_mean_area
Combined Habitat Patch size	Grassland, Hay/pasture, Agriculture, Shrub, Forest	patch_size
Mean Habitat Patch Shape	Grassland	hb_mean_p_a_ratio
	Hay/pasture	hp_mean_p_a_ratio
	Agriculture	ag_mean_p_a_ratio
	Shrub	ls_mean_p_a_ratio
Total Edge	Grassland, Hay/pasture, Agriculture, Shrub, Forest	edge
Patch Network Size	Grassland	hb_net
Distance to grassland	Grassland	Distance_grass
Null		.

Table 2.3. Models sets for single season analysis of bobwhite (*Colinus virginianus*) occupancy (ψ) in the Black Belt Prairie region of the Upper East Gulf Coastal Plain Joint Venture in spring 2013 and 2014. Models were run in R-program Unmarked to identify best (AICc ≤ 2.0) occupancy models in 2013 and 2014 to transition to a Bayesian multi-season occupancy model. Model 20 represents the null occupancy model.

Model	Occupancy (ψ) Model
1	prop_hb_500m+prop_hp_500m
2	ag_mean_area _500 + prop_ag_500m
3	prop_hb_500m+prop_hp_500m+prop_ag_500m+prop_ls_500m
4	patch_size_500m^2
5	fo_p_a_ratio_500m+hb_p_a_ratio_500m+hp_p_a_ratio_500m
6	prop_hb_500m+edge_500m
7	hb_mean_area_2km+hp_mean_area_2km
8	ag_mean_area_2km+prop_ag_2km
9	patch_size_2km^2
10	fo_p_a_ratio_2km+hb_p_a_ratio_2km+hp_p_a_ratio_2km
11	prop_hb_2km+edge_2km
12	prop_hb_2km+prop_hp_2km+prop_ag_2km+prop_ls_2km
13	distance_grass
14	prop_hb_500m+prop_hp_500m+prop_ag_500m+prop_ls_500m+net_size1
15	prop_hb_500m+prop_hp_500m+prop_ag_500m+prop_ls_500m+net_size3
16	prop_hb_2km+prop_hp_2km+prop_ag_2km+prop_ls_2km+net_size1
17	prop_hb_2km+prop_hp_2km+prop_ag_2km+prop_ls_2km+net_size3
18	net_size1
19	net_size3
20	.

Table 2.4. Models sets for single season analysis of eastern meadowlark (*Sturnella magna*) and dickcissel (*Spiza americana*) occupancy (ψ) in the Black Belt Prairie region of the Upper East Gulf Coastal Plain Joint Venture in spring 2013 and 2014. Models were run in R-program Unmarked to identify best (AICc ≤ 2.0) occupancy models in 2013 and 2014 to transition to a Bayesian multi-season occupancy model. Model 18 represents the null occupancy model.

Model	Occupancy Model
1	hb_mean_area_200m
2	hb_mean_area_200m+hp_mean_area_200m
3	hb_p_a_ratio_200m
4	hb_p_a_ratio_200m+hp_p_a_ratio_200m
5	hb_mean_area_200m+ag_mean_area_200m+hp_mean_area_200m
6	hb_p_a_ratio_200m+hp_p_a_ratio_200m+ag_p_a_ratio_200m
7	prop_hb_200m
8	prop_hb_200m+prop_hp_200m
9	prop_hb_1km
10	prop_hb_1km+prop_hp_1km
11	prop_hb_200m+prop_ag_200m+prop_hp_200m
12	prop_hb_1km+prop_hp_1km+prop_ag_1km
13	distance_grass
14	prop_hb_200m+prop_ag_200m+prop_hp_200m+net_size1
15	prop_hb_1km+prop_hp_1km+prop_ag_1km+net_size3
16	net_size1
17	net_size3
18	·

Table 2.5. Detection (p) model sets with covariate description (Covariate) and name (Model) for grassland bird occupancy (ψ) modeling using road side presence-absence surveys in the Black Belt Prairie region of the Upper East Gulf Coastal Plain Joint Venture, USA in 2013 and 2014 based on detection model type (Type).

Type	Covariate	Model
Spatial	Latitude	Latitude
Spatial	State of Survey Site	State
Temporal	Time of Day	Time
Temporal	Ordinal Date	Date
Disturbance	Wind Speed	Cars
Disturbance	Passing Cars	Cars
Weather	Temperature	Temp
Weather	Sky Conditions	Sky
Null		.

Table 2.6. Summary statistics of site habitat covariates (Covariate (ψ)) included in the best dynamic multi-season occupancy (ψ) models of prevalent grassland birds in the Black Belt Prairie region of the Upper East Gulf Coastal Plain Joint Venture, USA in 2013 and 2014. Average (Mean), standard deviation (SD), minimum value (Min), and maximum value (Max) were calculated for each covariate.

Covariate (ψ)	Units	Mean	SD	Min	Max
prop_ag_200m	proportion	0.220	0.253	0	0.893
prop_hp_200m	proportion	0.344	0.285	0	0.906
prop_hb_200m	proportion	0.002	0.015	0	0.134
prop_ag_1km	proportion	0.179	0.159	0	0.592
prop_hp_1km	proportion	0.337	0.197	0.003	0.864
prop_hb_1km	proportion	0.008	0.014	0	0.057
prop_ag_2km	proportion	0.147	0.118	0.007	0.449
net_size1	number of patches	3.353	4.364	1	27
net_size3	number of patches	592.029	546.503	1	1309
ag_mean_area_2km	ha	6.242	7.753	1.018	497.163

Table 2.7. Estimated number of occupied sites (n=102) resulting from best occupancy (ψ) and detection (p) models (ΔDIC ≤ 2.0) of prevalent grassland birds in the Black Belt Prairie region of the Upper East Gulf Coastal Plain Joint Venture, USA in 2013 and 2014. Parentheses indicate 95% credibility intervals.

Model	Species	2013	2014
p(state) ψ(prop_hb_1km+prop_hp_1km+prop_ag_1km)	Dickcissel	17.066 (17-18)	16.049 (16-17)
p(state) ψ(prop_hb_1km+prop_hp_1km+prop_ag_1km+net_size3)	Dickcissel	17.056 (17-18)	16.053 (16-17)
p(cars) ψ(net_size3)	Bobwhite	31.387 (29-35)	29.895 (28-33)
p(date) ψ (net_size3)	Bobwhite	31.396 (29-35)	29.899 (28-33)
p(cars) ψ(ag_mean_area_2km+prop_ag_2km)	Bobwhite	31.517 (29-36)	29.852 (28-33)
p(date) ψ(ag_mean_area_2km+prop_ag_2km)	Bobwhite	31.52 (29-36)	29.852 (28-33)
p(cars) ψ (prop_hb_200m+prop_ag_200m+prop_hp_200m+net_size1)	Eastern Meadowlark	41.551 (41-43)	41.616 (41-44)

Table 2.8. DIC (Deviance Information Criterion) results of dynamic multi-season occupancy (ψ) model selection for dickcissels (*Spiza americana*), eastern meadowlark (*Sturnella magna)* and northern bobwhite (*Colinus virginianus*) at 102 study sites in 2013 and 2014 in the Black Belt Prairie region of the Upper East Gulf Coastal Plain Joint Venture, USA. Models include covariates for detection (p) and occupancy (ψ) components and are reported with Deviance information Criterion (DIC), difference of model DIC to best model (ΔDIC), and model weight (W_i).

Model	DIC	ΔDIC	W_i
Dickcissel			
p(state) ψ (prop_hb_1km+prop_hp_1km+prop_ag_1km)	55.9	0	0.459
p(state) ψ (prop_hb_1km+prop_hp_1km+prop_ag_1km+net_size3)	56	0.1	0.437
p(wind) ψ (prop_hb_1km+prop_hp_1km+prop_ag_1km)	59.9	4	0.062
p(wind) ψ (prop_hb_1km+prop_hp_1km+prop_ag_1km+net_size3)	62.1	6.2	0.021
p(latitude) ψ (prop_hb_1km+prop_hp_1km+prop_ag_1km+net_size3)	63.3	7.4	0.011
p(latitude) ψ (prop_hb_1km+prop_hp_1km+prop_ag_1km)	63.7	7.8	0.009
Bobwhite			
p(cars) ψ (net_size3)	331.10	0.00	0.459
p(date) ψ (net_size3)	331.60	0.50	0.358
p(cars) ψ (ag_mean_area_2km+prop_ag_2km)	332.10	1.00	0.279
p(date) ψ (ag_mean_area_2km+prop_ag_2km)	332.20	1.10	0.265
p(state) ψ (net_size3)	333.40	2.30	0.145
p(state) ψ (ag_mean_area_2km+prop_ag_2km)	343.60	12.50	0.001
p(cars) ψ (prop_hb_500m+prop_hp_500m+prop_ag_500m+prop_ls_500m+net_size1)	384.00	52.90	0.000
p(date) ψ	384.80	53.70	0.000

(prop_hb_500m+prop_hp_500m+prop_ag_500m+prop_ls_500m+net_size1)			
p(state) ψ prop_hb_500m+prop_hp_500m+prop_ag_500m+prop_ls_500m+net_size1)	411.50	80.40	0.000
Eastern Meadowlark			
p(cars) ψ (prop_hb_200m+prop_ag_200m+prop_hp_200m+net_size1)	304.4	0.00	0.459
p(cars) ψ (prop_hb_200m+prop_ag_200m+prop_hp_200m)	307.6	3.20	0.093
p(temp) ψ (prop_hb_200m+prop_ag_200m+prop_hp_200m)	307.7	3.30	0.088
p(sky) ψ (prop_hb_200m+prop_ag_200m+prop_hp_200m)	307.8	3.40	0.084
p(sky) ψ (prop_hb_200m+prop_ag_200m+prop_hp_200m+net_size1)	309.2	4.80	0.042
p(wind) ψ (prop_hb_200m+prop_ag_200m+prop_hp_200m)	309.4	5.00	0.038
p(temp) ψ (prop_hb_200m+prop_ag_200m+prop_hp_200m+net_size1)	309.5	5.10	0.036
p(wind) ψ (prop_hb_200m+prop_ag_200m+prop_hp_200m+net_size1)	311	6.60	0.017

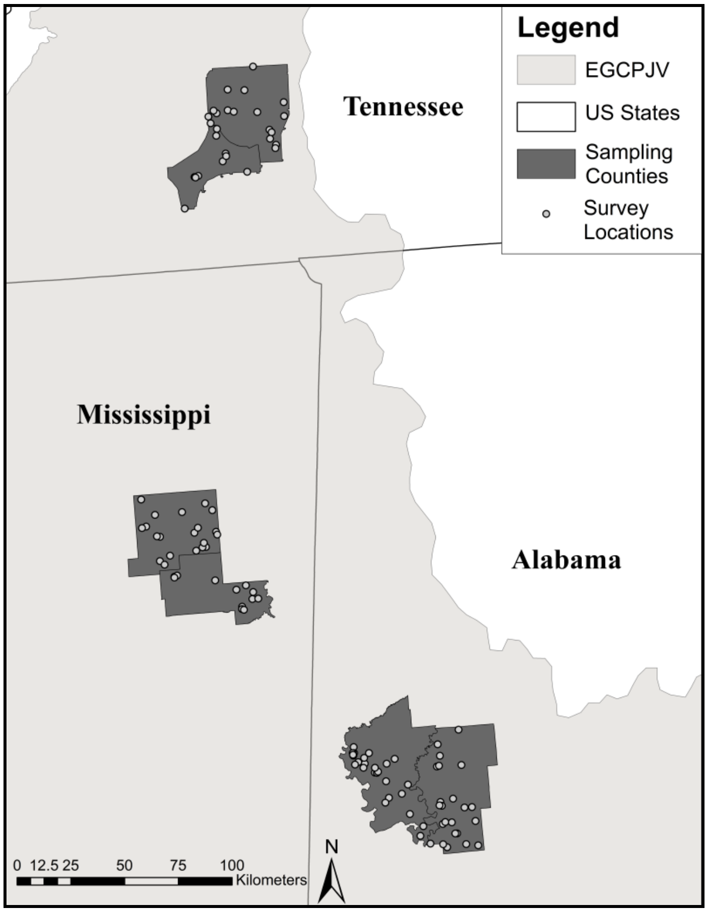

Figure 2.1. The boundary of East Gulf Coastal Plain Joint Venture includes five states within the USA and encompasses large portions of Mississippi and Alabama. One hundred and two survey sites were selected within 6 counties of interest throughout the Upper East Gulf Coastal Plain Joint Venture. Sampling counties in Mississippi and Alabama were part of the historic Black Belt Prairie region.

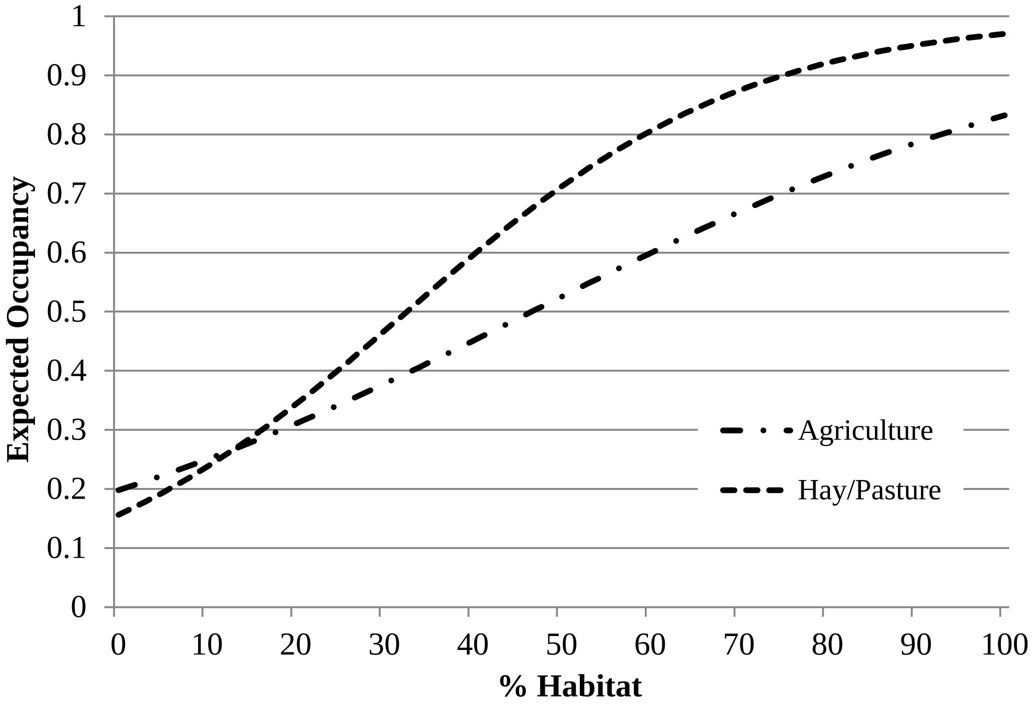

Figure 2.2. Independent relationships of expected occupancy probability of eastern meadowlark (*Sturnella magna*) in response to percentage of hay/pasture or agriculture land cover at a site in the Black Belt Prairie region of the Upper East Gulf Coastal Plain Joint Venture, USA in 2013 and 2014.

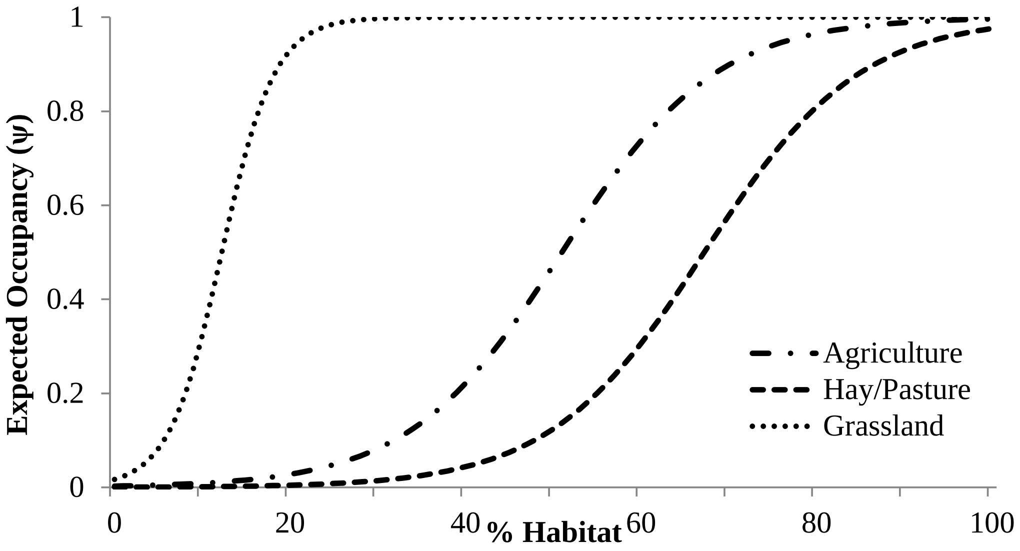

Figure 2.3. Independent relationships of expected Dickcissel (*Spiza americana*) occupancy probability to percentage of agriculture, hay/pasture and grasslands within 1 km in the Black Belt Prairie region of the East Gulf Coastal Plain Joint Venture, USA in 2013 and 2014.

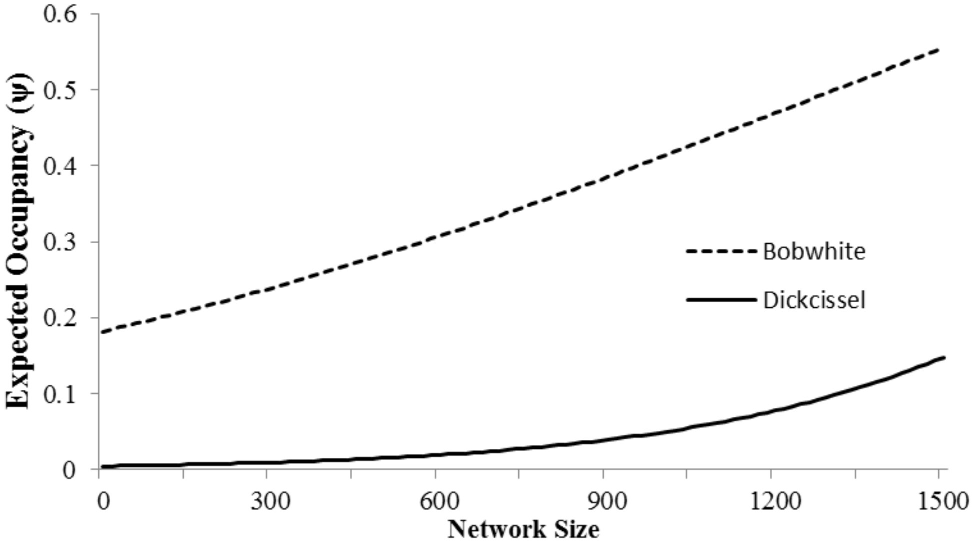

Figure 2.4. Relationship of expected occupancy probability of northern bobwhite (*Colinus virginianus*) and Dickcissel (*Spiza americana*) to 3 km grassland network size in the Black Belt Prairie Region of the Upper East Gulf Coastal Plain Joint Venture, USA in 2013 and 2014.

Chapter 3:

The utility of the North American Breeding Bird Survey to predict habitat relationships of grassland birds using prior knowledge from a small scale study

ABSTRACT

After several decades of population declines, grassland birds in North America are one of the most imperiled groups of bird species. To utilize North American Breeding Bird Survey data to support grassland bird conservation, we used route stop presence/absence information to estimate occupancy rates and habitat relationships of several grassland birds in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region from 2009 to 2013. We used a Bayesian analytic approach and we incorporated prior knowledge of habitat-relationships from a directed grassland bird study completed in chapter 1. Eastern meadowlark (*Sturnella magna)* showed fairly consistent habitat relationships with the directed study but results were inconsistent for bobwhite (*Colinus virginianus*) and dickcissel (*Spiza americana*). Even with informed priors and subsetting route data to specifically target route stops with early successional habitats, bobwhite and dickcissel occupancy exhibited no correlations with landscape scale habitat covariates. We suggest inspection of BBS data to determine the number of sites with species presence prior to utilization in an occupancy framework to limit difficulties encountered with low occupancy probabilities.

INTRODUCTION

Long term, large scale monitoring programs can provide valuable data for bird conservation and management. Management decision evaluation, future management decisions and ability to detect trends in population status are advantages of studies performed over a long temporal periods on a large scale (Gitzen 2012). Large scale, long-term monitoring efforts can also provide information for modeling of animal and plant distributions at a regional scale due to spatial and temporal longevity. This is inherently useful because nature has intricate dynamics often not evident in short term observations, which many management decision rely on (Gitzen 2012). Additionally, wildlife research questions have shifted to issues over larger areas or regions (Pollock et al. 2002) but few examples of large scale and long term wildlife surveys exist. One of the best examples of such programs is the North American Breeding Bird Survey (BBS) (Peterjohn and Sauer 1999).

The BBS is organized through the Patuxent Wildlife Research Center as part of the United States Geological Survey (USGS) and provides a readily available source of data to use in assessment of bird populations. The BBS uses programmatic level roadside point count surveys to track bird population changes over time (Sauer et al. 1997). The BBS represents the principal source for modeling factors associated with North American bird population dynamics (U.S. NABCI Committee 2009) and has data for over 420 bird species (Sauer et al. 2013). Moreover, this monitoring program is the only comprehensive, continental bird monitoring program containing a publically available database and has information from 1966 to the present. The BBS database provides many opportunities for research questions to be answered in support of bird conservation and management (Robbins et al. 1986)

BBS analyses can extend beyond relative abundance and trend analyses to habitat relationship inquiries. Robbins et al. (1986) proposed and executed habitat correlation to abundance for route stops starting in Maryland to assess habitat and landscape changes to relative abundance. The authors proposed several ways to obtain habitat data which included aerial photos, crop production information and satellite imagery. The latter has been used in several investigations of surveys and BBS data at large scales (Thogmartin et al. 2004, 2006, Gottschalk et al. 2005).

In addition to using satellite imagery-derived habitat information, using prior knowledge could improve our understanding of habitat relationships to population metrics. A vast majority of Bayesian ecological modeling efforts use uninformed priors for parameters of interest (Morris et al. 2015), underutilizing the capabilities of a Bayesian framework (Kery 2010). One reason for using uninformed priors is to allow the data to drive posteriors distributions of effect sizes and other estimates (McCarthy 2007). Another explanation is the possible decrease in model accuracy due to shifting of posterior distributions (Morris et al. 2015). However, effects of informed priors on model accuracy are few with variable results (Morris et al. 2015). On the other hand, increased precision of estimates was been widely found for ecological studies using informed priors (McCarthy and Masters 2005, Morris et al. 2015). Since Bayesian methods in ecology and wildlife are increasing (McCarthy 2007), we used informed priors and Bayesian techniques to understand grassland bird habitat relationships using large scale, satellite derived habitat information and avian database sources.

As an extension with BBS data, several studies have incorporated habitat and landscape features into population assessments (Roseberry and Sudkamp 1998, Thogmartin et al. 2004, 2006), but very few in the Southeast United States. An analysis of habitat associations, with prior information of habitat associations from an independent study, could improve the utilization of BBS data for conservation and management planning of grassland birds in Southeast United States. This study sought to evaluate habitat relationships for grassland birds in a historic Black Belt Prairie region of the Southeast United States to aide in conservation planning of grassland birds using BBS data. Grassland birds are also considered the most imperiled group of avian species in North America (Samson and Knopf 1994, Herkert 1994, Peterjohn and Sauer 1999, Askins 1999). Several recent studies used Bayesian analyses of BBS data to estimate range wide trend for grassland birds and found annual declines between 3.56% and 4.5% (Link 2008, Sauer et al. 2012).

In this paper we explored the utility of BBS data as an information source to predict habitat relationships of grassland birds for conservation planning. Additionally, we wanted to evaluate the ability of smaller scale study results to predict occupancy patterns at regional levels. We used BBS data for prominent grassland birds to determine habitat relationships using occupancy estimation techniques in a Bayesian framework (Royle and Kéry 2007) in the Black Belt Prairie region. Bayesian techniques allowed us to incorporate prior information of habitat relationships from the smaller scale study in the regional BBS analysis. We utilized important occupancy-covariate models from chapter 1 and informed priors for effect sizes of habitat relationships. We estimated BBS route stop dynamic occupancy and habitat relationships of bobwhite, eastern meadowlark, and dickcissel to capture a variety of habitat responses within the grassland bird guild in the Black Belt Prairie region of the Upper East Gulf Coastal Plain Joint Venture using increasingly favorable route sampling procedures. We predicted habitat relationships and occupancy rates would be similar to chapter 1 using BBS routes and informed priors would increase precision and accuracy of effect size estimates. Also, increasingly favorable route sampling procedures would increase the utility of BBS data by increasing occupancy probabilities of selected grassland birds.

Prominent grassland birds were used as focal species for conservation planning in the region. Lambeck (1997) described how focal species concepts have led to umbrella species to capture different landscape relationships of guild as an alternative to single species approaches (Franklin 1994). Additionally, species are required to have high enough occupancy rates to model relationships with enough accuracy and precision to observe occupancy patterns (Mackenzie and Royle 2005). We chose species representing grassland habitat with occupancy rates high enough to model habitat-relationships for conservation planning were chosen. Other species such as grasshopper (*Ammodramus savannarum*) or Bachman's sparrow *(Peucaea aestivalis)* were not chosen due to extremely low occupancy rates during breeding season, even though they are species of concern in the region.

STUDY AREA

The East Gulf Coastal Plain Joint Venture (EGCPJV) was created in 2006 and serves as a habitat-based region east of the Mississippi River in western Kentucky, western Tennessee, and much of Mississippi and Alabama. Joint Ventures are collaborative partnerships of diverse groups to conserve habitat for priority bird species (FWS 2015). The EGCPJV identified forming and implementing a landscape-scale grassland conservation strategy as a primary objective for bird conservation of the region. The land cover composition of the EGCPJV is forest (25 %), shrub (21 %), agriculture (16 %), herbaceous grassland (14 %), hay/pasture (7 %), water (6 %), wetland (6 %) and developed (5 %) (Fry et al. 2011); the region is dominated by a mosaic of forest patches agriculture, grassland, and pasture.

Our study specifically focused on the Black Belt region in the upper EGCPJV in Alabama, Mississippi and Tennessee (Figure 1). Fertile, dark soils distinguish the Black Belt region where natural vegetation was composed of bluestem (*Andropogon spp.*) prairie and sweetgum (*Liquidambar styraciflua*), post oak (*Quercus stellata*), and red cedar (*Juniperus virginiana*)-dominated forests (Omernik and Griffith 2012). This prairie region forms the shape of an arc spanning approximately 500 km long and 40 km wide from central Alabama to northern Mississippi. Using information from 1830s General Land Office surveys, an estimated 144,000 ha of natural prairie were spread across the Black Belt Prairie region (Barone 2005). Land cover conversions and fire suppression have altered much of the natural habitat leaving remnant natural grasslands in further isolated network of habitat patches (Noss 2012). Most habitats for grassland birds now consist of working landscapes including agriculture, hay and pasture land cover types.

METHODS

BBS Data Acquisition

BBS protocol creates point count survey routes established within 1 degree latitude/longitude blocks in the United States, Canada, and more recently Mexico. Each route consists of 50, 3 min stops 0.8 km apart and is run one morning each year by a single observer during locally determined peak breeding season. Observers run routes 0.5 hours before sunrise and are completed in May and June in the EGCPJV. At each route stop, observers record total numbers of each bird species seen or heard within a 400 m radius. At the start and finish of each route, observers record sky condition, wind speed (MPH), and temperature (°C) (Robbins et al. 1986).

We used Breeding Bird Survey data from active routes in 2009 to 2013 for bobwhite, dickcissel and eastern meadowlark within the historic counties of the Black Belt Prairie region and several counties in Tennessee just outside the Black Belt boundary (Figure 3.1) (Pardieck et al. 2014). Routes were considered active if the route was run at least one year from 2009 to 2013. If a route was not run during a particular year in 2009-2013, those values were represented as missing values (NA). Twenty-two routes were identified for analysis in the region and twenty-one routes were used in analysis (Table 3.1). Route number 51902 was excluded from analysis due to data complications. We choose these counties due to their proximity to historic grassland bird habitat in the Black Belt Prairie region and because they are within the same eco-region (e.g., the black belt prairie) as sites surveyed in our small scale field study described in chapter 1. Landscape features and land use composition are similar throughout the Black

Belt Prairie region; therefore we assumed habitat relationships and detection probabilities grassland were similar to our previous small scale study.

We generated 50 evenly spaced points within each line segment of the BBS routes (Essic 2005) in ArcMap 10.2 (ArcGIS Desktop: Release 10.2. Environmental Systems Research Institute, Inc., Redlands, CA). We assumed route stops were evenly spaced within routes to represent 800 m between stops due to site descriptions of each stop location and observer experiences (Sauer et al. 1994). We converted point count results for each route stop to presence/absence data for each year. We then sampled the route stops using several different procedures, described below.

Route Stop Sampling Procedures

We used five different procedures to select BBS route stops for occupancy analysis. We estimated occupancy probability in a Bayesian framework using both informed and uninformed priors, and ran 6 different occupancy modeling processes with route stop selection criteria that increasingly focused on sites with more open habitat composition. First, we used all BBS route stops in our defined Black Belt Prairie region with informed priors for effect sizes of habitat features on occupancy (n = 1050). Second, we used every fifth route stop along BBS routes in the region with informed priors (n = 210). Third, we classified each route stop into 3 primary categories based on the percentage of hay/pasture or agriculture (0-33%, 33-67%, 67-100%) within 400m. We then created 6 secondary classes using all possible combinations of agriculture and hay/pasture sites within each class (Table 3.2). For example, one class of sites had 0-33% hay/pasture and 67-100% agriculture. We selected up to 30 sites, when possible, at random from each of the six secondary classes (n = 121). Forth, we included all route stops with at least 30 % hay/pasture, agriculture or grassland at a site with informed priors of effect sizes occupancy-habitat relationships (n = 296). Fifth, we used the same sampling protocol habitat classes as in option 3 with exclusion of route stops with less than 33 % agriculture or less than 33 % hay/pasture at a site, which corresponds to the lowest class of valuable habitat based on low predicted occupancy probability for dickcissel and eastern meadowlark from chapter 1 results. All other habitat classes were merged and 150 random points were generated from merged collection of route stops (n = 150). Lastly, we used the same sampling protocol as the fifth sampling procedure but occupancy models were run with informed priors for effect sizes of habitat features on occupancy (n = 150). For ease of communication, each sampling procedure was named based on number of route stops in analysis and whether or not informed priors were incorporated into model. For example, the first sampling procedure described is named 1050IP, whereas 1050 equals the number of route stops and “IP” indicated informed priors in the model.

Statistical Analysis

We utilized the top models (DIC ≤ 2.0) from the small scale grassland bird occupancy study described in chapter 1 to run dynamic occupancy models with BBS data in the Black Belt Prairie region (Table 3.3). To incorporate covariates included in species-specific dynamic occupancy models from chapter 1, we acquired habitat metrics using the National Land Cover Data (NLCD) 2011 (Jin et al. 2013) around each point (Table 3.4). By using the NLCD 2011, we assumed habitat covariates at route stops were constant from 2009 to 2013. We calculated land cover percent composition at each route stop (400 m radius) and landscape level (1 and 2 km radii) for hay/pasture, herbaceous/grassland and agricultural. Second, we calculated average agricultural patch size at the landscape scale using ArcMap 10.2 (ArcGIS Desktop: Release 10.2. Environmental Systems Research Institute, Inc., Redlands, CA) Spatial Analysis tools.

For each species, we also included grassland connectivity covariate based on grassland network size relationships from chapter 1. Grassland patches were defined as a continuous collection of NLCD grassland pixels equal to one ha in size. We used MATLAB (Grant et al. 2008) to identify grassland patches on the landscape and calculate straight-line distances to other patches. We then calculated the number of grassland patches a species could potentially move to from any given grassland patch, constrained by movement ability, creating a network of patches. A grassland patch with closest straight line distance to each site was used to calculate grassland network size. Grassland network size incorporated into occupancy models were calculated with movement abilities of 1 km for meadowlarks and 3 km for bobwhite and dickcissel. Specific movement distances were chosen to reflected movement of bobwhite reported in past studies (Townsend et al. 2003, Fies et al. 2002, Cook et al. 2006, Liberati 2013) and limited our spatial extent to grassland patches within 100km of survey sites due to computational requirements and regional habitat characteristics. We used the same grassland network sizes for all species due to inter-continental movement potential of eastern meadowlark and dickcissel.

We then adapted a dynamic occupancy framework as described in Royle and Kéry (2007) with informed priors to accommodate single visit per season presence/absence data with habitat covariates. We implemented an alternative parameterization of the model in which occupancy was directly estimated each year at a site (MacKenzie 2006) because our objectives focused on habitat relationships to occupancy rather than inter-year dynamics of site occupancy for grassland birds. Also, instead of estimating detection probability with multiple surveys per season (MacKenzie et al. 2002), we used a fixed detection probability taken from the mean values of the posterior distribution from the null dynamic occupancy model for each species in chapter 1. We chose to use the null models because detection covariates utilized in chapter 1 are not available for BBS analysis. Estimated posterior mean detection probabilities were 0.612 (95% CI: 0.525 – 0.694) for bobwhite, 0.781 (95% CI: 0.724 – 0.833) for eastern meadowlark and 0.910 (95% CI: 0.846 – 0.958) for dickcissel and included as constant values. Informed priors for habitat covariate effect sizes were taken directly from chapter 1 results and included as normally distributed priors with posterior distribution mean and variance of effect size results from chapter 1. Habitat covariates were incorporated into models using a logit-link function (MacKenzie et al. 2003). Estimated effect sizes and occupancy probabilities were reported for each model. Average yearly occupancy probabilities were then compared to those predicted by chapter 1 habitat relationships at route stops.

We implemented models using Program-R (The R Foundation for Statistical Computing, 2013, version 3.0.2) through package R2WinBUGS (Sturtz et al. 2005) and WinBUGS 1.4 (Gilks et al. 1994). Posterior probabilities of occupancy rates and covariate effect sizes were based on 100,000 iterations with 20,000 iterations discarded as burn-in. A total of 3 MCMC chain were executed for each model with a chain thinning rate of 3.

We then compared habitat models to null models using Deviance Information Criterion (DIC) and predicted occupancy based on Chapter 1 habitat relationships using standardized effect sizes.

Results

Eastern meadowlark had the highest number of detections for all sampling procedures, whereas bobwhite had the lowest (Table 3.5).

Three bobwhite models contained positive relations of occupancy to composition of agriculture within 2 km but bobwhite occupancy probability had no association to 3 km grassland connectivity or agricultural patches within 2 km in any models (Table 3.6). Eastern meadowlark results were similar to previous habitat relationships (Chapter 1). All eastern meadowlark models estimated a positive response of occupancy probability to hay/pasture (Figure 3.2) and agriculture (Figure 3.3) at a site but our results indicate no associations between occupancy and grassland composition or 1 km network size (Table 3.7). We found a positive relationship to hay/pasture and agricultural 1 km composition in all models for dickcissel. Also, a positive relationship to grassland connectivity was estimated by 6 dickcissel models (Table 3.8). However, null models had equal or similar explanatory power as habitat covariate models for bobwhite and dickcissel (Table 3.9).

We used uninformed and informed priors for the n=150 sampling procedure to observed differences in precision and accuracy of habitat-occupancy relationships. We did not observe differences in precision or accuracy of models with informed priors versus uninformed prior habitat covariate estimates or occupancy probabilities (Table 3.10, 3.11).

Average yearly occupancy was generally lower than what was predicted by chapter 1 habitat relationships for all species (Table 3.12). Sampling procedures 1050IP and 210IP showed inconsistent values for predicted occupancy. For route stop selection criteria based on habitat composition (e.g. procedures 121, 296IP, 150, 150IP) expected occupancy based on small scale estimates were consistently higher than estimated occupancy probabilities from the BBS analysis. However, the trend of predicted occupancy based on the small scale results did follow the general increasing trend of estimated occupancy probability from the BBS analysis for all species.

Posterior distributions and means of yearly occupancy rates generally increased as sampling procedures favored more open habitat site selection for all species. Bobwhite had the lowest posterior distribution mean estimate of occupancy with sampling procedure n=1050 (Table 3.13). Eastern meadowlark and dickcissel both had the lowest posterior distribution estimate for occupancy with 210IP (Table 3.14, 3.15). The highest mean posterior estimate of occupancy probability for all species was calculated with the 150 and 150IP procedures.

Discussion

Grassland birds showed an inconsistent response to expected habitat-relationships from chapter 1. We also found informed priors did not increase the precision or accuracy of our effect size estimates. However, yearly occupancy did generally increase as sampling procedure excluded less suitable sites and increased open habitat at BBS route stops for two of the three species.

Our results indicate that bobwhites do not consistently respond to grassland connectivity and agricultural metrics, but 3 models did show a positive association between occupancy probability and landscape scale agriculture land cover around route stops. However, null models were within 2 DIC units of all but 1 bobwhite habitat model, indicating that the habitat covariates weak or little added value over a null model. Chapter 1 and Duren et al. (2011) found grassland connectivity to positively impact bobwhite occupancy. Occupancy in those studies was higher (~0.3) than what we estimated with the BBS analysis (<0.1). Our low occupancy probabilities and overall low number of bobwhite detections may have biased covariate effect size estimates for BBS route stops in this region (Mackenzie and Royle 2005). Low encounter rates results in sparse occupancy data and can lead to inconsistencies in habitat covariate effect sizes including grassland connectivity. Additionally, we were only able to extend grassland network analysis to 10 km from route stop locations due to computational limitations. Grassland network size variability may have not been representative of total network size, which includes patches beyond 10 km for route stops. Some models did find a positive relationship of agricultural landscape composition, similar to recent findings in other parts other Southeast United States (Bowling et al. 2014). This suggests landscape agricultural composition may have more value to bobwhites in the Southeast United States compared to other areas of bobwhite distribution.

Similar to bobwhite, dickcissel had an uncertain response to habitat connectivity and habitat composition. Several models had positive associations of dickcissel occupancy to hay/pasture, grassland, and agriculture landscape composition but null models had similar explanatory ability. A positive association of occupancy to grassland connectivity was also estimated in all including models. The inclusion of several habitat covariates may have created a very specific small scale model, which is does not generalize well to other datasets. The DIC values for covariate models compared to null models suggests the number of included parameters may have made it difficult to extrapolate habitat relationships to the Black Belt Prairie region for dickcissel. The explanatory ability, or goodness of model fit, of included covariates was not enough to overcome the DIC penalty for increasing the number of parameters (Spiegelhalter et al. 2002). Dickcissel contained multiple habitat relationships with positive effect sizes in each model, but the contribution to goodness of fit could not overcome parsimony (Royle and Dorazio 2008).

Having some consistencies with chapter 1 dickcissel habitat relationships suggest directed results of local studies could be extrapolated to other datasets or larger regions. Habitat models with fewer, broader covariates could provide similar explanatory ability of dickcissel habitat relationships, while striving for parsimony, increasing the utility of BBS occupancy habitat relationships.

Eastern meadowlark occupancy responded positively to agricultural and hay/pasture site composition across all sampling procedures. These positive associations have been reported in other studies (Renfrew and Ribic 2008) and are consistent with best models from chapter 1. Eastern meadowlark was also the only species with consistent effect sizes for habitat associations based on model selection results. This may be due to consistent, higher estimated occupancy probabilities of eastern meadowlarks at BBS route stops than bobwhite or dickcissel. Meadowlark results likely have less uncertainty than those for the other two species because of the higher number of detections and possibly higher detection probability along BBS routes. Chapter 1 reported higher occupancy probability for meadowlarks than dickcissel or bobwhite and in this analysis, fewer false negatives observations for eastern meadowlarks may have increased estimation precision and better enabled us to estimate habitat relationship effect sizes (Mackenzie and Royle 2005).

For all species, informed priors did not increase the precision or accuracy of our measurements. Recent studies have reported precision increases of parameter estimates from using informed priors (McCarthy et al. 2008, Morris et al. 2013). McCarthy and Masters (2005) reported not only an increase in precision of European dipper (*Cinclus cinclus)* survival probabilities, but also a reduction in length of study to achieve similar precision and accuracy measurements when using informed priors. However, using informed priors did not change our results, which could have been due to low encounter rates on the BBS routes or other factors influencing accuracy and precision. Occupancy probabilities were generally low in this study, possibly diminishing the precision of effect size estimates and clouding the influence of informed priors. Detection probability was not utilized in estimates of habitat relationships, but could also decrease confidence in effect sizes when very low (Mackenzie and Royle 2005). However, based on simulation studies reported in MacKenzie et al. (2002) and O’Brien (2010), grassland bird occupancy detection probability is less likely to diminish the precision of effect sizes because they are generally at least 0.5 (chapter 1, Duren et al. 2011). Sufficient detection probability may be hindered because of the 400 m BBS route stop site definition, which may decrease the detectability of species at distances beyond 100 m (Diefenbach et al. 2003).

Unlike informed prior responses, occupancy probability response to sampling procedures was not uniform across species. While trends of increasing occupancy as more specified site selection procedures were applied to BBS route stops, BBS based occupancy probabilities were generally underestimated compared to chapter 1 based predictions. Unlike chapter 1, BBS route stops were not focused specifically on grassland species which potentially lead to low numbers of encounters and estimated occupancy probabilities when using all route stops in the region. Even with sampling procedures targeted route stops with more open habitat, BBS based occupancy probabilities were still lower than predicted by chapter 1 relationships. Detection of these specific species may have been lower than in chapter 1 and account for the observation of similar trends but lower occupancy when restricting BBS route stops to locations with potentially suitable habitat. Chapter 1 survey procedures required 3, 5 minute point counts at each site and focused on several grassland associated bird species as opposed to the BBS which as 50 stops on each route, each with a single three minute survey counting all individuals of all species detected. It is possible that detection probabilities at BBS route stops are lower due to a shorter temporal period and increased number of target species.

We only observed an increase in posterior distributions of estimated occupancy probabilities for eastern meadowlark and dickcissel as sampling schemes favored more suitable habitat. Eastern meadowlarks are a widely distributed eastern North American open habitat species (Roseberry and Klimstra 1970), which was present at more route stops than bobwhite or dickcissel. The Black Belt Prairie region is on the eastern edge of dickcissel range where abundances have been reported to be lower (Sauer et al. 1995). However, we observed occupancy rates to be slightly lower than eastern meadowlark. Having increased abundance and occupancy within our study area may have contributed to observing increased occupancy to response to habitat suitability. Occupancy probability estimates for bobwhite were very low (<0.11) even for sites with 30% or greater grassland, hay/pasture or agriculture. Being a more generalist early successional species (Brennan 1999), bobwhite occupancy rates may not respond to increases in open habitat site composition like grassland obligate species.

Using NLCD and generated route stop locations leads to other considerations when using satellite derived habitat information. The accuracy of the NLCD land cover classifications is highly uncertain (Kleiner 2007), and accuracy of grassland type habitat has been reported to be very low (Thogmartin et al. 2004). Successional change since timing of imagery also create error in land cover classification since our route stops were surveyed both before and after imagery was taken for the NLCD 2011 (Veran et al. 2012). This could lead to biased effect sizes because of successional change or other alterations of the landscape sense time of imagery. Inaccurate route stops locations could be another factor creating error and uncertainty in effect sizes or misidentifying habitat-relationships. Our study did not have specific route stop information and generated route stop may not have correctly represented real-life locations, therefore land cover covariates in our study may not have precisely corresponded to the actual stop locations. Accurate record keeping of all BBS route stops with GPS locations and further investigations of NLCD accuracy and timing of satellite imagery could increase the utility of the BBS and large scale land cover data to inform conservation planning.

Our study demonstrated some utility of BBS data for conservation planning. More prominent species had very consistent relationships to habitat covariates but less prominent species did not. Also, extrapolation of small scale habitat relationships to large scale datasets maybe difficult when considering model parsimony in model selection process. Occupancy and detection probabilities may play a prominent role in our ability to observe occupancy-habitat relationships at route stops (Mackenzie and Royle 2005) and dampen the effects of informed priors. Considering the potential encounter of species for an analysis like this that supports conservation planning could be an important component of selecting focal species. Using our results, eastern meadowlark habitat relationships estimates could be incorporated as grassland specialist information to evaluate conservation focused habitat management decisions for the Black Belt Prairie region. Uncertainties in dickcissel and bobwhite habitat relationships and occupancy estimates reveal the need for directed studies designed with more general models or in areas of higher species occupancy.

If very low occupancy is observed for a species, route level analysis maybe an alternative method for evaluation of grassland birds (Thogmartin et al. 2004). Alternatives to route stop level habitat relationship evaluation may provide more usefulness when occupancy or detection is low. Past efforts have used route stop level analysis, but modeling was only successful for generalist species in some cases (Hepinstall and Sader 1997). For specialists or rare grassland birds, other studies have used BBS route level abundance to evaluate habitat relationships (Thogmartin et al. 2006a). We recommend route level analysis for occupancy estimation of species that are not observed at enough route stops to successfully estimate effect sizes of habitat relationships for conservation planning.

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TABLES AND FIGURES

Table 3.1. North American Breeding Bird Survey routes in the Black Belt Prairie Region of the Upper East Gulf Coastal Plain Joint Venture including several additional counties in Tennessee.

Route Number	Route Name
2019	LIBERTY
2020	RIDERWOOD
2021	LINDEN
2022	HARRELL
2023	GREENSBORO
2024	SPRAGUE
2027	WARRIOR STD
2048	EPES
2049	WEDGEWORTH
2050	WHITEHALL
2050	WHITEHALL
2051	LIBERTY CITY
2059	CARROLLTON
2063	ROCK CHAPEL
2065	CALEBEE
2210	GASTONBURG
51021	CORINTH
51022	TUPELO
51023	MACON
51024	SCOOBA
51025	ABERDEEN
51902	OKATIBBEE L.
82009	SWEETLIPS

Table 3.2. Occupancy (ψ) route stop sampling procedure (n = 121) based on agriculture and hay/pasture percentage composition within 400 m of route stop on BBS routes in the Black Belt Prairie Region of the Upper East Gulf Coastal Plain Joint Venture in 2009 to 2013. Each "x" represents a secondary class from which 30 route stops were potentially selected for dynamic occupancy estimation.

	Agriculture		
Hay Pasture	0 – 33%	33 – 67%	67 – 100%
0 – 33%	X	X	X
33 – 67%	X	X	
67 – 100%	X		

Table 3.3. Models sets for dynamic occupancy (ψ) analysis of bobwhite (*Colinus virginianus*), eastern meadowlark (*Sturnella magna*) and dickcissel (*Spiza americana*) occupancy in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA using North America Breeding Bird Survey Data for 2009 to 2013. Models were run in Program R and WinBUGS.

Species	Occupancy Model
Bobwhite	ag_mean_area_2km+prop_ag_2km
Bobwhite	net_size3km
Eastern Meadowlark	prop_hb_400m+prop_ag_400m+prop_hp_400m+net_size1
Dickcissel	prop_hb_1km+prop_hp_1km+prop_ag_1km
Dickcissel	prop_hb_1km+prop_hp_1km+prop_ag_1km+net_size3

Table 3.4. Dynamic occupancy habitat covariates used in analysis of grassland bird dynamic occupancy in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA using North America Breeding Bird Survey Data for 2009 to 2013. Covariates were incorporated at the site and landscape extent indicated by specific scales within the model covariates column.

Covariate	Land Cover Type	model covariate
Proportion of Habitat	Grassland	prop_hb (400m, 1km)
	Hay/pasture	prop_hp (400m, 1km)
	Agriculture	prop_ag (400, 1km, 2km)
Mean Habitat Patch Size	Agriculture	ag_mean_area (2km)
Patch Network Size	Grassland	net_size (1km, 3km)
Null		.

Table 3.5. Number of detections at BBS route stops in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region from 2009 to 2013. Parentheses indicate the number of route stops surveyed each year based on BBS route completion.

		Year				
Species	Sampling Procedure	2009 (950)	2010 (950)	2011 (1000)	2012 (750)	2013 (800)
Bobwhite	1050IP	36	31	31	24	13
Eastern Meadowlark	1050IP	90	82	93	84	94
Dickcissel	1050IP	47	40	53	50	44
		2009 (190)	2010 (190)	2011 (200)	2012 (150)	2013 (160)
Bobwhite	210IP	6	4	7	6	3
Eastern Meadowlark	210IP	17	14	16	13	18
Dickcissel	210IP	8	7	10	8	7
		2009 (113)	2010 (113)	2011 (118)	2012 (102)	2013 (126)
Bobwhite	121	4	8	3	4	2
Eastern Meadowlark	121	24	25	21	23	25
Dickcissel	121	18	18	21	25	16
		2009 (280)	2010 (280)	2011 (289)	2012 (250)	2013 (256)
Bobwhite	296IP	11	16	12	8	7
Eastern Meadowlark	296IP	67	61	69	59	71
Dickcissel	296IP	42	36	47	44	36
		2009 (142)	2010 (142)	2011 (147)	2012 (124)	2013 (126)
Bobwhite	150/150IP	6	10	5	6	4
Eastern Meadowlark	150/150IP	37	31	36	35	32

Dickcissel	150/150IP	27	23	28	27	24

Table 3.6. Standardized effect sizes of bobwhite (*Colinus virginianus*) dynamic occupancy model covariates using BBS route stops counts from 2009 to 2013 in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA utilizing 6 different sampling/modeling procedures. Sampling procedures progress in habitat suitability from top to bottom (best). Parentheses indicate 95% credibility intervals and bolded values indicate effect sizes whose credibility interval does not span zero.

Sampling Procedure	ag shape 2 km	ag% 2 km	network size 3 km
1050IP			1.093 (0.908 - 1.29)
1050IP	0.834 (0.622 - 1.083)	**1.004 (1.002 - 1.006)**	
210IP			1.368 (0.997 - 1.842)
210IP	0.77 (0.435 - 1.27)	1.002 (0.997 - 1.007)	
121			0.862 (0.535 - 1.358)
121	0.723 (0.341 - 1.426)	1.006 (0.999 - 1.014)	
296IP			1.001 (0.101 - 1.306)
296IP	0.84 (0.587 - 1.194)	**1.004 (1.001 - 1.008)**	
150			1.149 (0.79 - 1.614)
150	0.84 (0.587 - 1.194)	**1.004 (1.001 - 1.008)**	
150IP			1.247 (0.903 - 1.697)
150IP	0.942 (0.596 - 1.47)	1.003 (0.999 - 1.008)	

Table 3.7. Standardized effect sizes of eastern meadowlark (*Sturnella magna*) dynamic occupancy model covariates using BBS route stops counts from 2009 to 2013 in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA utilizing 6 different sampling/modeling procedures. Sampling procedures increase in habitat suitability from top to bottom. Parentheses indicate 95% credibility intervals and bolded values indicate effect sizes whose credibility interval does not span zero.

Sampling Procedure	hp% 400 m	hb% 400 m	ag% 400 m	network size 1 km
1050IP	**1.009 (1.008 - 1.01)**	0.999 (0.997 - 1.001)	**1.006 (1.005 - 1.007)**	0.956 (0.798 - 1.143)
210IP	**1.006 (1.004 - 1.008)**	0.998 (0.992 - 1.003)	**1.005 (1.004 - 1.007)**	0.561 (0.378 - 0.812)
121	**1.01 (1.007 - 1.014)**	1.001 (0.998 - 1.003)	**1.005 (1.002 - 1.008)**	0.6 (0.457 - 0.778)
296IP	**1.01 (1.007 - 1.014)**	1.001 (0.998 - 1.003)	**1.005 (1.002 - 1.008)**	0.6 (0.457 - 0.778)
150	**1.008 (1.005 - 1.01)**	1.001 (0.999 - 1.003)	**1.008 (1.005 - 1.011)**	1.014 (0.836 - 1.225)
150IP	**1.008 (1.005 - 1.011)**	1.001 (0.999 - 1.003)	**1.008 (1.006 - 1.011)**	1.015 (0.842 - 1.22)

Table 3.8. Standardized effect sizes of dickcissel (*Spiza americana*) dynamic occupancy model covariates using BBS route stops counts from 2009 to 2013 in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA region utilizing 6 different sampling/modeling procedures. Sampling procedures increase in habitat suitability from top to bottom. Parentheses indicate 95% credibility intervals and bolded values indicate effect sizes whose credibility interval does not span zero.

Sampling Procedure	hp% 1km	hb% 1km	ag% 1km	network size 3km
1050IP	**1.013 (1.011 - 1.014)**	1 (0.997 - 1.003)	**1.01 (1.009 - 1.011)**	**1.818 (1.464 - 2.016)**
1050IP	**1.012 (1.011 - 1.013)**	**1.003 (1.001 - 1.005)**	**1.01 (1.009 - 1.011)**	
210IP	**1.016 (1.011 - 1.021)**	1.002 (0.995 - 1.007)	**1.012 (1.008 - 1.016)**	**1.958 (1.067 - 3.264)**
210IP	**1.013 (1.01 - 1.016)**	1.004 (0.999 - 1.008)	**1.01 (1.007 - 1.012)**	
121	**1.016 (1.012 - 1.021)**	**1.006 (1.002 - 1.009)**	**1.016 (1.013 - 1.021)**	**1.571 (1.096 - 2.257)**
121	**1.015 (1.011 - 1.02)**	**1.008 (1.005 - 1.011)**	**1.015 (1.012 - 1.019)**	
296IP	**1.015 (1.013 - 1.018)**	1.002 (0.999 - 1.005)	**1.017 (1.015 - 1.02)**	**1.948 (1.586 - 2.396)**
296IP	**1.014 (1.012 - 1.017)**	**1.006 (1.003 - 1.008)**	**1.016 (1.014 - 1.019)**	
150	**1.016 (1.012 - 1.02)**	**1.002 (1 - 1.005)**	**1.021 (1.017 - 1.025)**	**1.952 (1.392 - 2.751)**
150	**1.015 (1.012 - 1.019)**	**1.005 (1.003 - 1.007)**	**1.019 (1.015 - 1.023)**	
150IP	**1.017 (1.013 - 1.021)**	**1.002 (1 - 1.005)**	**1.021 (1.017 - 1.026)**	**2.042 (1.504 - 2.849)**
150IP	**1.016 (1.012 - 1.017)**	**1.005 (1.003 - 1.006)**	**1.019 (1.015 - 1.020)**	

Table 3.9. Deviance Information Criterion (DIC) results of dynamic multi-season occupancy (ψ) models for dickcissels (*Spiza americana*), eastern meadowlark (*Sturnella magna*) and northern bobwhite (*Colinus virginianus*) at North American Breeding Bird Survey route stops in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA in 2009 to 2013. Null occupancy models are indicated as NULL.

Species	Habitat Model	Procedure	DIC	ΔDIC
Bobwhite	net_size3km	1050IP	273.7	0
	NULL	1050IP	273.9	0.2
	ag_mean_area_2km+prop_ag_2km	1050IP	274.2	0.5
	NULL	210IP	93.1	0
	ag_mean_area_2km+prop_ag_2km	210IP	93.3	0.2
	net_size3km	210IP	94.3	1.2
	NULL	121	84.9	0
	net_size3km	121	85.3	0.4
	ag_mean_area_2km+prop_ag_2km	121	85.9	1
	NULL	296IP	217.6	0
	net_size3km	296IP	218.1	0.5
	ag_mean_area_2km+prop_ag_2km	296IP	219.7	2.1
	net_size3km	150	125.3	0
	ag_mean_area_2km+prop_ag_2km	150IP	125.6	0.3
	NULL	150/IP	125.6	0.3
	net_size3km	150IP	125.8	0.5
	ag_mean_area_2km+prop_ag_2km	150	126.9	1.6
Eastern Meadowlark	NULL	1050IP	1056	0
	prop_hb_400m+prop_ag_400m+prop_hp_400m+net_size1km	1050IP	1072	16
	prop_hb_400m+prop_ag_400m+prop_hp_400m+net_size1km	210IP	154.9	0

	NULL	210IP	234.6	79.7
	prop_hb_400m+prop_ag_400m+prop_hp_400m+net_size1km	121	236	0
	NULL	121	353.5	117.5
	prop_hb_400m+prop_ag_400m+prop_hp_400m+net_size1km	296IP	633.4	0
	NULL	296IP	980	346.6
	prop_hb_400m+prop_ag_400m+prop_hp_400m+net_size1km	150IP	334.7	0
	prop_hb_400m+prop_ag_400m+prop_hp_400m+net_size1km	150	335.2	0.5
	NULL	150/IP	513.8	179.1
Dickcissel	NULL	1050IP	446.9	0
	prop_hb_1km+prop_hp_1km+prop_ag_1km+net_size3km	1050IP	459.9	13
	prop_hb_1km+prop_hp_1km+prop_ag_1km	1050IP	467.3	20.4
	NULL	210IP	48.3	0
	prop_hb_1km+prop_hp_1km+prop_ag_1km+net_size3km	210IP	55.2	6.9
	prop_hb_1km+prop_hp_1km+prop_ag_1km	210IP	81.3	33
	NULL	121	188.9	0
	prop_hb_1km+prop_hp_1km+prop_ag_1km	121	196.9	8
	prop_hb_1km+prop_hp_1km+prop_ag_1km+net_size3km	121	198	9.1
	NULL	296IP	395	0
	prop_hb_1km+prop_hp_1km+prop_ag_1km+net_size3km	296IP	409.1	14.1
	prop_hb_1km+prop_hp_1km+prop_ag_1km	296IP	422.6	27.6
	NULL	150/IP	248.8	0
	prop_hb_1km+prop_hp_1km+prop_ag_1km+net_size3km	150IP	267	18.2
	prop_hb_1km+prop_hp_1km+prop_ag_1km+net_size3km	150	267.3	18.5
	prop_hb_1km+prop_hp_1km+prop_ag_1km	150IP	270.3	21.5
	prop_hb_1km+prop_hp_1km+prop_ag_1km	150	270.7	21.9

Table 3.10. Predicted yearly occupancy probabilities of BBS route stops in the East gulf Coastal Plain Joint Venture Black Belt Prairie region, USA utilizing habitat relationships of best models from chapter 1 standardized mean posterior distribution effect sizes for bobwhite, eastern meadowlark, and dickcissel from 2009 to 2013. "a" refers to occupancy models including 3 km grassland network size for bobwhite and 1 km hay/pasture, grassland, and agriculture including 3km grassland network size for dickcissel and 400 m hay/pasture, grassland, and agriculture including 1 km grassland network size for eastern meadowlark. "b" refers to occupancy models including average 2 km agriculture composition and agriculture patch size for bobwhite and 1 km hay/pasture, grassland, and agriculture composition.

	sampling procedure									
	1050a	1050b	210a	210b	121a	121b	296a	296b	150a	150b
Bobwhite	0.311	0.244	0.311	0.238	0.276	0.429	0.410	0.545	0.284	0.446
Eastern meadowlark	0.204		0.196		0.452		0.454		0.492	
Dickcissel	0.219	0.222	0.211	0.214	0.527	0.527	0.539	0.545	0.582	0.585

Table 3.11. Posterior distribution standardized effect sizes of bobwhite (*Colinus virginianus*), eastern meadowlark (*Sturnella magna*) and dickcissel (*Spiza americana*) dynamic occupancy model covariates using BBS route stops counts from 2009 to 2013 in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA displaying the sampling procedure with 150 route stops with uninformed and informed priors. Parentheses indicate 95% credibility intervals.

		Standardized Effect Size Estimates			
Species	Sampling Procedure	ag area 2 km	ag% 2 km	network size 3 km	
Bobwhite	150			1.149 (0.790 - 1.614)	
	150IP			1.247 (0.903 - 1.697)	
	150	0.840 (0.587 - 1.194)	1.004 (1.001 - 1.008)		
	150IP	0.942 (0.596 - 1.470)	1.003 (0.999 - 1.008)		
		hp% 400 m	hb% 400 m	ag% 400 m	network size 1 km
Eastern Meadowlark	150	1.008 (1.005 - 1.010)	1.001 (0.999 - 1.003)	1.008 (1.005 - 1.011)	1.014 (0.836 - 1.225)
	150IP	1.008 (1.005 - 1.011)	1.001 (0.999 - 1.003)	1.008 (1.006 - 1.011)	1.015 (0.842 - 1.220)
		hp% 1 km	hb% 1 km	ag% 1 km	network size 3 km
Dickcissel	150	1.016 (1.012 - 1.02)	1.002 (1 - 1.005)	1.021 (1.017 - 1.025)	1.952 (1.392 - 2.751)
	150IP	1.017 (1.013 - 1.021)	1.002 (1 - 1.005)	1.021 (1.017 - 1.026)	2.042 (1.504 - 2.849)

150	1.015 (1.012 - 1.019)	1.005 (1.003 - 1.007)	1.019 (1.015 - 1.023)
150IP	1.016 (1.012 - 1.017)	1.005 (1.003 - 1.006)	1.019 (1.015 - 1.02)

Table 3.12. Posterior distributions of bobwhite (*Colinus virginianus*), eastern meadowlark (*Sturnella magna*) and dickcissel (*Spiza americana*) yearly dynamic occupancy estimates using BBS route stop counts from 2009 to 2013 in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA displaying the sampling procedure with 150 route stops with uninformed and informed priors. Parentheses indicate 95% credibility intervals.

		Estimated Site Occupancy				
Species	Sampling Procedure	2009	2010	2011	2012	2013
Bobwhite	150	0.075 (0.049 - 0.113)	0.103 (0.077 - 0.141)	0.065 (0.041 - 0.102)	0.093 (0.056 - 0.137)	0.076 (0.040 - 0.119)
	150IP	0.075 (0.049 - 0.113)	0.103 (0.077 - 0.141)	0.065 (0.041 - 0.102)	0.094 (0.056 - 0.137)	0.076 (0.040 - 0.119)
	150	0.074 (0.049 - 0.106)	0.102 (0.077 - 0.134)	0.064 (0.041 - 0.095)	0.090 (0.056 - 0.129)	0.073 (0.040 - 0.111)
	150IP	0.074 (0.049 - 0.113)	0.102 (0.077 - 0.134)	0.064 (0.041 - 0.095)	0.090 (0.056 - 0.129)	0.073 (0.040 - 0.111)
Eastern Meadowlark	150	0.296 (0.268 - 0.331)	0.256 (0.225 - 0.289)	0.273 (0.252 - 0.299)	0.346 (0.306 - 0.395)	0.316 (0.278 - 0.357)
	150IP	0.296 (0.268 - 0.331)	0.256 (0.225 - 0.289)	0.273 (0.252 - 0.299)	0.345 (0.306 - 0.387)	0.316 (0.278 - 0.357)
Dickcissel	150	0.212 (0.190 - 0.239)	0.184 (0.162 - 0.211)	0.21 (0.19 - 0.231)	0.245 (0.218 - 0.274)	0.217 (0.19 - 0.246)
	150IP	0.212 (0.190 - 0.239)	0.184 (0.162 - 0.211)	0.21 (0.19 - 0.231)	0.245 (0.218 - 0.274)	0.217 (0.19 - 0.246)
	150	0.213 (0.19 - 0.239)	0.184 (0.162 - 0.211)	0.211 (0.19 - 0.238)	0.243 (0.218 - 0.274)	0.216 (0.19 - 0.246)
	150IP	0.213 (0.19 -	0.185 (0.162 -	0.211 (0.19 -	0.243 (0.218 -	0.216 (0.19

	0.239)	0.211)	0.238)	0.274)	- 0.246)

Table 3.13. Posterior distributions of bobwhite (*Colinus virginianus*) dynamic occupancy estimates using BBS route stop counts from 2009 to 2013 in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie, USA utilizing 6 different sampling/modeling procedures. Sampling procedures increase in habitat suitability from top to bottom. Parentheses indicate 95% credibility intervals.

		Estimated Occupancy Probability				
Occupancy Model (ψ)	Sampling Procedure	2009	2010	2011	2012	2013
net_size3km	1050IP	0.049 (0.041 - 0.058)	0.049 (0.041 - 0.058)	0.04 (0.032 - 0.049)	0.038 (0.028 - 0.051)	0.05 (0.034 - 0.07)
ag_mean_area_2km+prop_ag_2km	1050IP	0.049 (0.041 - 0.058)	0.049 (0.041 - 0.059)	0.04 (0.032 - 0.049)	0.039 (0.028 - 0.051)	0.051 (0.034 - 0.07)
net_size3km	210IP	0.058 (0.037 - 0.084)	0.047 (0.026 - 0.074)	0.058 (0.04 - 0.085)	0.084 (0.053 - 0.127)	0.069 (0.025 - 0.119)
ag_mean_area_2km+prop_ag_2km	210IP	0.057 (0.037 - 0.084)	0.047 (0.026 - 0.074)	0.057 (0.04 - 0.085)	0.08 (0.047 - 0.12)	0.068 (0.025 - 0.119)
net_size3km	121	0.064 (0.035 - 0.106)	0.099 (0.071 - 0.133)	0.052 (0.025 - 0.085)	0.075 (0.039 - 0.118)	0.056 (0.02 - 0.098)
ag_mean_area_2km+prop_ag_2km	121	0.063 (0.035 - 0.097)	0.098 (0.071 - 0.133)	0.051 (0.025 - 0.085)	0.072 (0.039 - 0.118)	0.054 (0.02 - 0.098)
net_size3km	296IP	0.068 (0.061 - 0.093)	0.086 (0.068 - 30)	0.068 (0.052 - 0.09)	0.07 (0.048 - 0.096)	0.063 (0.043 - 0.09)
ag_mean_area_2km+prop_ag_2km	296IP	0.067 (0.05 - 0.089)	0.085 (0.068 - 0.107)	0.068 (0.052 - 0.09)	0.067 (0.044 - 0.096)	0.061 (0.039 - 0.086)
net_size3km	150	0.075 (0.049 - 0.113)	0.103 (0.077 - 0.141)	0.065 (0.041 - 0.102)	0.093 (0.056 - 0.137)	0.076 (0.04 - 0.119)
ag_mean_area_2km+prop_ag_2km	150	0.074 (0.049 - 0.106)	0.102 (0.077 - 0.134)	0.064 (0.041 - 0.095)	0.09 (0.056 - 0.129)	0.073 (0.04 - 0.111)

net_size3km	150IP	0.075 (0.049 - 0.113)	0.103 (0.077 - 0.141)	0.065 (0.041 - 0.102)	0.094 (0.056 - 0.137)	0.076 (0.04 - 0.119)
ag_mean_area_2km+prop_ag_2km	150IP	0.074 (0.049 - 0.113)	0.102 (0.077 - 0.134)	0.064 (0.041 - 0.095)	0.09 (0.056 - 0.129)	0.073 (0.04 - 0.111)

Table 3.14. Posterior distributions of eastern meadowlark (*Sturnella magna*) dynamic occupancy estimates using BBS route stop counts from 2009 to 2013 in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie, USA utilizing 6 different sampling/modeling procedures. Sampling procedures increase in habitat suitability from top to bottom. Parentheses indicate 95% credibility intervals.

		Estimated Occupancy Probability				
Occupancy Model (ψ)	Sampling Procedure	2009	2010	2011	2012	2013
prop_hb_400m+prop_ag_400m+prop_hp_400m+net_size1	1050IP	0.113 (0.103 - 0.124)	0.125 (0.115 - 0.136)	0.11 (0.101 - 0.12)	0.16 (0.147 - 0.173)	0.134 (0.111 - 0.159)
prop_hb_400m+prop_ag_400m+prop_hp_400m+net_size1	210IP	0.104 (0.089 - 0.121)	0.089 (0.074 - 0.111)	0.092 (0.08 - 0.11)	0.12 (0.093 - 0.153)	0.14 (0.119 - 0.169)
prop_hb_400m+prop_ag_400m+prop_hp_400m+net_size1	121	0.247 (0.221 - 0.283)	0.255 (0.23 - 0.292)	0.204 (0.178 - 0.237)	0.279 (0.245 - 0.324)	0.298 (0.265 - 0.343)
prop_hb_400m+prop_ag_400m+prop_hp_400m+net_size1	296IP	0.275 (0.257 - 0.296)	0.254 (0.236 - 0.279)	0.266 (0.249 - 0.287)	0.296 (0.268 - 0.324)	0.331 (0.305 - 0.359)
prop_hb_400m+prop_ag_400m+prop_hp_400m+net_size1	150	0.296 (0.268 - 0.331)	0.256 (0.225 - 0.289)	0.273 (0.252 - 0.299)	0.346 (0.306 - 0.395)	0.316 (0.278 - 0.357)
prop_hb_400m+prop_ag_400m+prop_hp_400m+net_size1	150IP	0.296 (0.268 - 0.331)	0.256 (0.225 - 0.289)	0.273 (0.252 - 0.299)	0.345 (0.306 - 0.387)	0.316 (0.278 - 0.357)

Table 3.15. Posterior distributions of dickcissel (*Spiza americana*) dynamic occupancy estimates using BBS route stop counts from 2009 to 2013 in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie, USA utilizing 6 different sampling/modeling procedures. Sampling procedures increase in habitat suitability from top to bottom. Parentheses indicate 95% credibility intervals.

		Estimated Occupancy Probability				
Occupancy Model (ψ)	Sampling Procedure	2009	2010	2011	2012	2013
prop_hb_1km+prop_hp_1km+prop_ag_1km	1050IP	0.056 (0.052 - 0.062)	0.049 (0.044 - 0.055)	0.058 (0.054 - 0.063)	0.076 (0.069 - 0.084)	0.06 (0.054 - 0.067)
prop_hb_1km+prop_hp_1km+prop_ag_1km+net_size 3	1050IP	0.056 (0.052 - 0.061)	0.049 (0.044 - 0.054)	0.058 (0.054 - 0.063)	0.077 (0.071 - 0.085)	0.061 (0.055 - 0.068)
prop_hb_1km+prop_hp_1km+prop_ag_1km	210IP	0.048 (0.042 - 0.058)	0.043 (0.037 - 0.058)	0.055 (0.05 - 0.065)	0.062 (0.053 - 0.08)	0.052 (0.044 - 0.069)
prop_hb_1km+prop_hp_1km+prop_ag_1km+net_size 3	210IP	0.048 (0.042 - 0.058)	0.043 (0.037 - 0.058)	0.055 (0.05 - 0.065)	0.063 (0.027 - 0.1)	0.059 (0.025 - 0.1)
prop_hb_1km+prop_hp_1km+prop_ag_1km	121	0.18 (0.159 - 0.212)	0.18 (0.159 - 0.212)	0.196 (0.178 - 0.22)	0.271 (0.245 - 0.304)	0.184 (0.157 - 0.216)

prop_hb_1km+prop_hp_1km+prop_ag_1km+net_size3	121	0.18 (0.159 - 0.212)	0.181 (0.159 - 0.212)	0.196 (0.178 - 0.22)	0.269 (0.245 - 0.304)	0.183 (0.157 - 0.216)
prop_hb_1km+prop_hp_1km+prop_ag_1km	296IP	0.168 (0.154 - 0.186)	0.147 (0.132 - 0.164)	0.178 (0.166 - 0.194)	0.197 (0.18 - 0.216)	0.161 (0.145 - 0.18)
prop_hb_1km+prop_hp_1km+prop_ag_1km+net_size3	296IP	0.167 (0.154 - 0.182)	0.146 (0.132 - 0.164)	0.178 (0.166 - 0.194)	0.196 (0.18 - 0.216)	0.16 (0.145 - 0.18)
prop_hb_1km+prop_hp_1km+prop_ag_1km	150	0.212 (0.19 - 0.239)	0.184 (0.162 - 0.211)	0.21 (0.19 - 0.231)	0.245 (0.218 - 0.274)	0.217 (0.19 - 0.246)
prop_hb_1km+prop_hp_1km+prop_ag_1km+net_size3	150	0.213 (0.19 - 0.239)	0.184 (0.162 - 0.211)	0.211 (0.19 - 0.238)	0.243 (0.218 - 0.274)	0.216 (0.19 - 0.246)
prop_hb_1km+prop_hp_1km+prop_ag_1km	150IP	0.212 (0.19 - 0.239)	0.184 (0.162 - 0.211)	0.21 (0.19 - 0.231)	0.245 (0.218 - 0.274)	0.217 (0.19 - 0.246)
prop_hb_1km+prop_hp_1km+prop_ag_1km+net_size3	150IP	0.213 (0.19 - 0.239)	0.185 (0.162 - 0.211)	0.211 (0.19 - 0.238)	0.243 (0.218 - 0.274)	0.216 (0.19 - 0.246)

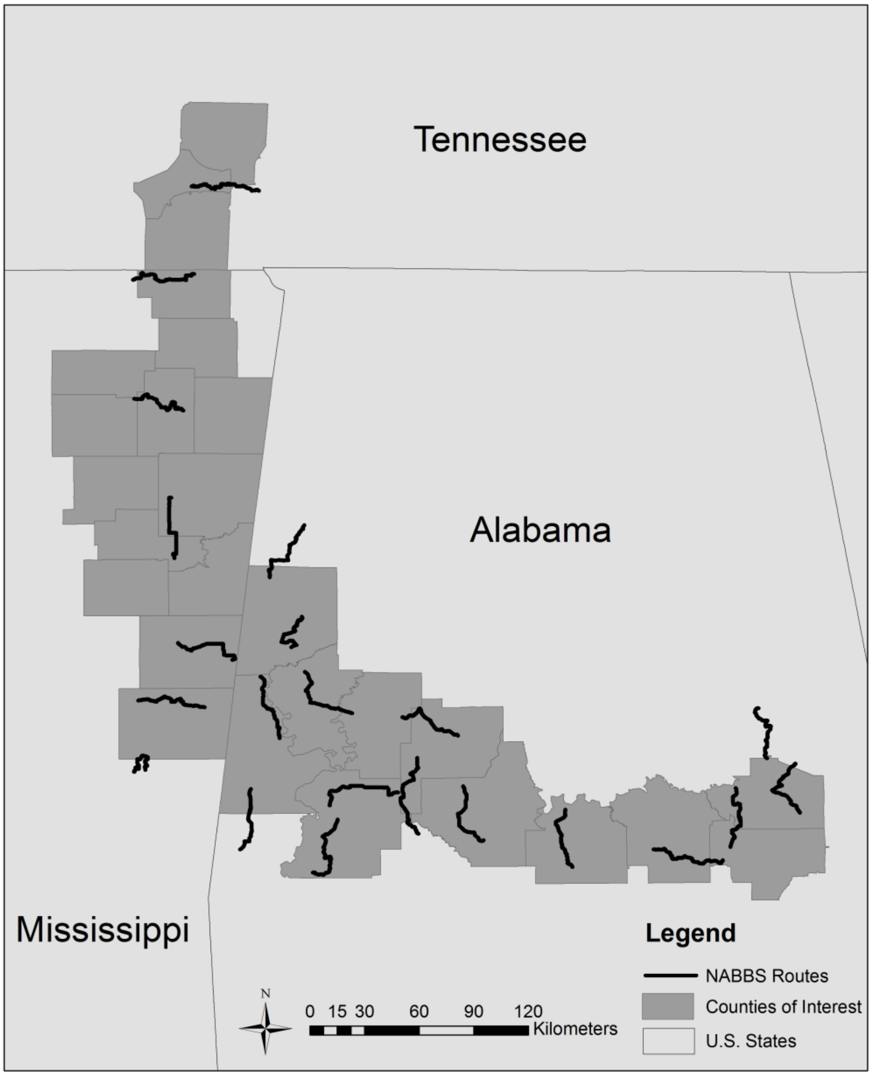

Figure 3.1. North American Breeding Bird Survey (NABBS) routes of the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA. A total of 21 routes were used in dynamic occupancy modeling of route stops to assess occupancy-habitat relationships of prominent grassland birds in the region.

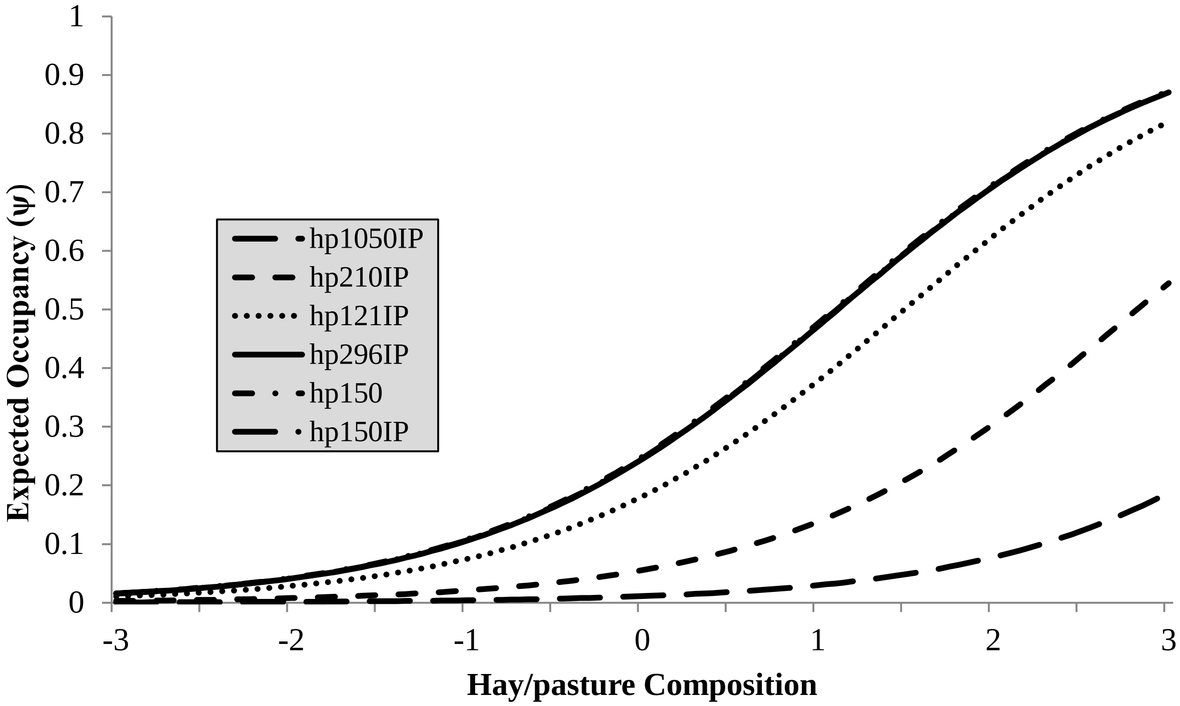

Figure 3.2. Mean posterior distribution of standardized covariate effects of hay/pasture composition within 400 m on eastern meadowlark (*Sturnella magna*) occupancy probability (ψ) along North American Breeding Bird Survey (BBS) route stops in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA in 2009 to 2013. Relationships are presented for six different BBS sampling/modeling procedures.

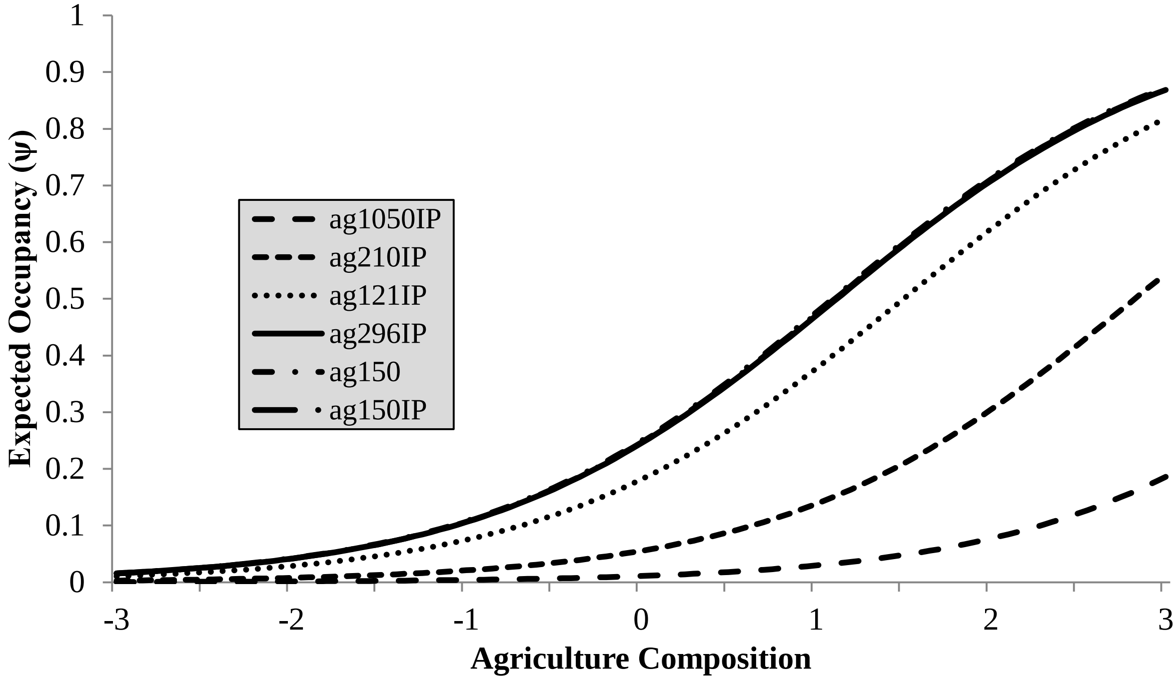

Figure 3.3. Mean posterior distribution of standardized covariate effects of agriculture composition within 400 m on eastern meadowlark (*Sturnella magna*) occupancy probability (ψ) along North American Breeding Bird Survey (BBS) route stops in the Upper East Gulf Coastal Plain Joint Venture Black Belt Prairie region, USA in 2009 to 2013. Relationships are presented for six different BBS sampling/modeling procedures.