A MULTI-SPATIAL-SCALE CHARACTERIZATION OF LARK SPARROW HABITAT AND THE MANAGEMENT IMPLICATIONS

Melanie Coulter

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Committee:

Karen V. Root, Advisor

Helen J. Michaels

Elliot J. Tramer

ABSTRACT

Karen V. Root, Advisor

Habitat requirement studies of endangered species often examine only one spatial scale since more lengthy multi-scale studies can delay conservation. However, not considering multiple scales could cause crucial habitat components to be overlooked, reducing the chances of successful conservation.

I designed a single season, multi-spatial-scale study of the habitat use of the state endangered Lark Sparrow in the Oak Openings Region of Northwest Ohio. This rapid assessment technique can be applied to species of concern to gain a detailed assessment of habitat requirements in a short amount of time. I assessed the Lark Sparrows' habitat requirements at three spatial scales: landscape, habitat patch, and territory. To characterize Lark Sparrow habitat, I compared the landscape context and vegetation structure of presence sites and absence sites. Presence sites were active breeding sites, and absence sites were former breeding sites that Lark Sparrows abandoned. The results suggest that Lark Sparrows responded to different habitat parameters at different spatial scales. At the landscape scale, patch size and shape were important. At the habitat patch scale, percent tree cover and vegetation height-density were important. At the territory scale, percent tree cover, percent shrub cover, vegetation height-density, and proximity to occupied territories were important. Studying a single spatial scale would have produced an incomplete picture of breeding Lark Sparrow habitat.

The habitat Lark Sparrows use in the Oak Openings is Midwest sand barrens, a globally rare early-successional plant community. I assessed the effectiveness of restoration efforts for Midwest sand barrens and Lark Sparrow habitat by comparing the land management histories of

active breeding sites and abandoned breeding sites. The number of management events (i.e. mowing and prescribed burns) in the most recent three years was significantly higher for active sites. These results suggest that habitat change happens quickly in Midwest sand barrens. If a site is not managed at least once every three years, it will cease to function as an early-successional habitat, and Lark Sparrows will abandon it. Managing sand barrens frequently enough to support successful Lark Sparrow populations will benefit the suite of early-successional specialists that inhabit the unique Midwest sand barren plant community.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

A MULTI-SPATIAL-SCALE CHARACTERIZATION OF LARK SPARROW HABITAT

Introduction

Conservation of rare and endangered species must begin with identifying the species' needs. Determining habitat requirements is a crucial step in any wildlife species conservation plan. Often, studies of habitat requirements investigate only a single spatial scale, frequently the habitat patch scale or the territory scale. This is especially true for endangered species when time is crucial and a lengthy multi-scale study will delay important conservation efforts. For birds in particular, most habitat studies have been limited to site-specific scales. Some studies of bird habitat requirements, though, have revealed the importance of the landscape scale (e.g. MacFaden and Capen 2002, Davis 2004, Robles et al 2007). Examining habitat use at multiple spatial scales is important for two reasons: 1) different factors may influence habitat use at different scales (Wiens et al 1987; Wiens and Rotenberry 1981; Luck 2002); 2) a species' local scale habitat requirements may influence habitat selection at the landscape scale (Orians and Wittenberger 1991; Walters et al 2002).

I argue that to sufficiently describe the habitat requirements of a bird, or likely any wildlife taxon, one must consider multiple spatial scales. Without consideration of multiple spatial scales, a crucial habitat component could be overlooked, and conservation of the species may be less successful (e.g. Haire et al 2000, Barg et al 2006). I designed a habitat use study that investigated multiple spatial scales simultaneously in only a single field season. This rapid assessment technique can be applied to species of concern to gain a detailed assessment of habitat requirements in a short amount of time.

Recent studies have found that some birds (such as grassland birds, woodpeckers, and warblers) respond to different habitat components at different environmental scales (e.g. Barg 2006, MacFaden and Capen 2002, Robles et al 2007). For example, Sprague's Pipits (*Anthus spragueii*), Baird's Sparrows (*Ammodramus bairdii*), Grasshopper Sparrows (*Ammodramus savannarum*), and Chestnut-collared Longspurs (*Calcarius ornatus*) respond to patch size and shape at the landscape scale and to vegetation structure at the patch scale (Davis 2004).

My study considers the habitat requirements of another grassland bird, the Lark Sparrow (*Chondestes grammacus grammacus*), to see if it, too, has different habitat requirements at different spatial scales. I assessed Lark Sparrows' habitat requirements at three spatial scales: 1) landscape, 2) habitat patch, and 3) territory.

Lark Sparrows and other ground-nesting birds that depend on early-successional habitats are of conservation concern because grassland habitats throughout the United States are being lost to woody invasion and development (Grant et al 2004). In Ohio the Lark Sparrow is listed as a state endangered species and is primarily found in Northwest Ohio. Lark Sparrow habitat in Northwest Ohio is a globally rare plant community, Midwest sand barren, which is heavily impacted by woody invasion. My multi-scale study of Lark Sparrow habitat use considers the impact of woody invasion on this early-successional habitat specialist and contributes to the sparse literature on sand barrens, an under studied system.

The Oak Openings

The Oak Openings region, a 200 square kilometer area in Northwest Ohio, has been designated as "one of America's last great places" and described as "one of the most important ecosystems in the U.S." (Green Ribbon Initiative 2004a). The Oak Openings contains some of

the United State's rarest plant communities, including black oak/lupine barrens (a classic oak savanna), twigrush wet prairie, mesic sand tallgrass prairie, and Midwest sand barren. Together, these plant communities support great biodiversity, including many rare and threatened flora and fauna. Unfortunately, these rare communities face multiple threats including invasive non-native plants, woody invasion, altered hydrology, and urbanization. It is in one of these rare communities, Midwest sand barrens, that Lark Sparrows are found.

Focal Species

Lark Sparrows are migratory, ground-nesting birds that are dependent on early-successional habitats across their range. In Northwest Ohio they almost exclusively use Midwest sand barrens in the Oak Openings Region. They arrive in Ohio to breed in April or May and leave in July or August. Lark Sparrows are territorial and have strong site fidelity (Martin and Parrish 2000). In the Oak Openings, males defend territories that range from 0.40-1.21 (mean 0.81) hectares in size (Grigore 1999). Males proclaim their territories by perching and singing on trees, shrubs, stumps, large forbs, etc. that occur on the borders of their territories (McNair 1982). Aerial defensive encounters occur between males as they vie for territory (Grigore 1999).

In the Oak Openings, during the middle of the breeding season, adults eat mostly grasshoppers and feed their young mostly caterpillars (Grigore 1999). Lark Sparrows often congregate for feeding, even during the territorial nesting season (Grigore 1999, Martin and Parrish 2000). In the Oak Openings, small groups of Lark Sparrows often forage along roads and near open sandy areas (Grigore 1999).

Though Lark Sparrow populations are abundant and stable in most of their range, they are less abundant and, perhaps, less stable in the eastern edge of their range, including Ohio. In

Ohio and other eastern states, Lark Sparrow numbers declined after the 1930s (Martin and Parrish 2000). However, it's likely that this decline was a correction after an abnormal peak in eastern Lark Sparrow populations. Prior to the late 1800s, Lark Sparrows' range likely ended at the eastern edge of the Great Plains. Then, forests were cleared and land was converted to agriculture, creating open, early-successional habitats, allowing Lark Sparrows to expand eastward (Martin and Parrish 2000). The drought of the 1930s expanded sparse habitats further, possibly allowing Lark Sparrow populations in Ohio and other eastern states to increase to their highest levels. In 1940 nesting Lark Sparrows were recorded in 39 Ohio counties (Swanson 1996). After the drought and economic hard times of the 1930s, much of Ohio's agricultural lands and pastures reverted back to woodland or became urbanized, causing Ohio's Lark Sparrow population to decline (Martin and Parrish 2000). By the 1960s they had disappeared from most of their Ohio range (Peterjohn 1989). In the late 1980s there were only 10-12 breeding pairs in the state, mostly in the Oak Openings Region (Peterjohn and Rice 1991, Swanson 1996).

Habitat suitable for Lark Sparrows, namely Midwest sand barren, was present in the Oak Openings Region before the massive removal of forests in the late 1800s. Additionally, the Prairie Peninsula extended from Indiana to northwestern Ohio, allowing the movement of prairie species into Ohio (Transeau 1935, Mack and Boerner 2004). Therefore, Lark Sparrows could have been in the Oak Openings Region before the alteration of Ohio's environment in the 1800s and the drought in the 1930s allowed the expansion of the bird's range. The earliest records of Lark Sparrows in the Oak Openings are in the Michigan portion in 1893 (Campbell 1968).

The Ohio Division of Wildlife listed the Lark Sparrow as a State Endangered Species. In the mid-1990s, land managers in the Oak Openings Region began managing for early-successional plant communities such as Midwest sand barrens. Lark Sparrow numbers in the Oak

Openings began to increase. In 1998 there were 17 known breeding pairs in the Oak Openings Region (Grigore 1999). In 2007 there were 24 documented breeding pairs in my study sites.

The Oak Openings is one of the few places Lark Sparrows still nest in Ohio (Peterjohn and Rice 1991). The Oak Openings population is a self-sustaining population with more births than deaths (Grigore 1999). In 2007 there were seven sites known to support breeding Lark Sparrows in the Oak Openings.

Midwest Sand Barrens

In northwestern Ohio, Lark Sparrows breed solely in Midwest sand barren, an early-successional plant community, which is one part of the globally rare oak savanna complex. Midwest sand barren is dominated by graminoids, including bunch grasses and sedges. The herbaceous layer is very open and is interspersed with a few species of shrubs. Patches of Midwest sand barren occur on well-drained sandy soils, often on sand ridges, steep-sloped sandy outwashes, or sand lakeplains (Faber-Langendoen 2001). Sand barrens are distributed in patches across the Oak Openings Region. Midwest sand barrens in the Oak Openings are open patches (ground cover usually consists of about 50% bare sand) with few shrubs and trees that are surrounded by woodland (Gardner and Haase 2004). Functioning sand barrens have few shrubs and trees because of the well-drained sandy soils and because of frequent disturbances such as fire (Brewer and Vankat 2004). Over the last several decades, fire suppression and human-caused hydrologic changes have allowed shrubs and trees to encroach into Midwest sand barrens (Brewer and Vankat 2004). In grassland-type communities, an increase in shrubs and trees fundamentally changes the structure and successional state of the vegetation community and

changes the avian community by reducing the number of grassland-dependent species (Grant et al 2004).

Lark Sparrows are indicators of the successional stage of habitat because they abandon sites that progress beyond an early-successional stage. By elucidating the habitat parameters associated with occupied and abandoned Lark Sparrow breeding sites and territories, I can suggest a threshold at which the successional state has been altered to such a degree that early-successional specialists can no longer use a site or territory.

My multi-spatial-scale study of Lark Sparrow habitat requirements in an ecosystem impacted by habitat change addressed several questions: 1) Do Lark Sparrows respond to different habitat parameters at the spatial scales of landscape, habitat patch, and territory?; 2) What landscape-scale characteristics influence Lark Sparrows' choice of breeding site?; 3) What characteristics distinguish occupied Lark Sparrow breeding sites from breeding sites that are no longer used by Lark Sparrows?; 4) Within a habitat patch, are there differences between the areas Lark Sparrows use as territories and the areas they don't use as territories?; and 5) Does woody invasion play a role in Lark Sparrow habitat use at any spatial scale?

Methods

Study Sites

I selected twelve sites in Kitty Todd Nature Preserve (KTNP) and Oak Openings Preserve Metropark (OOPM). See Figure 1. Each study site was a distinct patch of Midwest sand barren habitat. In the Oak Openings, patches of sand barren ranged in size from 1ha to 20+ha and were surrounded by a hard edge of oak woodland. In some cases a sand barren patch was bordered on one side by a wetland rather than a woodland.

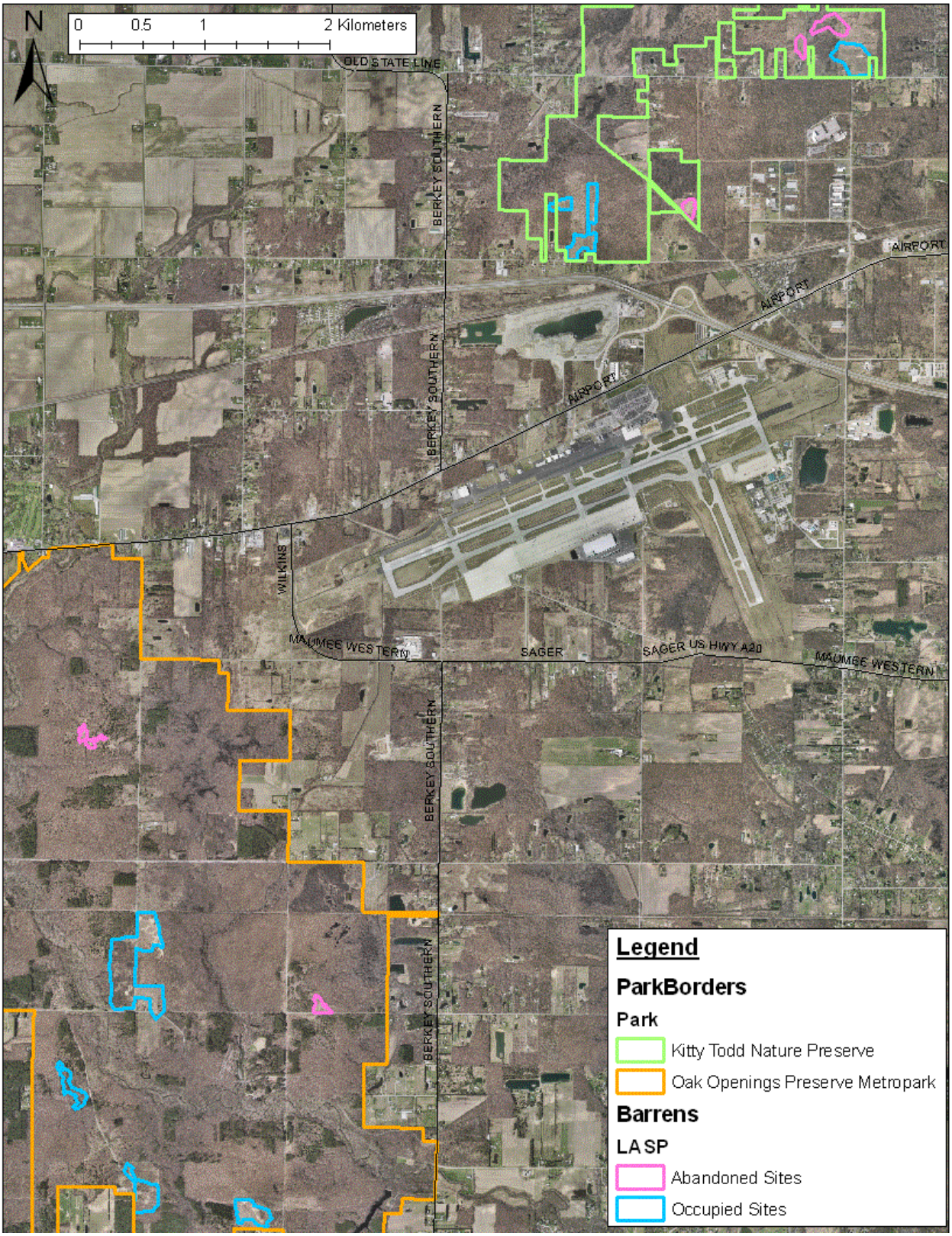

Figure 1: Map of spatial distribution of study sites on a 2004 aerial photograph (Lucas County Auditor 2007) of part of the Oak Openings Region. Park boundaries and study site boundaries are shown. Blue polygons represent Occupied Sites. Pink polygons represent Abandoned Sites.

In order to determine the habitat characteristics associated with Lark Sparrow breeding sites in the Oak Openings, I compared the habitat characteristics of presence sites to those of absence sites. Rather than employing the classic method of comparing simple presence sites to random absence sites on the landscape (Engler et al 2004, Vaughan and Ormerod 2005), I compared active breeding sites to sites at which Lark Sparrows bred in the past but no longer do.

I used active breeding sites (Occupied Sites) as presence sites because these sites are directly related to the population's success. Breeding sites could have more impact on population persistence than typical presence sites where the species just has to be present, not necessarily breeding. Furthermore, this single season study is a model of rapid assessment of the health of the system. I did not look exhaustively at Lark Sparrow habitat requirements, but rather focused on the breeding sites of this early-successional specialist to get a quick idea of the health of the sand barren plant community.

Active Lark Sparrow nests were confirmed in each Occupied Site by observing nest building, return-to-nest or chick feeding behavior and searching for nests where the behaviors were observed. During the 2007 nesting season, there were three Occupied Sites in KTNP: South Piels, Moseley Barrens and Moseley Barrens North. In OOPM there were four Occupied Sites: Greater Girdham Road, Badger Barrens, Jeffers Road Farm, and Ostrich Lane. Most Occupied Sites had multiple Lark Sparrow pairs nesting in adjoining territories. See Figure 2.

I used Abandoned Sites as absence sites to explore the effects of habitat change over time. Since these Abandoned Sites were once suitable for Lark Sparrows, the differences between the habitats of Abandoned Sites and Occupied Sites suggest the habitat changes that can drive Lark Sparrows to abandon a site.

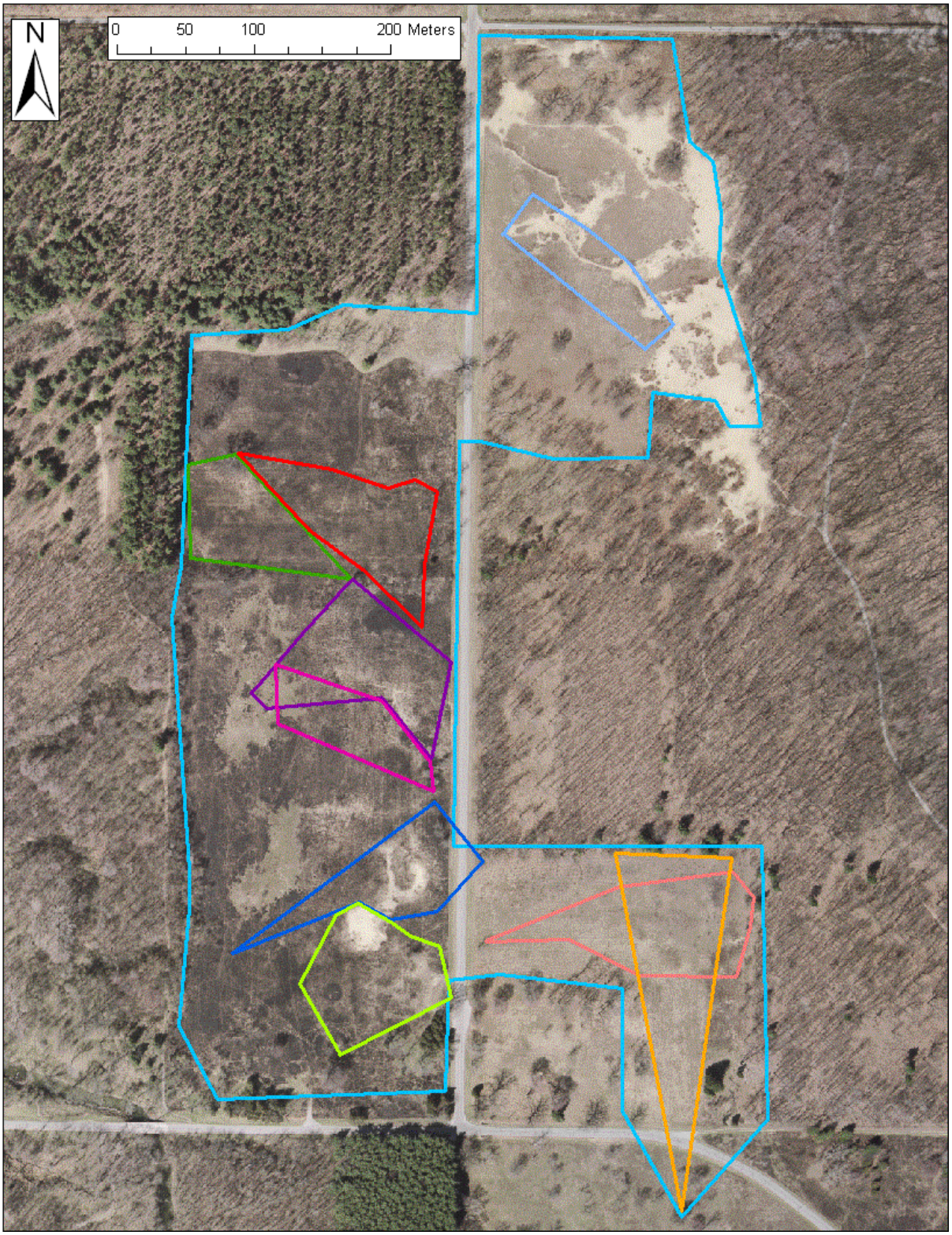

Figure 2: Spatial distribution of territories within a habitat patch. 2004 aerial photograph (Lucas County Auditor 2007) of Greater Girdham Road in Oak Openings Preserve Metropark. Each differently colored polygon is the active 2007 territory of a single Lark Sparrow pair. The light blue outline shows the boundary of the sand barren patch.

To find Abandoned Sites I consulted the literature on local Lark Sparrow populations and interviewed local birders to locate sites where Lark Sparrows bred at some time in the past 40 years but no longer do. In KTNP there were three abandoned sites: Kitty Todd Headquarters, Julia's Savanna and Garden Road (G. Haase, The Nature Conservancy, personal communication; T. Crail, University of Toledo, personal communication). In OOMP there were two abandoned sites: Tansel Lane and Wilkins Reed (Grigore 1999; T. Kemp, Anthony Wayne High School, personal communication). I collaborated with another researcher (Jeremy Ross of Bowling Green State University) to confirm that each Abandoned Site did not harbor nesting Lark Sparrows. Ross and I performed several early morning meander and audio surveys at the beginning of the nesting season. No Lark Sparrows were heard or seen (J. Ross, Bowling Green State University, unpublished data). At Garden Road, Ross found an empty nest. It was difficult to determine if the nest was built in 2006 or 2007 (J. Ross, Bowling Green State University, personal communication). The nest was found empty and untended very early in the nesting season, at a time when Lark Sparrows at active sites were still establishing their territories. We surveyed Garden Road periodically until the end of the nesting season, but no birds were seen or heard. Therefore, I treated Garden Road as an Abandoned Site since, if indeed the nest had been built in 2007, it was abandoned very early in the season, implying an inactive 2007 nesting season.

The five Abandoned Sites were last used by Lark Sparrows at different times. Kitty Todd Headquarters, Julia's Savanna and Garden Road were all used by Lark Sparrows in recent years (see Table 1). Tansel Lane and Wilkins Reed were last used by Lark Sparrows around 1975 (E. Tramer, University of Toledo, unpublished data). The three recently abandoned sites were managed in recent years (see Table 1). Tansel Lane and Wilkins Reed have either never been managed or not since the 1970s, with the exception that the pine plantation bordering one side of

Table 1: Use and management histories of Abandoned Sites. The two sites in bold font, Tansel Lane and Wilkins Reed, were abandoned by Lark Sparrows much longer ago than the other Abandoned Sites. These older Abandoned Sites have never been managed to restore or maintain sand barren plant communities.

Abandoned Sites	**Last Use by Lark Sparrows**	**Last Land Management**
Kitty Todd HQ (KT)	~4 years ago	~2 years ago
Julia's Savanna (JS)	~4 years ago	1 year ago
Garden Road (GA)	1 year ago	2 years ago
Tansel Lane (TL)	**~30 years ago**	**Probably never**
Wilkins Reed (WR)	**~30 years ago**	**Probably never**

Figure 3: Photograph of a late-successional Abandoned Site, Wilkins Reed. Note many trees, a sparse, short understory, and bare sand. This site has had no known Lark Sparrow nests since the 1970s and appears to have succeeded from a sand barren community to an oak savanna community. *Photo by Melanie Coulter.*

Wilkins Reed was removed just before the 2007 breeding season. Lack of management at Tansel Lane and Wilkins Reed has allowed succession to progress to a savanna/woodland stage at these two sites (Figure 3). Kitty Todd Headquarters, Julia's Savanna and Garden Road, on the other hand, are in a mid-successional state with many shrubs and sparse trees.

Mapping Lark Sparrow Territories

From late April to late May, male Lark Sparrows establish their territories with conspicuous singing and border disputes and continue to defend their territories throughout the breeding season. For five weeks beginning in early May, I observed and recorded the locations of territorial aggression to determine the boundaries of Lark Sparrows' 2007 territories. Many Oak Openings Lark Sparrows were color banded by J. Ross and B. Swanson (Bowling Green State University) from 2005 to 2007, so I was able to identify individual males and their territories. Usually males select trees or bushes as their territory boundaries and sing prominently from those perches. I marked the boundary-defining perches on a 1:1500 aerial photo (Lucas County Auditor 2007) on which individual trees and shrubs were clearly visible. I used ArcGIS 9.2 to digitize the maps into a layer with a polygon for each male's territory. Areas in a habitat patch that were not Occupied Territories were treated as Absence Territories. The Absence Territories in Occupied Sites were spatially accessible to Lark Sparrows yet remained un-exploited for nesting, though Lark Sparrows used some areas for foraging. In Abandoned Sites, I defined large-territory-sized areas as Absence Territories. Every square meter of each Abandoned Site was included in an Absence Territory. See Figure 4.

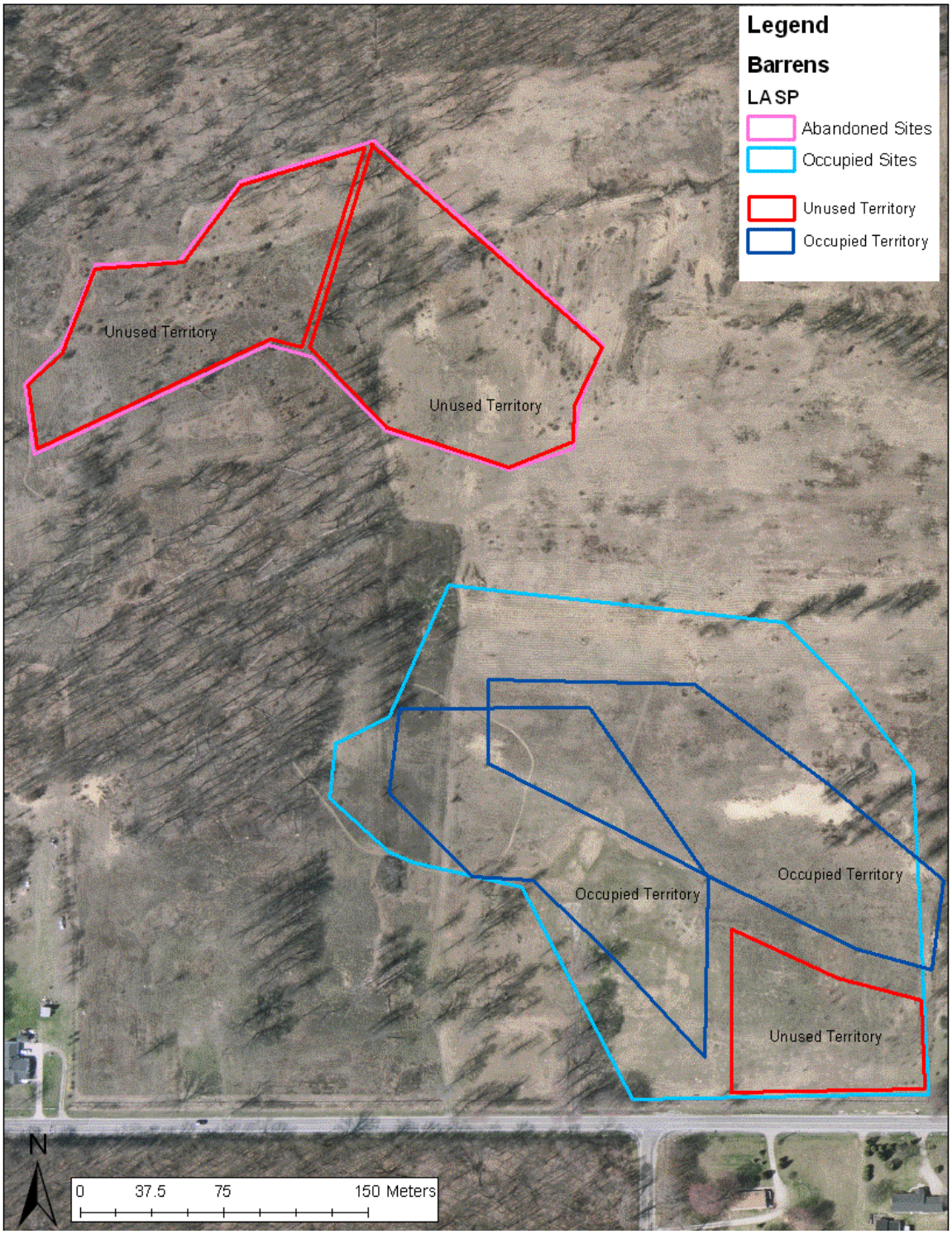

Figure 4: Occupied and Absence Territories. The Abandoned Site Julia's Savanna (pink polygon) and Occupied Site South Piels (light blue polygon) in Kitty Todd Nature Preserve are shown on a 2004 aerial photograph (Lucas County Auditor 2007). "Occupied Territories" were established by pairs in 2007. Absence Territories are un-occupied portions of Occupied Sites (e.g. the "Unused Territory" in South Piels) or territory-sized parts of Abandoned Sites (e.g. the two "Unused Territories" in Julia's Savanna).

Comparing Habitat Parameters in Abandoned and Occupied Sites

The habitat components I measured at each site fall into two categories:

- Vegetation Structure
- Landscape-Level Characteristics

I chose the specific habitat and landscape parameters described below based on Lark Sparrows' biology (Swanson 1996, Martin and Parrish 2000), the microhabitat of Lark Sparrow nest sites (Grigore 1999), the landscape characteristics that predict presence of oak savanna complex (Ricci 2006), and studies that investigated the influences of invasive plants (Flanders et al 2006, Lusk et al 2003, McAdoo et al 1989, Scheiman et al 2003) and habitat structure (Rotenberry 1985, Breininger and Schmalzer 1990, Scheiman et al 2003) on ground-nesting birds.

Vegetation Structure

I measured the vegetation structure of Abandoned and Occupied Sites in July 2007, when most Oak Openings Lark Sparrow broods were fledging. To describe the vegetation structure of Lark Sparrow habitat at multiple spatial scales, I used a survey design that measured the vegetation structure of whole habitat patches and individual territories simultaneously. I established multiple parallel transects in each habitat patch. The transects were set 50 meters apart and extended the entire length of the patch. Every 25 meters along each transect, I placed a 1m x 0.5m quadrat. I staggered the quadrats along adjacent transects by starting at the 0m mark on odd numbered transects and starting at the 10m mark on even numbered transects (Figure 5). This spatial design ensured a thorough and even sampling of the vegetation within each habitat

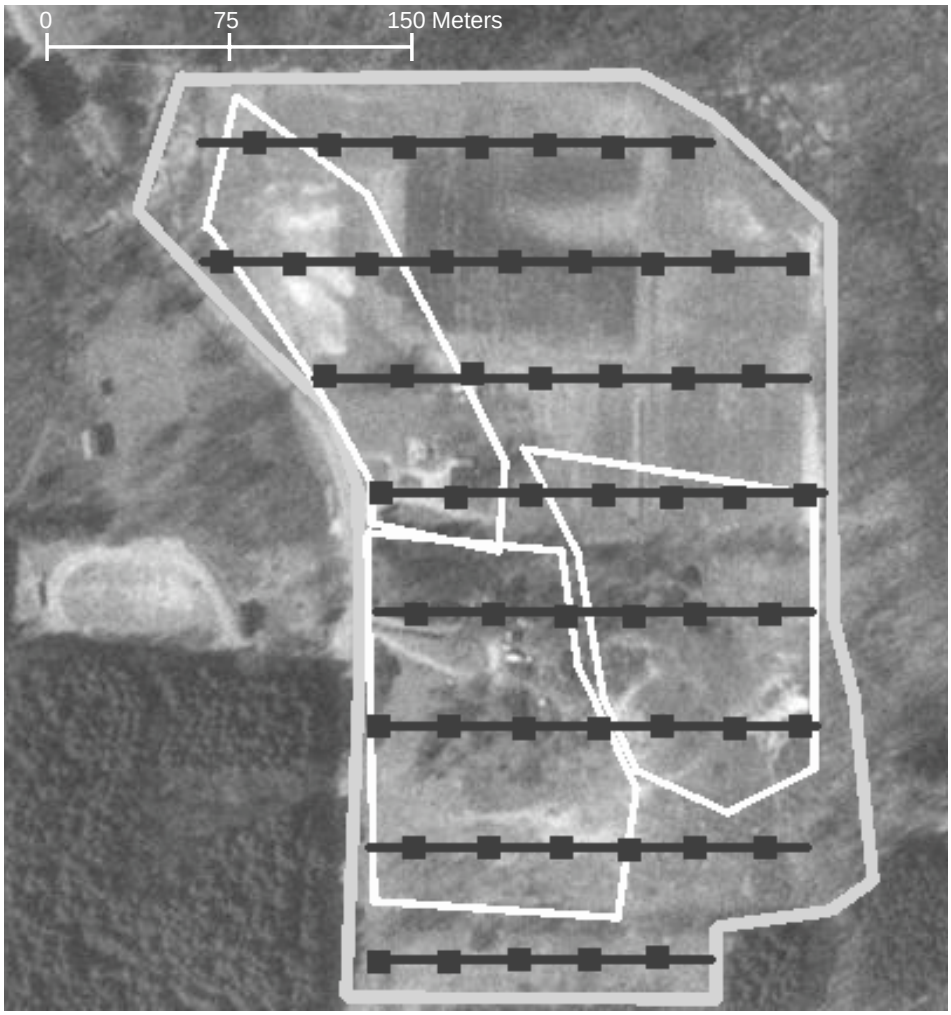

Figure 5: Representation of transects across a habitat patch. Large gray outline shows extent of sand barren patch. White polygons represent occupied territories. Black lines represent transects that extend across the barren, crossing occupied territories and unoccupied areas. Small black squares represent staggered quadrats (not to scale) along each transect.

patch. As each habitat patch was a different size, there were different numbers of transects and quadrats in each site (see Table 2).

Most transects cut across multiple adjacent Lark Sparrow territories and also intersected parts of the habitat patch that were not inside any territory (Figure 5). This allowed me to measure the vegetation characteristics within the habitat patch as a whole, within individual

Table 2: Number of vegetation transects and quadrats per site. Since I established transects and quadrats systematically with specified distances between each, different sized habitat patches contained different numbers of transects and quadrats.

Site	Status	Size (ha)	Number of Transects	Number of Quadrats
GA	Abandoned	1.82	2	10
JS	Abandoned	1.67	4	15
KT	Abandoned	1.15	1	6
TL	Abandoned	0.98	4	14
WR	Abandoned	0.99	3	14
BB	Occupied	2.6	3	16
GG	Occupied	20.03	11	98
JF	Occupied	4.29	8	46
MB	Occupied	5.23	5	61
MBN	Occupied	1.24	2	7
OL	Occupied	4.01	4	29
SP	Occupied	6.04	5	32

Occupied Territories and within Absence Territories. I used a Trimble Global Positioning System (GPS) unit to record the locations of the transects and quadrats. The GPS files were converted in ArcGIS 9.2 into a layer with a point representing the center of each quadrat. I overlaid this quadrat layer with the territory layer to identify which vegetation measurements were inside and outside the territories.

Along each transect I took four measurements of vegetation structure:

- Percent aerial cover of shrubs
- Percent aerial cover of trees
- Herbaceous vegetation height
- Vegetation height-density

I estimated percent shrub and tree cover by using the line-intercept method along each transect (Bonham 1989; e.g. Flanders et al 2006, Scheiman et al 2003, Haire et al 2000). I measured the length of the transect that was intercepted, or over-hung, by shrubs and trees. The length of transect intercepted by shrubs or trees divided by the total length of the transect estimated percent cover of shrubs or trees for that section of a habitat patch.

I estimated herbaceous vegetation height by measuring the height of the four herbaceous plants closest to each corner of each 1m x 0.5m quadrat. Heights of forbes, grasses, sedges and shrubs were measured; trees were not.

To measure vegetation height-density, I used a Robel pole placed in the center of each quadrat. A Robel pole measures the amount of visual obstruction caused by the vegetation at a site. Visual obstruction measurements indicate the height and density of vegetation and are highly correlated with biomass of vegetation (Robel et al 1970). I took four Robel measurements at each quadrat by standing two meters away from the pole in each of the four cardinal directions (see Robel et al 1970). My Robel measurements were in decimeters. A Robel measurement of 2 decimeters (dm) meant that the bottom 2 decimeters of the pole were completely obscured from view by vegetation, but above 2 dm the pole was at least partially visible (Figure 6).

Figure 6: How a Robel pole is used. This Robel pole measurement would be 5.5 dm. The top half of the red 5 dm band is visible, and the bottom 5.5 dm of the pole is completely obscured from view.

Landscape-Level Habitat Characteristics

For each habitat patch I measured the following landscape characteristics:

- Size of the habitat patch (hectares)
- Distance to closest Occupied Site (meters)
- Distance to closest human development, i.e. paved roads, buildings, agricultural fields (meters)
- Mean elevation (meters above sea level)
- Perimeter to area ratio (a measure of amount of edge relative to amount of core)

For each territory I measured the following landscape characteristics:

- Distance to closest occupied territory (meters)
- Distance to closest human development (meters)
- Mean elevation (meters above sea level)

In ArcGIS 9.2 I mapped each habitat patch on an orthorectified high-resolution (6") aerial photograph taken in 2004 (Lucas County Auditor 2007). Individual patches of sand barren, mostly treeless areas surrounded by woodland, were visible on the aerial photo. I used on-screen digitizing tools to draw polygons around each sand barren patch to create a habitat patch map layer. My vegetation surveys had revealed which parts of these treeless areas were actually wetlands, and I did not include wetland areas in the habitat patch polygons.

Using the habitat patch layer, I calculated the area of each patch. I also calculated the shortest distance between the edge of each patch and the closest Occupied Site. Human development such as paved roads and buildings were easily visible on the 2004 aerial photo. I overlaid the habitat patch layer with the aerial photo and calculated the shortest distance between the edge of each patch and human development.

I overlaid the territory layer (described in the "Mapping Lark Sparrow Territories" section) with the 2004 aerial photo and calculated the distances from each territory to the closest occupied territory and to the closest human development.

To find the mean elevation of each habitat patch and each territory, I overlaid the quadrats layer with a digital elevation model obtained from the U.S. Geological Survey Earth Resources and Observation and Science Center's online Seamless Data Distribution System (US Geological Survey 2005). I recorded the elevation at each quadrat.

I converted the habitat patch layer to a raster file and imported it into Fragstats 3.3. In Fragstats I calculated the perimeter to area ratio of each habitat patch. Perimeter to area ratio (also called edge to interior ratio) is a measurement of the amount of edge at a site. A habitat patch with a high perimeter to area ratio has a large amount of edge compared to the amount of interior habitat.

Analysis

I compared vegetation structure and landscape context across all sites to identify significant correlates with presence of breeding Lark Sparrows. I analyzed the data at three different spatial scales. Table 3 shows which habitat variables were analyzed at each spatial scale.

Table 3: Habitat variables analyzed at the three spatial scales: Landscape, Habitat Patch, and Territory. Units are shown in parentheses.

Landscape Scale	**Habitat Patch Scale**	**Territory Scale**
Size of habitat patch (ha)	Percent aerial cover of shrubs (%)	Percent aerial cover of shrubs (%)
Distance from habitat patch to nearest Occupied Site (m)	Percent aerial cover of trees (%)	Percent aerial cover of trees (%)
Distance from habitat patch to nearest human development (m)	Herbaceous vegetation height (cm)	Herbaceous vegetation height (cm)
Perimeter to area ratio of habitat patch	Vegetation height-density (dm on Robel pole)	Vegetation height-density (dm on Robel pole)
	Mean elevation of habitat patch (m)	Distance from territory to nearest occupied territory (m)
		Distance from territory to nearest human development (m)
		Mean elevation of territory (m)

To determine which habitat variables were significantly different in Occupied Sites versus Abandoned Sites, I used MiniTab 15.1.1.0 to run Mann-Whitney tests to compare the median values of the two site groups. The Results section presents the test statistic (U), the sample size (N), and the p-value for the Mann-Whitney tests. P-value of less than 0.05 was considered significant.

In addition, I performed a step-wise multivariate linear regression in MiniTab to model the expected value of Presence or Absence given the values of the habitat variables. Stepwise regression performs well as a method for selecting the most significant variables in habitat models (Reineking and Schroder 2006). The regression analysis created a descriptive model of Lark Sparrow presence and determined the relative importance of each variable in that model. All variables were non-normal with equal variances. Linear regression is robust to departures from the assumption of normality (Grimm and Yarnold 2000).

Results

Landscape Scale

Two habitat variables were significantly different between the Occupied Sites and the Abandoned Sites at the scale of the landscape. Habitat patch size was larger in Occupied Sites than in Abandoned Sites (Mann-Whitney: U= 17, N= 12, p= 0.015). Perimeter to area ratio (i.e. amount of edge) was lower in Occupied Sites than in Abandoned Sites (Mann-Whitney: U= 46, N= 12, p= 0.035). See Figure 7. Two habitat variables were not significantly different between the two groups of sites: distance from habitat patch to nearest Occupied Site and distance from habitat patch to nearest human development.

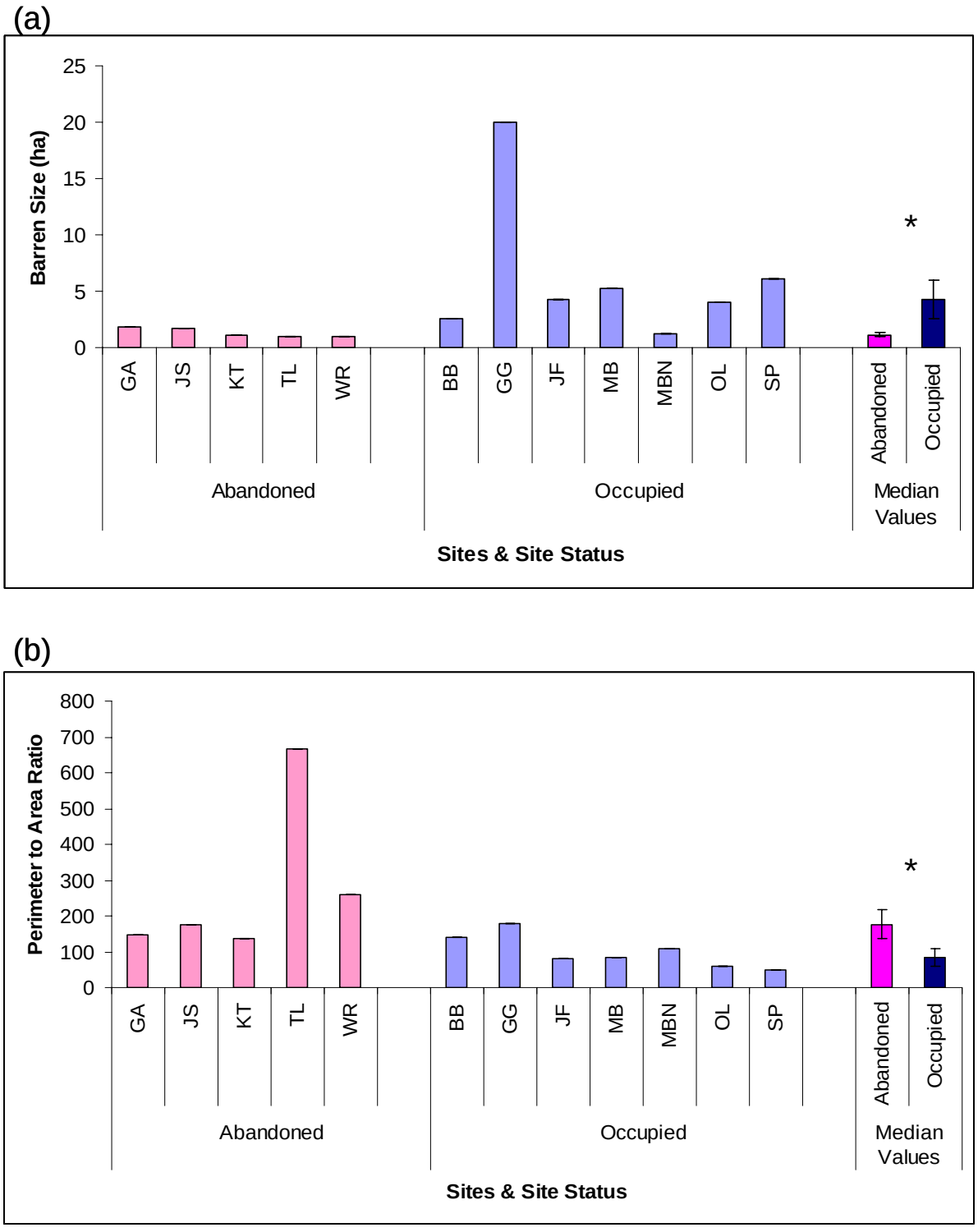

Figure 7: Statistically significant differences between Abandoned and Occupied Sites at the Landscape Scale. Pink bars represent the median (a) Barren Size and (b) Perimeter:Area Ratio of the Abandoned Sites. Blue bars represent the same measurements at Occupied Sites. Dark pink and dark blue bars represent the median of all Abandoned Sites and all Occupied Sites, respectively. Error bars are Median Absolute Deviations. *Statistically significant at $p<0.05$

Stepwise linear regression at the landscape scale produced a model using one habitat variable to predict the presence of breeding Lark Sparrows (R^2=30.16; Table 4). The probability of Lark Sparrow presence was negatively correlated with perimeter to area ratio (P=0.064).

Table 4. Results of the stepwise linear regression model predicting breeding Lark Sparrow presence at the landscape scale in Oak Openings Region, Ohio. T-value indicates the strength of the relationship between the predictor variable and the response variable (Grimm and Yarnold 2000).

Constant	N	R^2	Predictor Variable	Coefficient	t-value	p-value
0.88	12	30.16				
			Perimeter:Area	-0.0017	-2.08	0.064

Habitat Patch Scale

Two habitat variables were significantly different between the Occupied Sites and the Abandoned Sites at the habitat patch scale. Percent tree cover was lower in Occupied Sites than in Abandoned Sites (Mann-Whitney: U= 515, N= 53, p= 0.0059). Herbaceous vegetation height was higher in Occupied Sites than in Abandoned Sites (Mann-Whitney: U= 7742.5, N= 347, p= 0.0003). See Figure 8. Three habitat variables were not significantly different between the two groups of sites: percent shrub cover, vegetation height-density, and elevation.

Stepwise linear regression at the habitat patch scale produced a model using two habitat variables to predict the presence of breeding Lark Sparrows (R^2=53.10; Table 5). The probability of Lark Sparrow presence was negatively correlated with percent tree cover (P=0.017) and vegetation height-density (P=0.068).

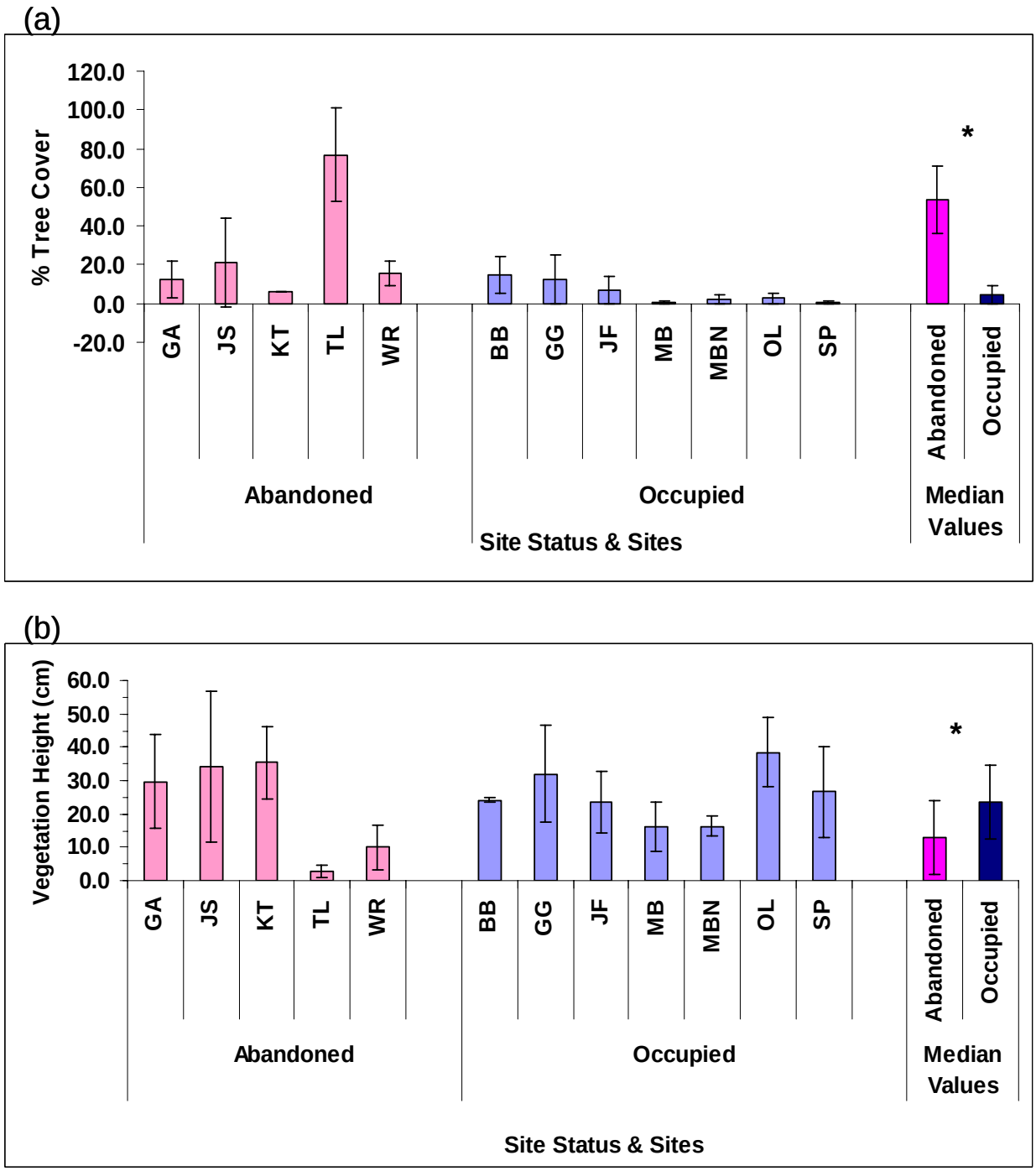

Figure 8: Statistically significant differences between Abandoned and Occupied Sites at the Habitat Patch Scale**.** Pink bars represent the median (a) Percent Tree Cover and (b) Herbaceous Vegetation Height of the Abandoned Sites. Blue bars represent the same measurements at Occupied Sites. Dark pink and dark blue bars represent the median of all Abandoned Sites and all Occupied Sites, respectively. Error bars are Median Absolute Deviations.
* Statistically significant at $p<0.05$

Table 5. Results of the stepwise linear regression model predicting breeding Lark Sparrow presence at the habitat patch scale in Oak Openings Region, Ohio. T-value indicates the strength of the relationship between the predictor variable and the response variable (Grimm and Yarnold 2000).

Constant	N	R^2	Predictor Variable	Coefficient	t-value	p-value
1.5583	12	53.10				
			Percent Tree Cover	-0.0201	-2.93	0.017
			Vegetation Height-Density	-0.31	-2.07	0.068

Territory Scale

Four habitat variables were significantly different between Occupied Territories and Absence Territories. Percent shrub cover (Mann-Whitney: U= 2092, N= 88, p= 0.0000), percent tree cover (Mann-Whitney: U= 2069.5, N= 88, p= 0.0001), vegetation height-density (Mann-Whitney: U= 22646, N= 286, p= 0.0001), and distance to closest occupied territory (Mann-Whitney: U= 393, N= 38, p= 0.0173) were lower in Occupied Territories than in Absence Territories. See Figure 9 a-d. Three habitat variables were not significantly different between the two groups of sites: herbaceous vegetation height, distance to nearest human development, and elevation.

Stepwise linear regression at the territory scale produced a model using four habitat variables to predict the occupancy of breeding sites (R^2=49.05; Table 6). The probability of Lark Sparrow presence was negatively correlated with percent shrub cover (P=0.000), vegetation height-density (P=0.000) and distance to nearest occupied territory (P=0.000). The probability of Lark Sparrow presence was positively correlated with herbaceous vegetation height (P=0.014).

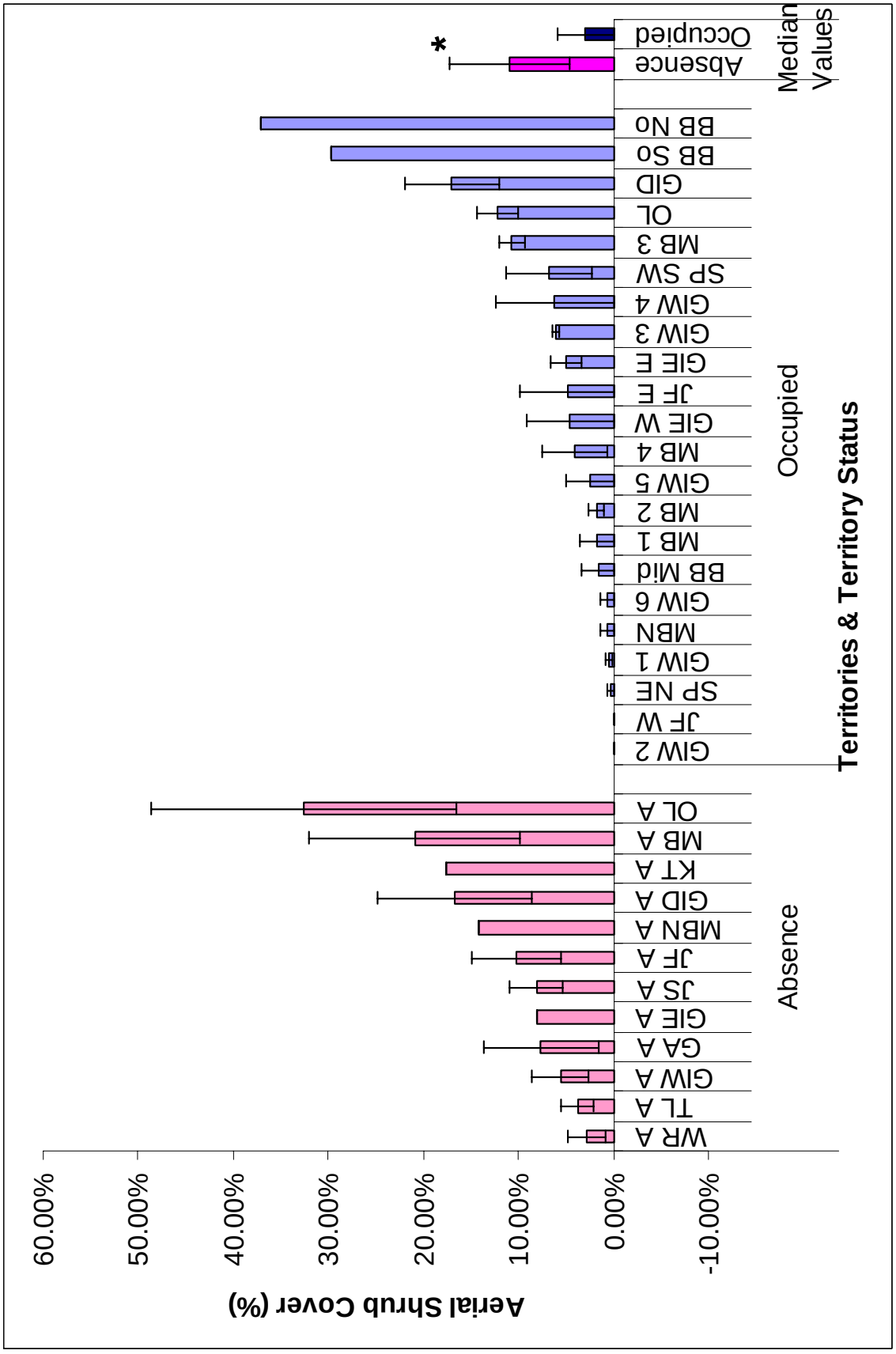

Figure 9a: Statistically Significant Differences between Occupied Territories and Absence Territories
Pink bars represent median Percent Shrub Cover at Absence Territories. Blue bars represent the same at Occupied Territories. Dark pink and dark blue bars represent the median of all Absence Territories and all Occupied Territories, respectively. Error bars are Median Absolute Deviations.

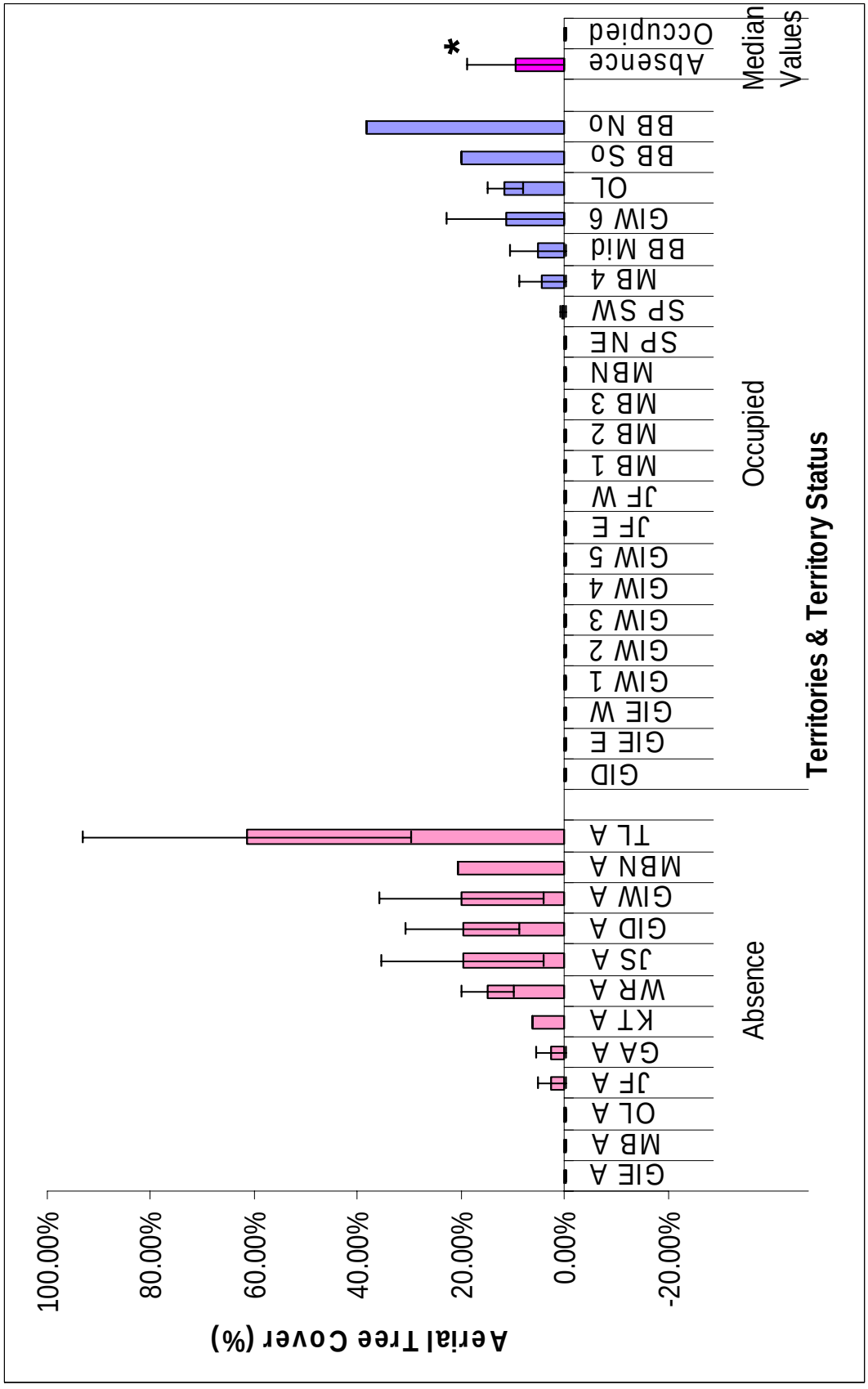

Figure 9b: Statistically Significant Differences between Occupied Territories and Absence Territories
Pink bars represent median Percent Tree Cover at Absence Territories. Blue bars represent the same at Occupied Territories. Dark pink and dark blue bars represent the median of all Absence Territories and all Occupied Territories, respectively. Error bars are Median Absolute Deviations.

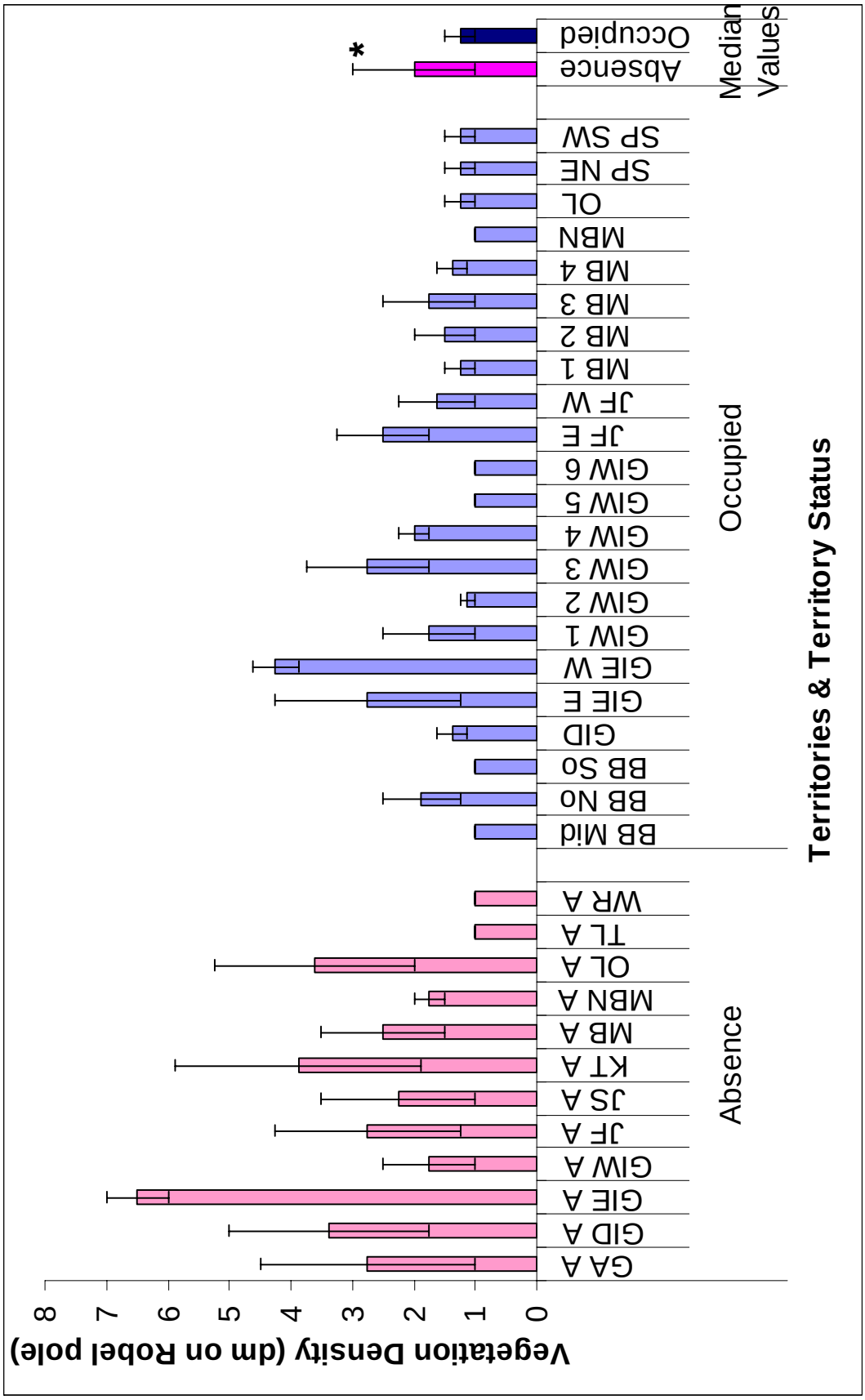

Figure 9c: Statistically Significant Differences between Occupied Territories and Absence Territories
Pink bars represent median Vegetation Density at Absence Territories. Blue bars represent the same at Occupied Territories. Dark pink and dark blue bars represent the median of all Absence Territories and all Occupied Territories, respectively. Error bars are Median Absolute Deviations.

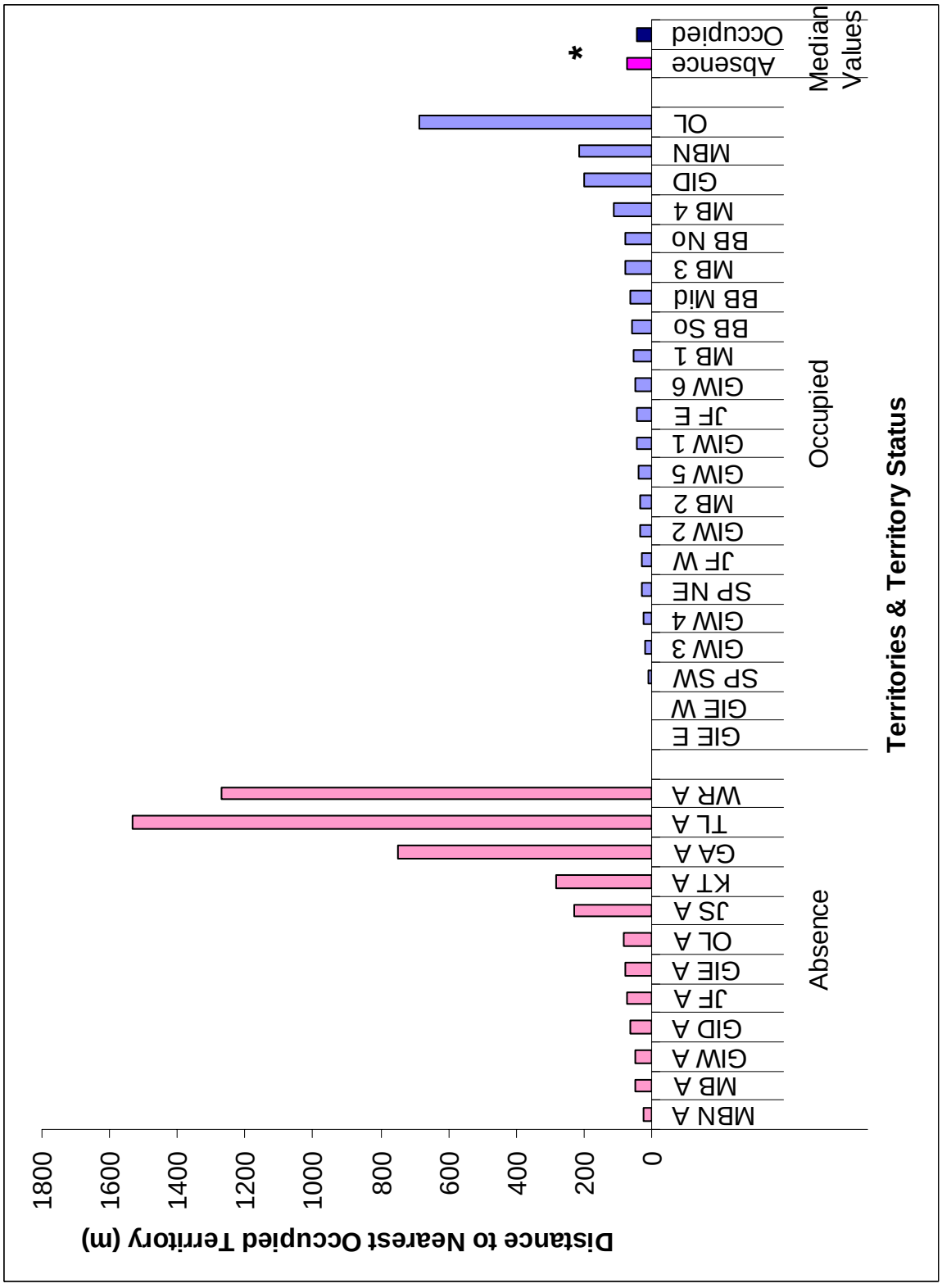

Figure 9d: Statistically Significant Differences between Occupied Territories and Absence Territories
Pink bars represent median Distance to Nearest Occupied Territory at Absence Territories. Blue bars represent the same at Occupied Territories. Dark pink and dark blue bars represent the median of all Absence Territories and all Occupied Territories, respectively. Error bars are Median Absolute Deviations.

Table 6. Results of the stepwise linear regression model predicting breeding Lark Sparrow presence at the territory scale in Oak Openings Region, Ohio. T-value indicates the strength of the relationship between the predictor variable and the response variable (Grimm and Yarnold 2000).

Constant	N	R^2	Predictor Variable	Coefficient	t-value	p-value
1.037	86	49.05				
			Percent Shrub Cover	-1.54	-4.49	0.000
			Herbaceous Vegetation Height	0.0095	2.52	0.014
			Vegetation Height-Density	-0.213	-4.86	0.000
			Distance to Nearest Occupied Territory	-0.00053	-4.84	0.000

Discussion

At the scale of the landscape, Lark Sparrows used large patches of sand barren with low edge to interior ratios. A more complete picture emerged as we scaled down to the habitat patch scale. Lark Sparrows used sand barren patches with low tree cover and relatively tall herbaceous vegetation. Low vegetation height-density may also be important to Lark Sparrows at this scale, as the regression selected vegetation height-density, along with tree cover, as an important predictor of Lark Sparrow presence. Scaling down further to individual territories revealed that within a habitat patch, Lark Sparrows select territories with low shrub cover, low tree cover, low vegetation height-density, and proximity to other occupied territories. The regression analysis also selected high herbaceous vegetation as a predictor of breeding Lark Sparrow presence. One explanation for these preferences is that low height-density of the herbaceous layer allows Lark Sparrows to see approaching predators while they are feeding and nesting on the ground, while the herbaceous layer that can grow under a sparse overstory provides protective cover and a potential source of food, e.g., insects and graminoid seeds.

The landscape scale analysis revealed that patch shape was a more important predictor of Lark Sparrow presence than patch size. Davis (2004) and Helzer and Jelinski (1999) also found that the ratio of edge to interior habitat was a better predictor than prairie patch size for presence of a variety of grassland birds. Occurrence of early-successional species may be negatively affected by larger amounts of edge because of increased risk of predation and brood parasitism near wooded edges (Johnson and Temple 1990, Winter et al. 2000). Davis (2004) stated that his study and Helzer and Jelinski's (1999) were the only studies that evaluated the effects of patch shape on grassland bird occurrence. I searched the literature and found one article that considered the effect of the extent of different types of edge (i.e. amount of woodland edge vs. grassland edge vs. road edge) (Fletcher and Koford 2002). Fletcher and Koford (2002) found that most grassland bird species in their study had lower densities in areas with high amounts of non-grassland edge. Fletcher and Koford (2002), Davis (2004) and Helzer and Jelinski (1999) did not study Lark Sparrows.

While several studies have evaluated the response of grassland birds to patch size (e.g. Winter et al 2006, Ribic and Sample 2001, Johnson and Igl 2001, Walk and Warner 1999, Thogmartin et al 2006), Lark Sparrows are under-represented in this body of literature. Some grassland species such as Grasshopper Sparrows (Davis 2004, Johnson and Igl 2001, Horn et al 2002), Baird's Sparrows (Davis 2004), and Henslow's Sparrows (Thogmartin et al 2006, Walk and Warner 1999) occur more frequently in larger prairie or pasture patches. Other grassland birds such as Clay-colored Sparrows (Davis 2004), Savannah Sparrows (Davis 2004, Ribic and Sample 2001, Johnson and Igl 2001), Field Sparrows (Horn et al 2002), Brown-headed Cowbirds (Horn et al 2002), and Meadowlarks (Johnson and Igl 2001) are not sensitive to patch size. Grigore's (1999) study of Oak Openings Lark Sparrows found that a minimum habitat patch size

was important. The smallest patch in which she found nesting Lark Sparrows was 1.9 ha. I found a nest in a 1.24 ha patch. However, that site (Moseley Barrens North) is very close (180 m) to Moseley Barrens, and much of the land between the two sites is fairly sparse oak savanna, which could increase the size of the patch as perceived by Lark Sparrows.

Lack of other studies that show the importance of patch size and shape to Lark Sparrow occurrence is probably due to the differences between habitat in the Oak Openings Region and habitat in the main part of Lark Sparrows' range. In the core of their range, Lark Sparrows often inhabit large, unbroken prairies or fields (Martin and Parrish 2000). This is possible in western U.S.A. because the dryer climate and more frequent disturbances such as wildfire and livestock grazing promote larger tracts of sparse, early-successional plant communities. In the Oak Openings, Lark Sparrows use small patches of Midwest sand barren that are surrounded by oak woodland. It makes sense that habitat patch size and amount of woodland edge would be important in such a landscape context. The importance of patch size and shape to Lark Sparrows in the Oak Openings complements studies that show the importance of patch size and shape in fragmented environments.

Lark Sparrows may not be sensitive to proximity to human activity, as the distance to nearest human development was not significantly different between Occupied and Abandoned Sites. In fact, Occupied Sites were closer to development (median 60.7 m) than were Abandoned Sites (median 132 m), though the difference was not statistically significant. Additionally, Lark Sparrows often fed right along the shoulders of roads, scattering only briefly or not at all when cars passed. The proximity of breeding sites to roads, however, could be due in part to the fact that areas closer to roads were easier to manage and, hence, were managed more frequently, making the vegetation structure more suitable for Lark Sparrows. However, if I had compared

nest success rather than presence versus absence, I may have found that proximity to development is detrimental to Lark Sparrow success because of increased predation rates.

At the habitat patch scale, percent aerial tree cover was the strongest predictor of breeding Lark Sparrow presence. Long-term woody invasion leading to too many trees is one way that habitat becomes inhospitable to Lark Sparrows. Martin and Parrish (2000) state that Lark Sparrows prefer structurally open herbaceous ground cover containing scattered trees or shrubs with <24% canopy cover. In northeastern Colorado Lark Sparrows were found in overgrazed prairies with widely spaced cottonwoods (Jacobson 1972, Fitzgerald 1978). In pinon-juniper communities, Lark Sparrow abundance increased with decreasing tree density (Tazik 1991). Our study in the Oak Openings indicated that at around 15% tree cover the habitat patches tipped away from being open enough for nesting Lark Sparrows, suggesting a potential threshold that would be important for management and conservation.

The results indicating that vegetation is taller in Occupied Sites than in Abandoned Sites may be misleading. Two of the Abandoned Sites, Tansel Lane and Wilkins Reed, are late-successional woodland or savanna communities and have a lot of trees (76.7% and 15.7% aerial cover) compared to the other Abandoned Sites (6% to 21% aerial cover). As discussed in the site descriptions, this difference is due to the lack of land management at Tansel Lane and Wilkins Reed. At these two sites, the herbaceous layer cannot grow very high in the shade of the trees. The median herbaceous vegetation height at these two sites was 3 cm and 10 cm, much lower than the more recently managed Abandoned Sites' range of 24 cm to 35 cm. The difference between these two sets of Abandoned Sites could have skewed the results of the Herbaceous Vegetation Height analysis.

To test this, I removed Tansel Lane and Wilkins Reed from the analyses and found no significant difference between the herbaceous vegetation height of Occupied Sites and the remaining Abandoned Sites (Mann-Whitney; P=0.34). The median vegetation heights of the more recently managed Abandoned Sites and Occupied Sites were 33 cm and 23.5 cm, respectively. By evaluating the two sets of Abandoned Sites separately, I could identify what is unsuitable at sites that haven't been managed in decades and what is unsuitable at sites that have experienced more recent land management. The un-managed sites had too much tree cover (53% vs the Occupied Sites' 4%), whereas the more recently managed sites had too much visual obstruction (i.e. too tall and dense vegetation: 2.3 dm height-density on a Robel pole vs the Occupied Sites' 1.5 dm).

Elevation was not significantly different between Occupied and Abandoned Sites probably because Abandoned Sites once functioned as Midwest sand barrens and contained suitable Lark Sparrow habitat. In order to have been healthy sand barrens before, the Abandoned Sites must have met the general soil, elevation, and climatic requirements of the vegetation that make up the Midwest sand barren plant community. Since Occupied Sites also are Midwest sand barrens, they must have the same elevation (and soil and climate) as the Abandoned Sites.

It appears that Lark Sparrows' territories must meet more rigid suitability standards than does the habitat patch in which the territories are located. At the territory scale, I found five significant habitat variables, and four variables were included in the most parsimonious regression model. At the habitat patch scale, only two habitat variables were significant, and two were included in the regression model. Other studies have found that habitat requirements narrow as smaller spatial scales are considered (e.g. Barg 2006, Wiens and Rotenberry 1981).

At the territory scale, vegetation height-density seems to be the most important variable. My results indicate that Lark Sparrows select territories with lower vegetation height-density in the habitat patch. Grigore (1999) also found vegetation density a crucial component of Lark Sparrow habitat, but she found that sites with the most Lark Sparrows had higher vegetation density (as measured at 10-20 cm above ground) than sites with low or no Lark Sparrow presence. These seemingly different results are probably a result of Grigore measuring vegetation structure along a single meandering transect that went through what looked to her like suitable Lark Sparrow habitat. In other words, she was selecting for and only measuring in the least dense parts of the sand barren patch.

I could not find other studies that specifically measured vegetation height-density of Lark Sparrow habitat. However, several studies found that Lark Sparrows used grazed or overgrazed prairies more than ungrazed prairies (Jacobson 1972, Fitzgerald 1978, Bock and Webb 1984, Holmes and Geupel 1998). Presumably overgrazed prairies have lower vegetation density (and vegetation height) than ungrazed prairies. Additionally, Martin and Parrish (2000) and Swanson (1996) described Lark Sparrow breeding habitat as structurally open habitat with short vegetation and lots of bare ground. These three characteristics combined could be described as low vegetation height-density.

That herbaceous vegetation height was included in the regression model (despite not being statistically significant in the Mann-Whitney test) should, again, be tempered by the fact that the woodland/savanna Abandoned Sites were so different from the other Abandoned Sites. Also, the studies cited in the previous paragraph indicate a preference for low vegetation height.

Percent tree cover is likely the least important significant variable at this scale, as it was not included in the regression model, despite having a Mann-Whitney p-value of 0.0001. Percent

tree cover ranged from 0%-38% in Occupied Territories and 0%-61.5% in Absence Territories. However the Occupied Territory with 38% tree cover (Badger Barrens North) had only a single vegetation survey transect running through it. This entire transect just happened to fall in a thin line of trees and shrubs running the length of the territory. The rest of the territory had almost no trees. The location of the transect likely overestimated the total tree cover in this territory.

Lark Sparrows in the Oak Openings used territories with low shrub cover. Shrub encroachment is an important early stage of woody invasion that can reduce the suitability of a site for Lark Sparrow territory establishment. Other studies have found that Lark Sparrows and other grassland birds respond to amount of shrub cover. Davis et al (2000) found that Lark Sparrows were associated with frequently burned sites rather than infrequently or unburned sites. Burned sites used by Lark Sparrows had lower shrub density (18,800 to 60,000 stems/ha) than unburned sites. Another study Bock and Webb (1984) found that Lark Sparrows used sites with shrub canopy cover of 1.4%. McAdoo et al (1989) found that Lark Sparrow abundance was negatively correlated with shrub density. Our study in the Oak Openings indicated that at around 15% shrub cover the habitat patches tipped away from being open enough for nesting Lark Sparrows, suggesting a potential threshold that would be important for management and conservation.

Finally, my territory scale analyses revealed that spatial position of territories was important, as Occupied Territories were closer to each other than Absence Territories were to Occupied Territories. However, this data might have been skewed by the great distances between the Absence Territories in some Abandoned Sites and the closest Occupied Site. I found only one other study of grassland birds that considered the importance of proximity to conspecifics'

breeding sites. Niemuth (2003) found that presence of active Prairie Grouse leks were negatively associated with distance from nearest known lek.

It is generally agreed that many birds breed near conspecifics (Magrath 2001, Martinez and Zuberogoitia 2004, etc.) and that grassland birds are sensitive to shrub cover (Wiens and Rotenberry 1981, Lusk et al 2003, Pons et al 2003, etc.). For Lark Sparrows, these observations might depend on the spatial scale being considered. In my study, the importance of low amounts of shrub cover and proximity to other occupied territories might have been overlooked if these habitat variables were only considered at larger spatial scales, where neither variable emerged as significant.

At the scale of the territory, elevation and distance to human development were again not significantly different between Occupied and Abandoned Sites, probably for the reasons I outlined earlier in the Discussion.

An additional spatial scale that could be considered is the nest site. While I did not collect data at the nest site scale for Lark Sparrows in the Oak Openings, Grigore (1999) did. Grigore quantified the micro habitat within one square meter centered on each Lark Sparrow nest. She found that the presence of a small amount of grass (median 9%), a moderate cover of dewberry (median 19%), <51% bare ground, <20% shrub cover, a small amount of litter cover (median 6.5%), and a higher vegetation density than unsuccessful nests comprised the average microhabitat at successful nests. Grigore found that litter cover and vegetation density were the major determinants of successful nests.

Other studies have quantified the microhabitat parameters of Lark Sparrow nests. Lusk et al (2003) found that the most important parameters were percent cover of shrubs or plants that provide similar structural cover to shrubs (>9%), distance to nearest structural element

(<270cm), bare-ground exposure (<87%), and percent litter cover (<74%). While Grigore's (1999) study found that Lark Sparrows use nest sites with shrub cover below a certain threshold, Lusk et al found that the birds require shrub cover above a certain threshold. Again, I think that the much larger tracts of grassland in which Lusk et al performed their study is the reason for the different results. Lark Sparrows are influenced by a preference for singing perches. In large tracts of grassland with large amounts of interior habitat, shrubs would be a limiting factor. In the Oak Openings' small sand barren patches surrounded by woodland, singing perches are not limited, and large numbers of encroaching shrubs can alter the vegetation structure to a state undesirable for Lark Sparrows.

These nest site studies reveal that there is yet another spatial scale that affects Lark Sparrow habitat requirements. Grigore's study, which was performed at the same sites I studied, is especially revealing. She concluded that Lark Sparrows prefer different habitat parameters at the habitat patch scale than at the nest site scale. For example, percent cover of litter was the strongest determining factor at the nest site but was not important at the habitat patch. Percent dewberry cover strongly influenced territory placement, but only slightly influenced nest placement.

My study supports the conclusion that Lark Sparrows respond to different habitat parameters at different spatial scales, while expanding the scope of Grigore's study to include Landscape Scale, Patch Scale, and Territory Scale. The low R^2 values of my regression analyses at each scale imply that no single scale is adequate in predicting breeding Lark Sparrow presence. Lark Sparrow may be a bird that responds to multiple environmental scales, as are certain other species of grassland birds (Davis 2004, MacFaden and Capen 2002, Wiens and Rotenberry 1981). For example Davis (2004) found that Baird's Sparrows and Horned Larks

responded to the landscape scale variables patch size and shape as well as the patch scale variable vegetation structure. Wiens and Rotenberry (1981) found that Sage Sparrows, Brewer's Sparrows, and Sage Thrashers were strongly correlated with habitat structure at the "continental scale" and with coverage of certain plant species at the regional scale.

In my study, all scales put together reveal a descriptive model of Lark Sparrow breeding habitat in the Oak Openings Region. Specifically, Lark Sparrows used sites with the characteristics listed in Table 7.

Table 7: Characteristics of Lark Sparrow Breeding Habitat in the Oak Openings. Ranges of the significant variables found in Occupied Sites and Occupied Territories are listed.

Significant Habitat Variable	**Suitable Range for Breeding Lark Sparrows**
Habitat patch size	minimum 1.24 ha
Habitat patch perimeter to area ratio	50 to 139
Habitat patch tree cover	0.6% to 15%
Habitat patch vegetation height-density	1 to 2 dm on a Robel pole
Territory shrub cover	0% to 37% (more likely 0% to 17%)*
Territory tree cover	0% to 38% (more likely 0% to 20%)*
Territory vegetation height-density	1 and 4 dm on a Robel pole
Distance to nearest occupied territory	0 m to 686 m (more likely 0 m to 212 m)**

*Removed the occupied territory, Badger Barrens North, which is probably an overestimation of shrub and tree cover due to the single vegetation survey transect falling exactly on the only line of trees and shrubs in the territory.
**At Ostrich Lane there was only one confirmed and mapped territory, but there was other Lark Sparrow activity there indicating a likely second territory at the site that we were unable to confirm and map. 686m was the distance from the confirmed Ostrich Lane territory to the nearest confirmed territory (in Jeffers Farm), but the likely territory in Ostrich Lane would have been closer, potentially negating the 686m distance.

Conclusion

My study revealed a definition of Oak Openings' Lark Sparrow breeding habitat that showed the importance of different habitat parameters at different spatial scales. Many of the important habitat parameters can be affected by land management. The importance of low shrub and tree cover highlights the threat that woody invasion poses if it is not managed actively. In Chapter 2, I explore the management implications of this study's results.

My study supports the conclusions of the only two other studies that have considered the importance of patch shape to grassland birds. The conclusion that patch shape has more influence than patch size on occurrence of some grassland bird species suggests that conservation objectives should consider shape, not just size, of early-successional habitat patches. Moreover, early-successional habitats with low perimeter to area ratios are more likely to be source habitats than are sites with more edge (Perkins et al. 2003).

Finally, my study of Lark Sparrows adds support to other recent studies that concluded that some birds respond to habitat variables at multiple spatial scales. The basic methods of my study could easily be applied to other species and systems to 1) develop descriptive habitat models that are more relevant because of their consideration of multiple spatial scales, and 2) broaden the scope of studies that test the hypothesis that birds respond to more than one environmental scale.

CHAPTER 2

USING LARK SPARROW HABITAT REQUIREMENTS TO INFORM SAND BARREN MANAGEMENT

Introduction

Grassland habitats throughout the United States are being lost to woody invasion and development (Grant et al 2004). Many early-successional habitat specialists, especially birds, have seen declines due to this loss of habitat (Herkert 1994, Vickery et al 1994). The Lark Sparrow, a ground-nesting bird dependent on early-successional plant communities, has been impacted by habitat loss in the eastern edge of its range, including Ohio. In northwestern Ohio, Lark Sparrows breed in a globally rare plant community called Midwest sand barren, which is located in the Oak Openings Region.

In a previous study (see Chapter 1), I compared occupied Lark Sparrow breeding sites to abandoned Lark Sparrow breeding sites in the Oak Openings to determine the habitat requirements of nesting Lark Sparrows at multiple spatial scales. The objective of the current study was to use the multi-spatial-scale habitat characteristics associated with Lark Sparrow breeding sites to evaluate the impacts of land management history on the suitability of sites for Lark Sparrow breeding.

The Oak Openings is one of the few places Lark Sparrows still nest in Ohio (Peterjohn and Rice 1991). Protecting the Midwest sand barren habitat in Oak Openings is of critical importance to the Lark Sparrow's viability in Ohio as a whole. My research could help managers improve habitat in this critical region and bolster this crucial Lark Sparrow population. Also, my results give insight into the habitat components that might be important for other early-

successional habitat specialists, especially birds, and the land management practices that can maintain those habitat components effectively.

The Oak Openings

See Chapter 1, Section: Introduction, Sub-section: The Oak Openings, for an introduction to the rare and biotically rich Oak Openings Region in Northwest Ohio.

Lark Sparrow Ecology and Status

See Chapter 1, Section: Introduction, Sub-section: Focal Species, for an introduction to the life history and conservation status of the Lark Sparrow.

Midwest Sand Barrens

See Chapter 1, Section: Introduction, Sub-section: Midwest Sand Barrens, for an introduction to the composition of the Midwest sand barren plant community.

Sand Barren Management

Metroparks of the Toledo Area owns and manages several areas within the Oak Openings, including Oak Openings Preserve Metropark (OOPM), a 1,457 ha preserve. The Nature Conservancy owns Kitty Todd Nature Preserve (KTNP), a 283 ha preserve in the Oak Openings region. Both OOPM and KTNP have Lark Sparrow breeding sites and somewhat degraded sand barren sites.

Managers at KTNP and OOPM started restoring sand barren habitat in the 1990s by reintroducing disturbance to the system. The Oak Openings' population of Lark Sparrows

increased from 3 to 17 breeding pairs over six years (1994-1999) due in part to sparrows colonizing the newly restored barrens. The new sites were readily inhabited, usually within the first year (Grigore 1999). This indicates that if more restorable patches of sand barren are managed appropriately, the Lark Sparrow population in the Oak Openings could increase further. After continued management of five sites, in 2006 sixty-five adult Lark Sparrows were banded in KTNP and OOPM (J. Ross, Bowling Green State University, unpublished data).

At KTNP and OOPM, some sand barrens, including the known Lark Sparrow breeding sites, are actively managed to keep the sites at an early-successional state and to limit encroachment of trees and shrubs. Management consists of prescribed fire, mowing, tree girdling, thinning, foliar spraying of non-native woody plants, and a combination of these (G. Haase, The Nature Conservancy, personal communication; J. Jaeger and T. Gallher, Metroparks of the Toledo Area, personal communications). My research involved evaluating the effectiveness of current management by determining if managed sites meet the breeding habitat requirements of Lark Sparrows.

My study addressed the questions: 1) Do current land management practices adequately restore and maintain the habitat components that are crucial for Lark Sparrow breeding and sand barren function?; 2) What are the most appropriate management practices for restoring early to mid-successional communities after woody invasion?

Methods

Study Sites

I selected twelve sites in Kitty Todd Nature Preserve (KTNP) and Oak Openings Preserve Metropark (OOPM). See Figure 1. Each study site was a distinct patch of Midwest sand

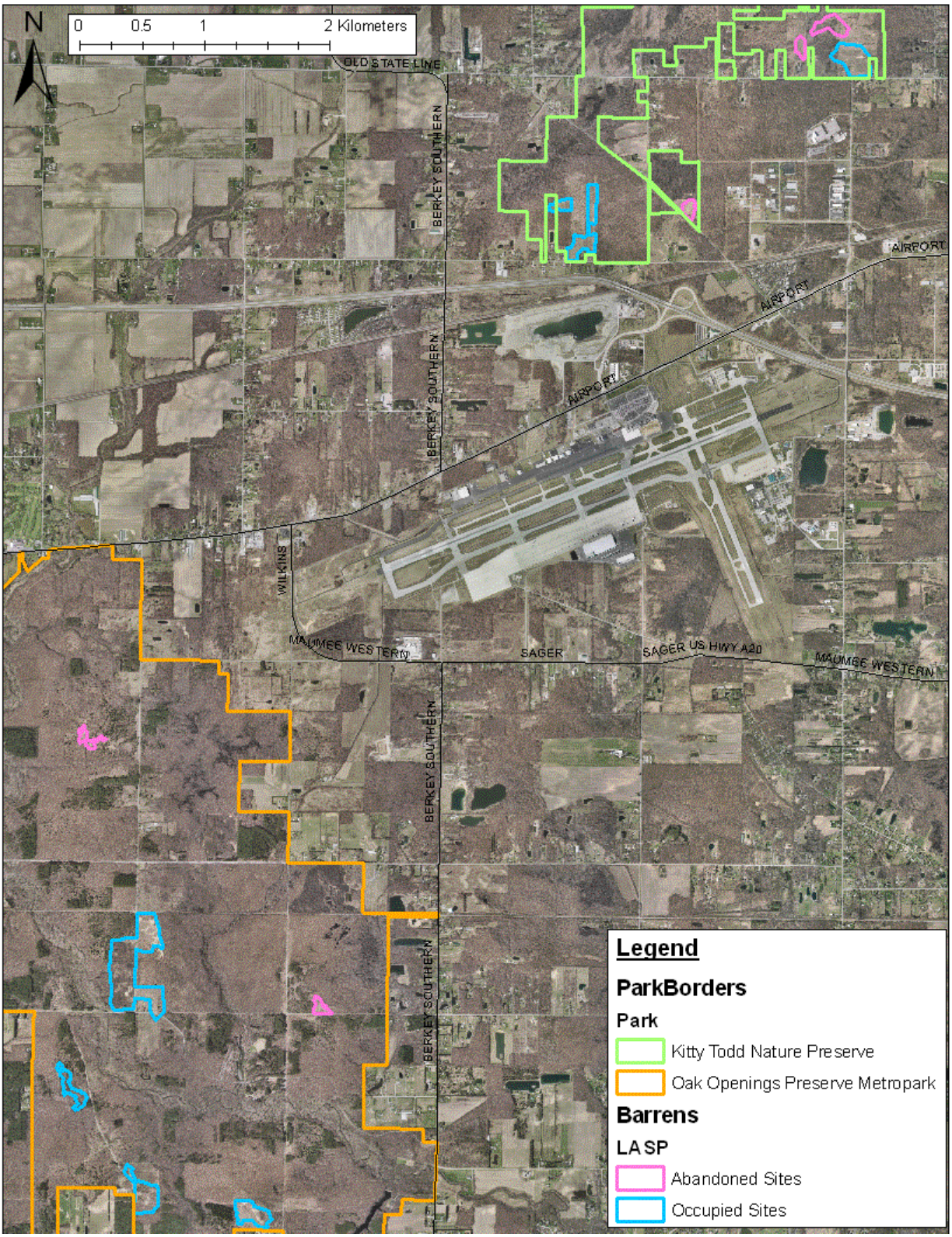

Figure 1: Map of spatial distribution of study sites on a 2004 aerial photograph (Lucas County Auditor 2007) of part of the Oak Openings Region. Park boundaries and study site boundaries are shown. Blue polygons represent Occupied Sites. Pink polygons represent Abandoned Sites.

barren habitat. In the Oak Openings, patches of sand barren ranged in size from 1ha to 20+ha and were surrounded by a hard edge of oak woodland. In some cases a sand barren patch was bordered on one side by a wetland rather than a woodland.

My twelve study sites included seven occupied Lark Sparrow breeding sites and five sites that Lark Sparrows used in the past but then abandoned. During the 2007 nesting season, there were three Occupied Sites in KTNP: South Piels, Moseley Barrens and Moseley Barrens North, and four Occupied Sites in OOPM: Greater Girdham Road, Badger Barrens, Jeffers Road Farm, and Ostrich Lane. At KTNP there were three Abandoned Sites: Kitty Todd Headquarters, Julia's Savanna and Garden Road (G. Haase, The Nature Conservancy, personal communication; T. Crail, University of Toledo, personal communication). At OOMP there were two Abandoned Sites: Tansel Lane and Wilkins Reed (Grigore 1999; T. Kemp, Anthony Wayne H.S. - retired, personal communication).

The five Abandoned Sites were last used by Lark Sparrows at different times. Kitty Todd Headquarters, Julia's Savanna and Garden Road were all used by Lark Sparrows in recent years (see Table 1). Tansel Lane and Wilkins Reed were last used by Lark Sparrows around 1975 (E. Tramer, University of Toledo, unpublished data). The three recently abandoned sites were managed in recent years (see Table 1). Tansel Lane and Wilkins Reed have either never been managed or not since the 1970s, with the exception that the pine plantation bordering one side of Wilkins Reed was removed just before the 2007 breeding season. Lack of management at Tansel Lane and Wilkins Reed has allowed succession to progress to a savanna/woodland stage at these two sites (Figure 2). Kitty Todd Headquarters, Julia's Savanna and Garden Road, on the other hand, are in a mid-successional state with many shrubs and sparse trees.

Table 1: Use and management histories of Abandoned Sites. The two sites in bold font, Tansel Lane and Wilkins Reed, were abandoned by Lark Sparrows much longer ago than the other Abandoned Sites. These older Abandoned Sites have never been managed to restore or maintain sand barren plant communities.

Abandoned Sites	**Last Use by LASP**	**Last Land Management**
Kitty Todd HQ (KT)	~4 years ago	~2 years ago
Julia's Savanna (JS)	~4 years ago	1 year ago
Garden Road (GA)	1 year ago	2 years ago
Tansel Lane (TL)	**~30 years ago**	**Probably never**
Wilkins Reed (WR)	**~30 years ago**	**Probably never**

Figure 2: Photograph of a late-successional Abandoned Site, Wilkins Reed. Note many trees, a sparse, short understory, and bare sand. This site has had no known Lark Sparrow nests since the 1970s and appears to have succeeded from a sand barren community to an oak savanna community. *Photo by Melanie Coulter.*

Comparing Land Management Histories

I compared the land management history of Occupied and Abandoned Sites to determine whether different types and frequencies of management are good predictors of the presence or absence of breeding Lark Sparrows.

I interviewed land managers from Kitty Todd Nature Preserve and Oak Openings Preserve Metropark for records of the management regime on Occupied and Abandoned Lark Sparrow Sites. I compared management regimes to determine which types (i.e. mowing or burning) and frequencies (i.e. number of management events in the past 6 years) are correlated with successful Lark Sparrow breeding sites. A management event is a discrete occurrence of a land management activity, such as the mowing of a field on a particular date. In this study, management events were one of the following: mowing, burning, physical removal of woody plants (thinning), and chemical treatment of woody plants.

Analysis

To analyze the land management data, I divided management events into three time sets: 2002-2004, 2005-2007, and 2002-2007. This gave me the number of management events in each site during the past six years, during the past three years, and during the first three years of the past six years. This allowed me to consider the importance of frequency and timing of management events. I tested the management event data, and it was normally distributed. I used T-tests to look for differences between Occupied and Abandoned Sites

Results

I obtained reliable data on the management history since 2002 of four Abandoned Sites and six Occupied Sites (Table 2). I could not get an accurate management history for one Recently Abandoned and one Occupied Site because the small sites are managed as part of a larger management zone, and the specific management done to these small sections could not be isolated. However, anecdotally, the Occupied Site is mowed more frequently than the Recently Abandoned Site (G. Haase, The Nature Conservancy, personal communication).

Table 2: Frequency of management events for past six years at Abandoned and Occupied Lark Sparrow Sites. The first two columns of numbers show the number of management events in each site during 2002-2004 and 2005-2007, respectively. The last column shows the total number of management events during 2002-2007.

Site Status	Site Name	Number of Management Events (Mowing or Burning)		
		2002-2004	2005-2007	2002-2007
Abandoned Recently	Julia's Savanna	2	2	4
Abandoned Recently	Garden Rd	3	1	4
Abandoned Earlier	Tansel Lane	0	0	0
Abandoned Earlier	Wilkins Reed	0	0	0
Occupied	South Piels	5	3	8
Occupied	Girdham Road	3	4	7
Occupied	Moseley Barrens	1	3	4
Occupied	Badger Barrens	0	4	4
Occupied	Jeffers Rd Farm	1	3	4
Occupied	Ostrich Lane	1	3	4

The number of management events (e.g., mowing, burning, etc.) from 2002-2007 ranged from 0 to 4 (mean=2) in Abandoned Sites and from 4 to 8 (mean=5.2) in Occupied Sites. I looked more closely at the two Recently Abandoned Sites and four Occupied Sites that had 4 management events in the past 6 years. The Occupied Sites had 3 to 4 management events in the most recent three years, while the Abandoned Sites had 1 to 2 management events in the most recent three years. See Figure 3.

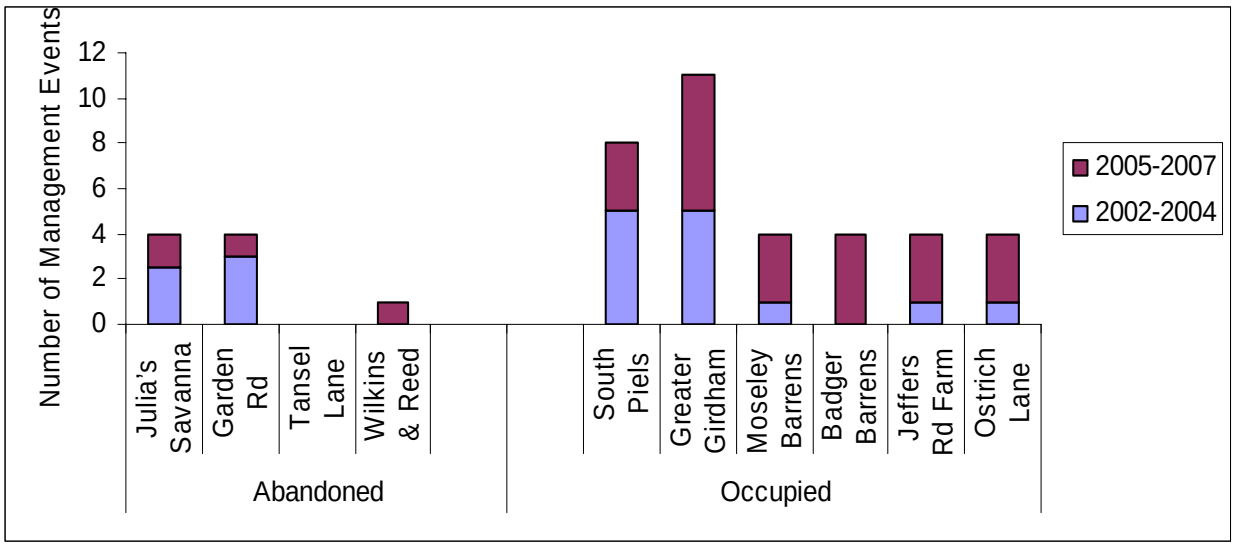

Figure 3: Management history of Abandoned and Occupied Sites. Total bar heights represent the number of management events at each site from 2002-2007. Blue segments represent management events from 2002-2004. Maroon segments represent management events from 2005-2007.

Of the 12 t-tests I ran, only All Management Events 2005-2007 and Mowing Events 2005-2007 were significantly different between Occupied and Abandoned Sites. See Table 3. The number of management events from 2002-2004 and from 2002-2007 were not significantly different. Nor were the number of mowing events from 2002-2004 and from 2002-2007. The

number of burn events and the number of other (not mowing or burning) management events were not significant in any of the three date ranges.

Table 3: Statistically significant differences between the management regimes of Occupied Sites and Abandoned Sites.

		Mean Number of Events	P-value from t-test
All Management Events 2005-2007	Occupied	3.67 (+/- 1.2)	0.003
	Abandoned	0.88 (+/- 0.63)	
Mowing Events 2005-2007	Occupied	2.83 (+/- 0.75)	0.002
	Abandoned	0.63 (+/- 0.75)	

Discussion

Soil type and elevation are important to the occurrence of Midwest sand barrens and, therefore, Lark Sparrows in the Oak Openings. My study of Lark Sparrow habitat requirements (Chapter 1) did not investigate these two landscape parameters because Ricci (2006) previously determined that the right soil type and elevation are crucial elements to produce the right vegetation composition and structure of a sand barren. I compared currently occupied sites (presence) to sites that have been occupied in the past (absence). Since my absence sites were presence sites once, they must have the basic building blocks (soil type, elevation, and climate) to be functioning Midwest sand barren. (Ricci 2006). Since the absence sites once had the correct habitat parameters for Lark Sparrow use, the soil type and elevation of the absence sites should be similar to the currently occupied sites.

To find potential Midwest sand barrens in the Oak Openings, one needs to consider the birds' landscape scale requirements: the right combination of soil type, elevation (Ricci 2006), habitat patch size, and habitat patch shape (Chapter 1). Then the habitat patch scale and territory scale must be considered. Within the potential sand barren defined by landscape characteristics, one must look at vegetation structure to determine if the site can function as a healthy sand barren and can be used by nesting Lark Sparrows. The important vegetation structure parameters are percent tree cover, percent shrub cover and vegetation height-density.

Management Implications

Though I measured multiple habitat parameters for this study (see Chapter 1), the easy-to-measure parameters listed in Table 4 were the most important predictors of Lark Sparrow presence. I used ArcGIS and FragStats to measure habitat patch size and perimeter to area ratio, but a manager could manually measure these on an aerial photograph with a known scale. A Robel pole is a cheap, fast, and easy way to measure vegetation height-density and see if a site is at an early-successional stage. Percent tree cover and shrub cover were the most time-consuming parameters to measure since I used the line-intercept method (see Chapter 1). A manager could try a less time-consuming method to assess number of trees and shrubs, such as counting the number of stems along transects or in a few randomly placed plots (see Bonham 1989). In small habitat patches, a manager might be able to visually estimate the shrub and tree cover. Finally, since I found that active Lark Sparrow territories are close to other occupied territories (see Chapter 1), a manager should restore the appropriate vegetation structure in an area large enough to fit at least two Lark Sparrow territories of ~0.8 ha.

Table 4: Characteristics of Lark Sparrow breeding sites in the Oak Openings Region. Significant habitat characteristics were determined by using Mann-Whitney tests to compare Occupied Sites to Abandoned Sites (see Chapter 1). All characteristics were significant with p-values of <0.05

Significant Habitat Characteristic	**Suitable Range for Breeding Lark Sparrows**
Habitat patch size	minimum 1.24 ha
Habitat patch perimeter to area ratio	50 to 139
Vegetation height-density	1 to 2 dm on a Robel pole
Percent aerial tree cover	0.6% to 15%
Percent aerial shrub cover	0% to 17%
Distance between two nearest occupied territories	0 m to 212 m

Occupied breeding sites, on average, had more than 3 management events in the most recent 3 years. This implies that Midwest sand barrens need to be managed annually or almost annually to maintain a functioning early-successional plant community that can support Lark Sparrows. The fact that multiple Abandoned and Occupied Sites had the same number of management events in the past 6 years but the Abandoned Sites had less management in the most recent 3 years, indicates that these sites change quickly with lack of management. This is exemplified by one section of the Greater Girdham site, Girdham Dunes. Girdham Dunes had 3 Lark Sparrow territories in 1998 (Grigore 1999) and in 2004 (J. Ross, Bowling Green State University, unpublished data). (I found no records of number of territories before 1998 or from 1999-2003.) In 2007 there was only 1 territory in Girdham Dunes, presumably due to a loss of suitable habitat caused by a reduction in management in recent years. There were two management events at Girdham Dunes from 2002-2004, but only one from 2005-2007.

Another indication that Midwest sand barrens respond quickly to management is the fact that Occupied Sites with only four management events in the past 6 years were managed more frequently in the past 3 years. Prior to the management in the past three years these sites had little to no Lark Sparrow breeding. In 2007 these sites supported several nesting pairs. For example, Badger Barrens had a few nesting pairs in the 1990s. Then management tapered off, and so did use by Lark Sparrows. From 1999 to 2004 there was no land management at Badger Barrens. In 2005 there were no Lark Sparrows breeding there. In 2005 land managers started mowing once or twice a year. In 2007, three pairs of Lark Sparrows nested at Badger Barrens. This illustrates that sand barren vegetation and Lark Sparrows are quick to respond to management or disturbance.

Other studies have found that Lark Sparrows are affected by rapidly changing plant communities after a disturbance. Immediately after a fire in 1996, Lark Sparrow densities increased on sites where invasive smooth brome (*Bromus tectorum*) had increased fire intensity (Martin et al 1999). The fire significantly increased bare soil exposure and reduced herbaceous vegetation density, shrub coverage, shrub density and shrub height. Three years after the 1996 fire, Lark Sparrows abandoned nesting efforts except in areas that were burned again in 1998 (Martin et al 1999). In Texas, some types of prescribed burns increased numbers of nesting Lark Sparrows, especially burns that led to the dominance of clump grass and burns that did not remove all woody species (Renwald 1977). Yet another study revealed that Lark Sparrows only responded positively to burned sites for 3 years after a burn (Bock and Bock 1987). My results also support the conclusion that three years without disturbance (mowing or fire) is enough to cause Lark Sparrows to abandon nesting at a particular site.

However, disturbances or management events can be too intense for nesting Lark Sparrows. In a Montana study, nesting Lark Sparrow numbers declined only slightly in burned areas that had partial sagebrush removal, but Lark Sparrows completely abandoned sites with 100% sagebrush removal (Bock and Bock 1987). Complete removal of woody species negatively impacts Lark Sparrow nesting and nest success. Though my study of Lark Sparrow habitat requirements found that too many shrubs limited Lark Sparrow occurrence (see Chapter 1), studies in habitats with less shrubs found that too few shrubs was limiting (Lusk et al 2003). It appears a balance must be struck in managing for ground nesting birds that use perches for territorial singing displays. The management goal for shrub cover should depend on the structure of the surrounding landscape, not just the composition of the breeding sites. My Lark Sparrow habitat study suggests that managing for 9% to 17% shrub cover is appropriate for sand barrens in the Oak Openings which are surrounded by a landscape that is a continual source of shrubs.

Because many sites were managed with more than one technique and no sites were exclusive burn sites, I was not able to evaluate which type of management produces the best results for Lark Sparrows. The sites with the highest density of Lark Sparrow nests were managed with a mix of mowing and burning, with much more frequent mowing. Mowing is more likely to reduce the height-density of plants throughout a site. For example, Greater Girdham, the most active breeding site, had 2 burns and 6 mows from 2002-2007. See Figure 4.

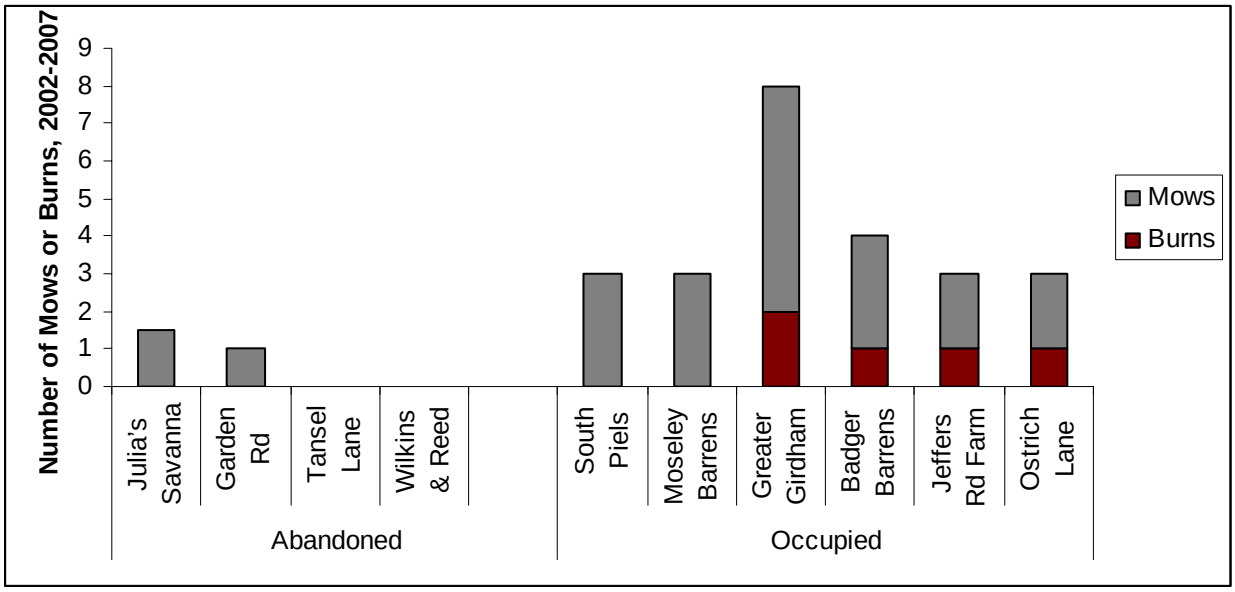

Figure 4: Mowing vs. burning in Midwest sand barrens. Mowing was used more frequently than burning for removing vegetation and re-setting sand barrens to an early successional state.

Conclusion

Habitat change happens quickly in Midwest sand barrens and, potentially, in other early successional habitats. In the absence of natural fire and floods, frequent management is necessary to maintain sites as early-successional Midwest sand barren plant communities and support early-successional specialists like Lark Sparrows.

The Oak Openings Region is a mosaic of many plant communities in different stages of succession. Before intense human occupation, this ecosystem was a shifting mosaic. A site that started out as a sand barren might naturally succeed into an oak savanna which might naturally succeed into an oak woodland. An oak savanna might burn after a lightning strike, and become a sand barren again. As climate oscillated between wet and dry periods and natural events proceeded without interference, sites in the Oak Openings naturally shifted back and forth among the different successional plant communities. Now, however, with fire suppression, alteration of hydrology, and widespread development, the mosaic no longer shifts naturally. Mostly, sites that

are left alone succeed to oak woodland. If managers want to preserve examples of other plant communities, namely Midwest sand barrens and oak savannas, they must maintain some sites in stable early- or mid-successional states. Because of the complex pattern of land use and land ownership, this requires managing the region as a static mosaic.

Restoring and managing sand barrens to a standard that supports successful, self-sustaining Lark Sparrow populations will benefit more than just ground-nesting birds. Midwest sand barren is a unique ecosystem that supports a suite of other species, including the rare plants purple three-awned grass (*Aristida purpurescens*), Canada St. Johns wort *(Hypericum canadense),* dwarf dandelion (*Krigia virginica*), hairy pinweed (*Lechea villosa)* plains puccoon (*Lithospermum carolinense*), eastern prickly pear cactus (*Opuntia humifusa*) and sand cherry (*Prunus pumila var. cuneata)* (The Nature Conservancy 2007). Rare fauna that live in Midwest sand barrens include antenna-waving wasp (*Tachysphex pechumani)* and blue racer (*Coluber constrictor*) (Green Ribbon Initiative 2004b). By using the Lark Sparrow as an indicator of healthy sand barrens, we can conserve this plant community for all the species that depend on it.

The Oak Openings is a unique ecosystem and one of the few places Lark Sparrows still nest in Ohio (Peterjohn and Rice 1991). Protecting the Midwest sand barren habitat in the Oak Openings is of critical importance to Lark Sparrow viability in Ohio as a whole. My single breeding season study of habitat use by breeding Lark Sparrows has indicated a potential rapid assessment approach to determining the quality and function of early-successional vegetation communities. Locally, managers can use this knowledge to improve habitat in this critical region and bolster this crucial Lark Sparrow population. Elsewhere, others can use this technique to evaluate the states of early-successional habitats or determine the important habitat parameters for ground-nesting birds in their area.

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