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Effects of Vegetation Structure and Composition on Grassland Bird Habitat Occupancy

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Effects of Vegetation Structure and Composition on Grassland Bird Habitat Occupancy

A Major Qualifying Project submitted to the Faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree in Bachelor of Science in Biology and Biotechnology

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October 11, 2016

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Professor Marja Bakermans, BBT

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Executive Summary

Grassland habitat decline has become a substantial problem for grassland birds in the Northeast (Vickery et al. 1995, Sauer et al. 2014). Grassland habitat requires significant disturbances to prevent succession, usually in the form of grazing and fire (Best and Rodenhouse 1984, Vickery et al. 1995). Decreasing occurrences of these disturbances leads to succession and the development of forest, decreasing available grassland bird habitat (Vickery et al. 1995, Motzkin and Foster 2002). Grassland habitat is highly variable across the eastern United States, requiring evaluations of wildlife, land use, and soil nutrient availability to determine proper management tactics (Cody 1985, Vickery et al. 1995). Grassland management typically involves the introduction of fertilizers, periodic burning, and delayed tillage (Moog et al. 2002, Phillips et al. 2004, Conant et al. 2016). Management practices that are not species and area specific can sometimes lead to a decrease in overall site wildlife diversity, creating a need for area-specific and species-specific management plans (Grace 1999). In order to accomplish this and develop site management goals, wildlife habitat preferences must be examined (Vickery et al. 1995).

This study analyzed the habitat preferences of grassland birds in Worcester County. Grassland birds are typically small, nest exclusively on the ground, and require large open habitat with limited woody vegetation (Cornell University 2015, National Audubon Society 2016). Grassland bird decline has led to several species being declared threatened on national and state levels (Mass Audubon 2016, National Audubon Society 2016). Grassland bird habitat selection is primarily dependent on competition and vegetation structure (Cody 1981, Cody 1985). Habitat preferences develop in response to the evolutionary advantages and disadvantages of each decision made during the process of habitat selection, with natural selection favoring preferences that cater to the behavioral needs of each bird species (Cody 1968, Wiens 1969, Krausman 1999). Each grassland bird species in this study has been studied in the past to determine vegetation preferences, but each study typically focused on only a single species at a time and only considered one vegetation measurement at a time (Fisher and Davis 2012, Vickery et al. 1992). The goal of this project was to
identify key vegetation characteristics that can be used to determine appropriate grassland management tactics. To accomplish this, we analyzed relationships between vegetation characteristics and grassland bird densities site-wide, as well as compared vegetation characteristics within sites to bird territory occupancy.

We completed grassland surveys from 23 May – 9 July 2016 at 6 sites within Worcester County. We surveyed each site 4-5 times during peak breeding season to create spot maps for adult male birds, which were combined to determine territories and site densities. Behavioral observations were conducted to observe individual male Bobolinks for 15min intervals for vegetation used, number of calls, and time perching and flying. We also surveyed site vegetation in sample plots randomly selected within 1ha subplots. In each plot, we took measurements of vegetation thickness, effective height, density, maximum height, and percent cover for each plant species present.

We chose vegetation measurements to include in correlation analysis based on measurements showing significance in past studies, measurements that characterized a large portion of our sites, and measurements that were associated in vegetation we saw being utilized during behavioral observations (Fisher and Davis 2010). We identified and eliminated highly correlated vegetation measurements to reduce redundancy in analyses (Spearman’s Rank). Correlation between site-averaged vegetation measurement and bird densities was analyzed to reveal possible characteristics of high quality sites (CCA). We also evaluated the statistical significance of these correlations (Permutation). Finally, we determined significant differences between vegetation averages in areas within occupied territories and their unoccupied surroundings (MANOVA).

Results of bird surveys showed that Bobolinks were the most widely distributed (present at 5 out of 6 sites), as well as the most abundant (highest density was 3 males/ ha) species. Each of the other species surveyed in this study were much less commonly found (present at 1 out of 6 sites). Behavioral observations revealed that Bobolinks spent the most time perching on hay and grass, but
utilized a variety of different perches. CCA axis scores showing the same sign revealed positive and negative relationships between bird species and vegetation measurements, but was determined to be statistically insignificant (p= 0.518). Scores resulted in two main groups of values forming in relation to the axis which accounted for the majority of variation in the data. MANOVA results of groups containing samples that were within occupied territories and samples that were not indicated statistically insignificant relationships when considering only sites that each species occupied (all p >0.05), but statistically significant relationships in analyzing vegetation across all sites (all p <0.05).

Results of CCA combined with parameters eliminated from analysis with bird densities using Spearman’s ranks revealed two main groups of correlated preferences. Vegetation thickness, effective height, hay density and height, forb density and height, grass density, height and cover, and abundance of vetch and bedstraw showed positive relationships with Bobolinks and Savannah Sparrow density but negative relationships with Grasshopper Sparrow and Vesper Sparrow density. Conversely, litter depth, bare ground cover, and woody vegetation density showed positive relationships with Grasshopper and Vesper Sparrow density but negative relationships with Bobolink and Savannah Sparrow density. The strongest correlations were seen with measurements reflecting differences in overall vegetation structure (woody density, effective height, and bedstraw cover), which reflects vegetation structure’s effect on food availability, foraging space, and cover from predators (Wiens 1969, Cody 1985). The formation of two groups of bird species and vegetation preferences represent a shift in historically documented habitat preferences, possibly due to competition (Cody 1985). Differences between this study results and those obtained in previous research support the continuing of local studies in order to determine area-specific best management practices (Winter et al. 2005). Despite statistical insignificance in CCA, results may be biologically significant based on the number of parameters included in analysis compared to the number of sites (Palmer 2003).
Difference in MANOVA based on the inclusion of unoccupied sites reflects the manner in which birds select territories by first settling into sites, then selecting territories (Hoover 2003). Insignificant vegetation differences indicated by MANOVA at occupied sites implies that more suitable habitat may exist at these sites that could support higher densities (Vickery et al. 1995). Because of this, we recommend management practices tailor desired outcomes to fit within the ranges of means at occupied study sites, with particular attention paid to measurements reflecting vegetation structure. Future studies should consider expanding the number of study sites and take into account site size and surroundings (Cody 1985). We also recommend considering nest success as a measure of bird populations to ensure available habitat allows for population sustainability (Vickery et al. 1992).
Chapter 1
Grassland Habitat of New England

This project focused on four bird species that feed, breed, and nest in grasslands. An important step in conserving these obligate grassland species is making sure habitat suitable for their survival exists, requiring an understanding of their relationship with the area they choose to inhabit. To gain insight into this habitat type, we researched grasslands’ composition, their changes in New England over time, and ways that these changes are managed.

Composition and Development

While grasslands are present all over the world, their composition and structure vary greatly depending on geographical areas, climates, and maintenance practices (Vickery et al. 1995). Grassland components include grasses, forbs, shrubs, and trees, with grasses being the densest and shrubs and trees the rarest (Wiens 1969, Motzkin and Foster 2002). Periodic disturbances are necessary for grassland maintenance and can include fires, grazing, and erosion (Best and Rodenhouse 1984, Vickery et al. 1995). In the absence of these, grasslands follow a process of succession where trees and shrubs grow in abundance, eventually developing into forests (Vickery et al. 1995, Motzkin and Foster 2002). This change, along with changes in water availability and litter accumulation that accompany it, significantly affects the habitat’s suitability for wildlife (Wiens 1969, Moog et al. 2002).

Grasslands existing in the United States include western shortgrass prairies, midwestern tallgrass prairies, and eastern grasslands (Vickery et al. 1995). Western shortgrass prairies have short grasses, little rainfall, and poor, shallow soils, which historically required frequent grazing to be maintained (Cody 1985, Vickery et al. 1995). Midwestern tallgrass prairies have taller grasses, relatively more rainfall, and deeper soils, resulting in most of this land’s conversion into farmland (Cody 1985, Vickery et al. 1995). Eastern grasslands, which are the focus of this project, are highly variable compared to the other two types, as they encompass a range of different climates (Vickery
et al. 1995). New England grasslands specifically exist as a result of farming during the 17th century, and are historically dry with relatively nutrient-poor soil (Vickery et al. 1995, Foster et al. 2002). Farming generally increases grassland soil’s nutrient availability, meaning that more recently farmed grasslands tend to be richer in carbon, nitrogen, and other organic elements important for plant primary production (Conant et al. 2016). Currently, officials classify existing grasslands in New England based on their uses and composition, including planted cover, pastureland, and hayland, which influences chosen management tactics (Moog et al. 2002, Phillips et al. 2004). Dominant plant species vary greatly between grasslands, and many of the underlying factors explaining plant species distribution remain unknown (Eriksson and Jakobsson 1998).

Decline and Management of Grasslands

Grasslands are one of the most threatened ecosystems in the United States, as land use has changed greatly in recent history (Vickery et al. 1995). Humans have affected the amount of grasslands available in the Northeast significantly by preventing natural disturbances like fire, grazing, and erosion, which allow low density grasslands to exist (Best and Rodenhouse 1984, Foster et al. 2002). Urban development and fire suppression resulting in overgrowth of woody vegetation have led to habitat fragmentation, which is also a major problem for grassland wildlife (Vickery et al. 1995, Fletcher and Koford 2003). Grasslands also have not been immune to the effects of global warming. Increases in minimum springtime temperatures have decreased primary production of grasses and left fields more vulnerable to invasive species (Alward et al. 1999). Additionally, changes in rainfall resulting from climate change can have harmful effects on grassland plant growth, degrading what habitat is still available by negatively impacting primary productivity (Alward et al. 1999, Wever et al. 2002).

In addition to habitat loss, invasive species are a substantial threat to current grassland structure. Currently, over 10 invasive grass species and 35 invasive forbs species threaten New England grasslands, most of which have been introduced through horticulture (Center for Invasive Species and Ecosystem Health 2016, Mass Audubon 2016). While invasive species are not the drivers
of habitat change, in recent history they have become able to thrive in new areas due to other environmental changes (MacDougall and Turkington 2005). These changes allow invasive species to outcompete native species, resulting in several cases of native species endangerment (MacDougall and Turkington 2005, Reichard and White 2001). The introduction of invasive species can cause significant change in wildlife habitat and adversely affect local plant species population levels (MacDougall and Turkington 2005, Reichard and White 2001).

These changes in grassland abundance and composition have had harmful effects on a number of plant and animal species, and in response, management practices have been put into place that preserve grasslands for a variety of purposes (Vickery et al. 1995, Foster et al. 2002). Current grassland management practices place a large focus on fields cultivated for agricultural use, and include optimizing harvest times and reducing nutrient emissions (Hassink 1994, Hopkins and Wilkins 2006). Retention of soil carbon has been a major goal of grassland management because of its link to increased plant biomass and primary production (Grace 1999, Conant et al. 2001). Land management organizations accomplish this using a variety of methods, including the addition of fertilizers, irrigation, and the introduction of certain grasses and earthworms (Conant et al. 2001). While this increase in plant biomass and primary production is beneficial for some species, it is not always the case, and has thus resulted in some cases of limited grasslands species diversity (Grace 1999). Because of this, implemented management practices should be specific to the species within the site (Vickery et al. 1995).

For areas not farmed, management recommendations typically include prescribed fires that provide the disturbances grasslands need to be maintained (Vickery et al. 1995, Winter et al. 2005). It is recommended that these fires take place every few years, as vegetation varies between years of burning to the point where habitat can become unsuitable for certain wildlife (Moog et al. 2002, Winter et al. 2005). Additionally, fields in the same local area should stagger burning years to provide wildlife with habitat in different years of succession (Vickery et al. 1995). Alternative management methods to periodic burning include grazing, mowing, and mulching twice a year,
which could be appropriate depending on the grassland’s use and surroundings (Moog et al. 2002). While grassland management tactics have led to improvements in habitat suitability for wildlife, resistance from farming communities and increasing understanding of grassland ecosystems require this to be a continuously evolving science (Vickery et al. 1995, Moog et al. 2002).

**Grassland Bird Habitat Selection**

The term “grassland birds” refers to bird species that nest exclusively on the ground and require large open fields for survival (Cornell University 2015, National Audubon Society 2016). In response to declining habitat, these birds have experienced sustained population decline (Vickery et al. 1995, Sauer et al. 2014). To explore the relationship between declining grasslands and the bird species that inhabit them, we researched habitat selection and the specific habitat preferences of each bird species surveyed in this study.

**Habitat Selection**

Habitat selection is the process by which animals go about selecting the area they will utilize for survival (Krausman 1999). This process is the result of both innate and learned behaviors, and leads to general habitat preferences within species (Krausman 1999). Resource availability, which is highly dependent on several environmental factors, controls the suitability of habitat for different species and individuals based on their adaptations (Cody 1968, Wiens 1969).

Interspecific and intraspecific competition play significant roles in determining suitable habitat for individuals. Competing individuals take resources away from one another, with poorly competing birds losing access to resources necessary for the habitat to be suitable (Wiens 1969, Cody 1985). Researchers have extensively studied this relationship for competing bird species and created graphical models to predict habitat selection outcomes (Rosenweig 1981). This competition limits habitat availability, but results in occupancy of a greater variety of habitats (Cody 1985). Intraspecific competition has a similar effect on resource availability, resulting in varying habitat suitability for individuals based on site population density (Rosenweig 1981, Cody 1985). For
example, in areas of low bird population density, birds can occupy lower quality habitat because the
decrease in competition allows for the occupation of larger territories (Cody 1985). Habitat selection also relates to a number of individual behavioral processes. These include search costs for new habitat and territory shifting within a season based on nest success (Wiens 1969, Rosenweig 1981). Habitat selection also plays a role in mating, as females select males based both on the male himself and his territory (Cody 1985). Resulting from this, males who occupy the highest quality habitat are more likely to be polygamous (Martin 1974, Cody 1985).

A major component of habitat selection, and the focus of this project, are the effects of vegetation structure and composition. Vegetation parameters related to structure, such as height and density, play a critical role in habitat selection by grassland birds specifically because of their relatively small size (Cody 1981, Cody 1985, Fisher and Davis 2010). Vegetation structure is likely to be a more influential factor than composition because of its effects on productivity and food availability, as well as the likelihood that birds are generally unable to distinguish individual plant species (Cody 1968, Cody 1981). However, invasive species may be of particular interest because of the significant impact they have on the composition of habitats and ecosystems as a whole (Reichard and White 2001). The variability of habitat between years makes selection particularly interesting in grassland birds, and usually results in the failure of migratory grassland birds to return to the same site every year (Wiens 1969, Cody 1985). Habitat selection also tends to differ depending on the type of grassland, with tall grassland birds tending to be more selective because feeding is more difficult (Cody 1985). Comparatively, short grassland birds have more suitable habitat available, resulting in increased competition and smaller territories (Cody 1985).

A review of 57 studies of 31 grassland bird species by Fisher and Davis (2010) determined that the most common predictors of habitat use were bare ground exposure, vegetation height, and litter depth (Fisher and Davis 2010). They found these to be significant in 36-50% of studies, and many studies also indicated significance in percent cover and density of grass, forbs, and shrubs
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(Fisher and Davis 2010). Because these factors vary among species, we looked more closely at the individual bird species studied here and the factors influencing their habitat use.

Key Species

This project studied the habitat selection and behavior of four grassland bird species: Grasshopper Sparrows (*Ammodramus savannarum*), Vesper Sparrows (*Pooecetes gramineus*), Savannah Sparrows (*Passerculus sandwichensis*), and Bobolinks (*Dolichonyx oryziorus*). We looked at their specific behaviors and habitat preferences to help understand each species’ process of habitat selection.

**Grasshopper Sparrows**

Grasshopper Sparrows are a relatively small member of the New World Sparrows family that breed in grasslands, hayfields, and prairies with frequent patches of exposed ground (Cornell University 2015, National Audubon Society 2016). Grasshopper Sparrows nest on the ground in dense weeds, shrubs, or patches of grass and stay mostly hidden, except to sing and defend territories on low perches (National Audubon Society 2016). While their Midwest and Northeast habitat remains relatively intact, their Florida habitat is shrinking, resulting in the endangerment of the Florida race of Grasshopper Sparrows and the National Audubon Society declaring this bird a priority for conservation (National Audubon Society 2016). Although not as high of a concern as the Florida populations, Grasshopper Sparrows in the Northeast have seen population decline as well, and have been declared threatened in the state of Massachusetts (Sauer et al. 2014, Mass Audubon 2016). Breeding Bird Survey data shows the population decline of Grasshopper Sparrows in the New England/ Mid-Atlantic Coast region (Figure 1). The population index in Figure 1 is a measure of the raw population number relative to its starting value (Sauer et al. 2014). Here, the decline indicates a population decrease of 3.8% annually in the New England/ Mid-Atlantic Coast region from 1966 to 2013 (Sauer et al. 2014).
Analyses of Grasshopper Sparrow habitat preferences have shown significant relationships with some vegetation characteristics. (Whitmore 1981). For example, Grasshopper Sparrows have been shown to favor bunch-type grasses over sod-type grasses (Whitmore 1981). Additionally, researchers have associated decreases in Grasshopper Sparrow densities with increases in vegetation density and have characterized commonly utilized habitat by relatively short grass and abundant forbs for perching (Wiens 1969, Whitmore 1981). Analysis of Grasshopper Sparrow territory has shown that territories in the center of clusters, typically occupied first and thought to contain the highest quality habitat, have greater forb height and density than those adjacent to them (Wiens 1973, Vickery et al. 1992). Among these preferences, the characteristics of central territories are of particular interest, since site population density is not an accurate indicator of overall breeding success for this species (Vickery et al. 1992). This suggests that areas occupied first include optimal habitat and birds arriving to sites later occupy the area around it, which may not be as high quality (Wiens 1973, Vickery et al. 1992). It has been recommended that the specific type of grasslands which Grasshopper Sparrows occupy are maintained through burning about every 5 years.

Figure 1: Breeding Bird Survey Data from 1966-2013 for Grasshopper Sparrow Population Index in New England/ Mid-Atlantic Coast region (Sauer et al. 2014)
to prevent the over-growth of woody vegetation, with local fields rotated in their burning to provide habitat in different stages of succession (Vickery et al. 1995).

**Vesper Sparrows**

Vesper Sparrows are also members of the New World Sparrow family, which observers often find singing at night (Cornell University 2015, National Audubon Society 2016). Vesper Sparrows behave similarly to Grasshopper Sparrows, nesting at the base of grass, weeds, and shrubs and singing from high perches to defend territories (National Audubon Society 2016). Vesper Sparrow habitat is also highly threatened, leading to a significant population decline and threatened status in the state of Massachusetts (Sauer et al. 2014, Mass Audubon 2016). Specifically, the population in the New England/ Mid-Atlantic Coast region declined 4.1% annually from 1966 to 2013 (Sauer et al. 2014).

Vesper Sparrows range throughout the Midwest and West, and, although rarely, are seen in the Northeast (Audubon 2016). These birds are found in meadows, fields, prairies, and on roadsides, often in typically dry areas with exposed soil (Cornell University 2015, National Audubon Society 2016). Suitable habitat can be found in hay, corn, and soybean fields despite crop harvesting causing disruptions in the habitat which have led to decreased breeding success (Rodenhouse and Best 1983). Because of this, researchers recommend that harvesting not take place during peak breeding season for Vesper Sparrows and other grassland birds, and that incentives be created for farmers to encourage delayed tilling (Rodenhouse and Best 1983, Vickery et al. 1995). Characterization of Vesper Sparrow habitat has shown that lower vegetation density and lower grass and forb cover are positively correlated with higher population density and territory occupancy (Wiens 1969, Best and Rodenhouse 1984). While open ground is necessary, it can also lead to increased exposure to predators, resulting in occupied territories having a relatively small amount of bare ground cover and increased litter depth (National Audubon Society 2016, Thomas Wray and Whitmore 1979). Additionally, areas with more potential perches, such as shrubs, crop residues, and fence posts, tend to be occupied more often (Best and Rodenhouse 1984).
**Savannah Sparrows**

Savannah Sparrows are the most widespread of the New World Sparrows in this project, encompassing the widest range and residing in the most diverse habitat types (National Audubon Society 2016). They nest in low vegetation among grass and weeds and feed on a wide variety of seeds and insects, allowing them to inhabit fields, meadows, marshes, prairies, dunes, and shores (Cornell University 2015, National Audubon Society 2016). Despite their versatility, Savannah Sparrows, like the other birds in this study, have seen population decline in the Northeast (Sauer et al. 2014). The Breeding Bird Survey reports an annual 2.8% population decline from the years 1966 to 2013 in the New England/ Mid-Atlantic Coast region (Sauer et al. 2014).

Savannah Sparrows also show preferences for many habitat and vegetation characteristics. Savannah Sparrows tend to form adjacent territories, with the first territories being set up in the most suitable habitat and subsequent territories established around them (Welsh 1975, Wiens 1973). Savannah Sparrows have the highest reproductive success at sites with relatively low population density, which can be problematic because it means population density is not an accurate predictor of reproductive success, like was seen with Grasshopper Sparrows (Vickery et al. 1992). Centrally located territories and areas occupied most often tend to have medium to high litter depth and high grass coverage, which could be associated with the variety of grass types necessary for Savannah Sparrow nesting (Welsh 1975, Weins 1973, Winter et al. 2005). Additionally, Savannah Sparrows tend to occupy areas with low forb height and density first and more often, signifying that this may be an indicator of highly preferential habitat (Wiens 1969, Wiens 1973). Studies have shown that greater vegetation height has been associated with reproductive success, and that low predation and a lack of human disturbance play a critical role as well (Welsh 1975, Winter et al. 2005).

**Bobolinks**

Bobolinks are the only type of bird in this study that are members of the Blackbird and Oriole family (National Audubon Society 2016). A tall grassland bird, Bobolinks were historically
found in dense meadows and prairies with some low bushes, but loss of this kind of habitat has led to hayfields being their most common type of habitat (Cornell University 2015, National Audubon Society 2016). This habitat loss, thought to be caused in part by climate change, has also lead to continuous declines in population (Sauer et al. 2014 National Audubon Society 2016). An average 2.7% annual population decline was reported from 1966 to 2013 in the New England/ Mid-Atlantic Coast region, which, in addition to its decline in other areas, led to Bobolinks being declared a priority bird by the National Audubon Society (Sauer et al. 2014, National Audubon Society 2016).

Conservation recommendations for Bobolink habitat include delaying tilling of fields in order to allow eggs to hatch and young to fledge (Vickery et al. 1995, Herkert 1997). However, limited field availability has negatively impacted the population more significantly than tilling practices (Herkert 1997). Habitat fragmentation is also a particular concern for Bobolinks, as they tend to avoid nesting at the edges of sites (Fletcher and Koford 2003, Bollinger and Gavin 2004).

Bobolink nest success has shown positive correlation with polygamy. Polygamous males only assist primary females in feeding young, resulting in more nest failure in secondary nests due to starvation (Martin 1974). Polygamous males tend to arrive earlier in the season, and their habitat has relatively higher percent forb cover and greater vegetation height, signifying that these may be indicators of higher habitat quality (Wiens 1973, Wittenberger 1980, Winter et al. 2005). Additionally, increased habitat occupancy was associated with the same factors, along with low litter depth, high grass and litter cover, and high vegetation density (Wiens 1969, Cody 1981).

Research showed that multiple measures of grassland birds featured in this study, including their density, nest success, and territory occupancy, have significant relationships with characteristics of the vegetation within their utilized habitat. This study compared population density and territory occupancy of these birds to aspects of vegetation in their habitat to look for significance in their habitat preference in the New England area.
Grassland Bird Survey Methods

A variety of different field methods exist to survey our chosen sites for their bird populations. This section examines these options and assesses their benefits and limitations to determine the optimal methodology for this study. Additionally, this section describes the methodology used to record behavioral observations, which were completed to obtain a deeper understanding of why vegetation that is most often utilized by grassland birds may be important.

Site navigation

Different choices of sampling locations provide different levels of exposure to the species located within surveyed sites. Roadside counts are a simple method for obtaining basic information about the birds utilizing a site (Hanowski and Niemi 1995). By standing on the side of the road and listening and looking, researchers can determine some or all of the species present at that site, obtaining general information about the sites’ species richness or determining the presence of a specific species (Hanowski and Niemi 1995, Keller and Fuller 1995). While roadside surveying requires little time and no special permits, it does limit the amount of data researchers can obtain, and can lead to some inaccuracies (Emlen 1971, Hanowski and Niemi 1995, Keller and Fuller 1995). These inaccuracies are likely to occur for species easily concealed by vegetation because they are small or inactive, or for species with a disproportionate amount of birds that live in the shrubs and trees along roads but not within the site of interest (Emlen 1971, Hanowski and Niemi 1995, Keller and Fuller 1995). Most birds, including grassland birds, can be detected within 100m of the count site, and some larger species can be detected up to 400m away (Nat 1980, Savard and Hooper 1995). While roadside counts are effective for some, such as researchers interested in the presence of migratory species, it is not appropriate for determining exact locations of birds within sites (Hanowski and Niemi 1995).

Researchers can obtain more information by actually entering the site, using either already existing or custom paths. Natural and manmade paths already existing in sites increase its exposure, leading to a more accurate reflection of the species utilizing that habitat (Hanowski and Niemi 1995).
This is useful for studies that begin to associate habitat characteristics with measures of bird populations (Hinsley et al. 1995, Keller and Fuller 1995). However, walking pre-existing paths does not always offer enough access to far distances within sites, making it unsuitable for determining the precise location and number of birds within sites (Hinsley et al. 1995).

Methods that involve creating custom paths through sites include walking transects and gridlines. Transects are straight lines drawn throughout the site, spaced evenly apart at a distance adjusted to the detectability of the bird species present (Bibby 2000). Transects should be distanced so that most birds are detectable but unlikely to be double counted, typically 200-500m apart (Emlen 1971, Bibby 2000, Wheater et al. 2011). As researchers walk these paths, they record all bird detections along with the bird’s approximate distance away from the path and the point along the transect where the bird is detected (Rodenhouse and Best 1983, Wheater et al. 2011). This takes more time than walking pre-existing paths, but gives a more accurate approximation of bird locations and decreases the amount of birds that can remain hidden by vegetation, resulting in a more accurate estimate of bird density (Emlen 1971, Emlen 1977).

Similarly, the grid method uses a map overlain with a grid made of boxes 50 m² on both sides (Wheater et al. 2011). Researchers walk along the grid lines so that they access every spot in the site within 50m (Wheater et al. 2011). While walking a grid takes more time than transects and can lead to multiple encounters with the same birds, it gives a more exact estimate of bird location and makes it unlikely that any birds will be overlooked, making it a more effective method when making spot maps (Wheater et al. 2011). Both the grid and transect methods rely on several assumptions, including unchanging bird detectability, birds not moving before they are detected, and that the detection of individual birds can happen independently of other birds’ presence (Bibby 2000). With these limitations in mind, and taking into account the relatively small size of our study sites, we used the grid method for as many sites as we could in order to obtain the most precise location and count of each bird and species. However, due to special considerations from some organizations overseeing sites, we utilized manmade paths.
The amount of time each surveys require is dependent on the type of terrain. For open grasslands like the ones in this study, recommendations range from 3-4 hrs for 50-100ha to 4 hrs for 60-80ha (Bibby 2000, Wheater et al. 2011). Within this range, it is also important that the rate remains consistent between sites. Given the amount of time available to complete these surveys, the average time spent surveying was about 4-5ha per hour, and the amount of time spent surveying each site was calculated and kept consistent throughout the season.

**Survey data collection**

After establishing plans for site visits, we considered different data collection options, including direct counts, point counts, and spot maps. Direct counts are the simplest of these options, where only the presence or absence of species and their approximate population size is recorded (Richardson 1978). This method is effective when surveying a large area for multiple species, such as in studies monitoring the location of migratory birds that are only present at a site for a short amount of time, or when density comparisons are being made across a large number of sites, restricting time for data collection (Richardson 1978, Nilon et al. 1995). With no limit on time, a more precise determination of bird populations within sites was appropriate for this study.

Another method of data collection is point counts. Point counts require more time than direct counts, typically taking 5-20 minutes with more time required when more species are present, and take record of every bird detected around them along with their behavior (Keller and Fuller 1995, Bibby 2000). These behavioral observations allow researchers to exclude birds that only visit the site briefly and emphasize ones that use it more heavily and are most prevalent (Campbell 2009). Point counts can be appropriate when comparing birds present in drastically different habitats, such as forests, greenbelt, and urban habitat (Keller and Fuller 1995, Campbell 2009). Point counts cover less area per unit time than a method involving continuously walking through the site, making studying the location of birds within a site more difficult (Wheater et al. 2011).

The final method considered for recording survey data was spot mapping, which differs from point counts in that a researcher walks through sites continuously while recording bird detections.
and behaviors (Bibby 2000). Territory maps are created by comparing the location of birds seen between visits and the number of birds approximated to be present, with special attention paid to counter-singing and aggressive behavior to mark the boundaries of bird territories (Terborgh et al. 1990, Vickery et al. 1992, Bibby 2000). Territory maps are effective in analyzing the location of birds within a site, but can lead to an overestimation of abundance for species with high detection rates (Gottschalk and Huettmann 2011, Terborgh et al. 1990). This method creates the most detailed and precise record of birds within a site, as well as provides additional information about territory locations, and so was chosen for this study (Terborgh et al. 1990, Bibby 2000).

**Behavioral Observations**

This study included additional observations of bird behavior at sites containing Bobolinks using a time budget analysis to quantify behaviors. One method of collecting data for this type of study, described by Dwyer (1975), involves running a clock and recording the activity of a single bird every 10-15 seconds (Dwyer 1975). This is effective for analyzing behavioral patterns at different times during a season or day, but not as useful when looking at the proportion of time spent completing different activities (Dwyer 1975). Verner (1965) described a more effective strategy for this study, which included observing birds and writing down the duration of each observed behavior, estimated to the nearest 5 seconds (Verner 1965). Noting patterns in observed behaviors allows researchers to make broader inferences, such as categorizing long stretches of time as used for courtship, nest building, foraging, or territory defense (Verner 1965, Wiens 1969). Because this study focused on birds’ relationship with vegetation, we employed the method described by Verner to obtain a more detailed look at how birds use the vegetation in their chosen habitat.

**Characterization of Vegetation Composition and Structure**

We completed vegetation surveys to compare vegetation structure and composition between sites to grassland bird populations. We selected methods for these surveys based on time requirements, simplicity, and the level of detail in the data obtained. The selected methods are outlined below, along with the reasoning behind their choosing.
Sample Selection

Because of the large size of the sites we are studying, we could not take detailed measurements of each site entirely. Some studies obtained vegetation density estimates of entire plots by analyzing aerial photographs (Phillips et al. 2004, Cousins 2009). However, researchers cannot identify exact species using just aerial photography, which was desired in this study (Cousins 2009). Researchers also use plotless sampling for large plants to estimate vegetation density, but this is ineffective for the small plants of grasslands (Wheater et al. 2011). Because of this, we selected sample plots for this study that served to reflect the whole sites’ composition.

Shape and sizes of vegetation sample plots vary based on the type of data collected (Coulloudon et al. 1999, Wheater et al. 2011). When plot edge effects are not of concern, long rectangular plots are preferred over circles because they reflect more of the area’s diversity (Coulloudon et al. 1999, Wheater et al. 2011). Sample plot size should reflect the landscape type, with grassland plots typically ranging from 0.25-4m², or even smaller when measuring percent cover of specific plants (Bonham et al. 2004, Wheater et al. 2011). This study used a 1m² frame for each of its samples (Wiens 1969, Wheater et al. 2011).

The number of samples taken at each site is dependent on the site’s size and heterogeneity (Coulloudon et al. 1999, Winter et al. 2005). Researchers can adjust the number of samples taken to reflect vegetation variability by taking samples until the standard deviation or standard error in frequency values for key species is smaller than the mean (Ambuel and Temple, 1983, Coulloudon et al. 1999). Another method involves calculating the number of samples necessary to reach a certain confidence level after taking a small number of samples to gauge the diversity of the site (Elzinga et al. 1998). The equation below is used to calculate this when the goal of the study is to estimate differences in mean plant population totals (Elzinga et al. 1998).
\[ n = \frac{(Z_\alpha)^2 s^2}{B^2} \]

Where 
- \( n \) = Uncorrected sample size
- \( Z_\alpha \) = Standard normal coefficient from Table 1 in Appendix I
- \( s \) = Standard deviation
- \( B \) = Desired precision level, calculated by multiplying the desired confidence level expressed as a decimal by the mean of the sample data set.

This equation is a simplified version of a more complex formula (Elzinga et al. 1998). The sample number calculated by the complex formula based on the calculation from the equation above can be found in Table 2 of Appendix I for a confidence level of 80%, which was used in this study (Elzinga et al. 1998). While the number of samples required according to these calculation was too many to feasibly be achieved in this study, the calculations were completed as a way to compare the confidence level achieved at different sites (Elzinga et al. 1998). The number of samples in this study was approximated as 1 sample per ha, which resulted in a standard error smaller than the mean for grass and forb densities at each site (Ambuel and Temple, 1983, Coulloudon et al. 1999). Both of these methods are helpful in ensuring an adequate number of plots are sampled, but vegetation studies are typically limited by the amount of time available to complete surveys (Wheater et al. 2011). Ideally, vegetation sample area would total 5% of the entire plot area, but it is rare that researchers are able to reach this amount (Winter et al. 2005, Wheater et al. 2011). Ultimately, time spent taking measurements within sample plots should be limited so that researchers can acquire more samples (Fisher and Davis 2010, Wheater et al. 2011).

When choosing the location of sample plots, researchers typically split large sites into smaller sections and chose the sample site at random within the smaller section to aid in the samples’ reflection of the whole site (Ambuel and Temple 1983). This presents a challenge in locating samples, so grids or transects are often used to provide a navigation system (Wiens 1969). These systems are similar, using a random number generator to determine how many paces to travel away from the transect line or grid corner (Wiens 1969, Winter et al. 2005). Sampling along transects can be additionally beneficial when there is a suspected gradient of change in the
Bombard 28

vegetation (Wheater et al. 2011). This was generally not the case in this studies’ sites, therefore we used the grid method to keep consistent with the maps used for bird surveys (Wiens 1969, Wheater et al. 2011).

Vegetation Measurements

Several studies looked at the relationship between vegetation and grassland bird habitat selection, so we chose aspects of vegetation structure and composition that would most likely see correlation based on their previous results (Fisher and Davis 2010, Wiens 1969). These include species composition, vegetation density, percent cover by different plant types, vegetation height, litter depth, and visual obstruction (Bakker et al. 2002, Fisher and Davis 2010). Methods for obtaining these measurements are described below.

Composition

While many studies only look at composition by identifying the main plant classes that make up each sample plot (grass, forb, tree, etc.), this study looked at the correlation between bird densities and territories and some key plant species (Fisher and Davis 2010). Methods for tracking species involve recording a description of each plant and assigning it a code, allowing researchers to identify the same species across many plots (Wiens 1969). These descriptions, along with photographs, allow the species to be classified using field guides (Wiens 1969, Coulloudon et al. 1999). The composition of larger sites is represented quantitatively as a measure of frequency, which is calculated by dividing the number of plots where a species is present by the number of plots sampled across the site, reported as a percent (Coulloudon et al. 1999, Wheater et al. 2011).

Vegetation Density

Vegetation density is a measure of plants per unit area, which researchers calculate by dividing the number of individual plants counted by the size of the sample plot (Coulloudon et al. 1999, Wheater et al. 2011). Normally, the number of plants is counted easily, but for smaller and denser organisms this can be more difficult, making it more practical to estimate density using a different method (Wiens 1969). After measuring the distance from the center of the sample plot to
the location of the nearest individual of the species in each of four equal sections of the plot, researchers calculate plant density using the equation below (Wiens 1969).

\[
density \text{ per } .01 \text{ acre} = \frac{404710.7}{\left(\sum \frac{d}{N}\right)^2} \left[\frac{n_1}{N}\right]
\]

where 
- \( d \) = distance to the closest plant in quarter
- \( n_1 \) = number of quadrants where plant is recorded
- \( N \) = number of quadrants samples
- 404710.7 = cm² per .01 acre

Vegetation density values are used for calculating the total population size of plants, which can be useful when investigating endangered or invasive species (Coulloudon et al. 1999, Wheater et al. 2011). The formula below is used to calculate this (Wheater et al. 2011).

\[
Population = \frac{\text{mean number per sample} \times \text{number of samples}}{\text{sampling fraction (portion of total area sampled)}}
\]

While it is not practical to compare density values of different kinds of plants, since it does account for plant size, it is useful in comparing the populations of similar sized plants both within and across sites (Coulloudon et al. 1999, Wheater et al. 2011). Considering the difficulty associated with counting individual plants for all species, this study recorded and calculated vegetation density values for only plant classes where correlation has been most commonly identified in previous studies, which included grasses, forbs, and shrubs, estimating when counting was too time consuming (Fisher and Davis 2010).

**Percent Cover**

Percent cover refers to the amount of space within a plot that a plant occupies (Wiens 1969, Coulloudon et al. 1999). This differs from vegetation density in that it also reflects plant size, not just the number of individuals (Coulloudon et al. 1999, Wheater et al. 2011). Researchers can accomplish this by visually assessing the sample plot and estimating percent cover using the DAFOR, Braun-
Blanquet, or Domin scales (Rodenhouse and Best 1983, Wheater et al. 2011). These scales split percent cover estimates into groups; for example, the Braun-Blanquet scale places different percent cover estimates into categories numbered 1-5, separated as 1-5%, 6-25%, 26-50%, 51-75%, and 76-100% (Wheater et al. 2011). Difficulty in making this estimation increases with sample plot size, leading to the development of the Daubenmire method in which estimates are taken using a 50cm x 20cm frame with color markings to show different distances along the edge of the frame (Coulloudon et al. 1999, Bonham et al. 2004). The Daubenmire method also uses a modified version of the Braun-Blanquet scale, where the 5th level is split into levels 5 and 6, covering 75-95% and 95-100% respectively (Coulloudon et al. 1999, Bonham et al. 2004). While this estimation process is much simpler and less time consuming than a more quantitative method, it is less exact and more prone to inconsistent results between researchers (Bonham et al. 2004, Wheater et al. 2011).

Researchers can also determine percent cover using subdivided quadrants (Wheater et al. 2011). To calculate percent cover with subdivided quadrants, nine cords are placed both horizontally and vertically through a square to create 100 points, and the number of points that touch the plant of interest represents the percent cover (Wheater et al. 2011). This method eliminates the subjectivity present in visual assessments, but is still prone to error because the placement of intersections may not reflect the sample’s area (Bonham et al. 2004, Wheater et al. 2011). Therefore, researchers use the Daubenmire method more often when evaluating grasslands (Fisher and Davis 2010). This study used a modified version of this method, with the same scale but a larger 1m² frame, and included evaluations of the percent cover of litter and bare ground which were significant in past grassland bird habitat evaluations (Weins 1969, Fisher and Davis 2010).

**Height**

Methods for measuring height of vegetation are generally similar, with a marked pole placed next to a specific kind of vegetation or at the corners of the sample plot (Wiens 1969). However, height of plants within a sample plot varies between individuals, so generalizations must be made (Wiens 1969). Many studies look at the tallest plant of each class, as well as litter depth, sometimes
taking multiple measures within a sample plot and averaging to account for variation (Bakker et al. 2002, Winter et al. 2005). Measuring maximum height is helpful because it allows the researcher to focus analysis on types of plants that are more influential in bird habitat selection, but does not provide as detailed a description of the vegetation structure as a whole (Wiens 1969, Fisher and Davis 2010). An alternative method involves inserting the same type of marked pole into the plot and counting the number of plants of any type that fall within each 10cm height range within a 2cm radius of the pole (Wiens 1969). Another common approach is to measure the effective height, which is the height at which a pole is 90% visually obstructed at a distance of 5m (Wiens 1969). Measuring effective height is a much simpler method which provides similarly useful data, so researchers use it more often than placing all plant species into 10cm height intervals (Fisher and Davis 2010). This study measured effective height at the 4 corners of the sample plot, as well as the maximum height of each plant species surveyed to efficiently obtain information about the structure as a whole and any individual plant species that may be of interest (Wiens 1969, Fisher and Davis 2010).

Vegetation Thickness

Vegetation thickness is a common measure that relates to the overall structure of the vegetation in an area (Robel et al. 1970, Fisher and Davis 2010). Researchers assess this most often using the visibility of marks on a pole, called a Robel pole, which is inserted into the vegetation and observed from a distance of 4m away from the pole and 1m off the ground (Robel et al. 1970, Elzinga et al. 1998). The pole has marks every 5cm, and researchers observe the lowest mark that can be viewed from each cardinal direction (Robel et al. 1970, Winter et al. 2005). Other methods for assessing vegetation thickness include clipping samples and weighing them, which provides additional information about individual species and their biomass (Coulloudon et al. 1999, Wheater et al. 2011). The Robel pole, however, offers more information about the overall vegetation structure and requires less disturbance in the vegetation, making it one of the most commonly used
techniques to survey grasslands (Robel et al. 1970, Fisher and Davis 2010). This study used a Robel pole to assess vegetation thickness because of its simplicity and ability to cause less disturbance.

**Statistical Analysis**

Multiple statistical tests are available to identify significant relationships within the data collected in this study. First, correlation was determined between measured vegetation parameters. We considered two possible options for this test: Pearson’s and Spearman’s correlation coefficients. Both of these tests use arbitrary functions to determine the likelihood that variables in two groups follow the same pattern (Hauke and Kossowski 2011). However, they differ in that Pearson’s coefficient assumes a linear relationship between variables, while Spearman’s coefficient does not (Hauke and Kossowski 2011, Hammer 2016). Because vegetation measurements exist on different scales (for example, some density counts exceeded 2000 but percent cover is measured on a scale of 1-6), we chose to use Spearman’s rank correlation coefficients (Hauke and Kossowski 2011, Hammer 2016). This analysis yielded two values, r and p. R values represent correlation values, and p values represent the probability that values are unrelated (Hammer 2016). Significant values were determined when p < 0.05 (Hauke and Kossowski 2011).

We explored a number of additional tests to determine the relationship between vegetation measurements and bird population measurements. Some studies investigating bird territory size and populations use t-tests or analysis of variance (ANOVA) to compare results between bird species (Weins 1969, Best and Rodenhouse 1984). Studies that utilize these or other univariate analyses combined collected data into one parameter that was compared between groups (Wiens 1969, Best and Rodenhouse 1984). However, since this study analyzed relationships between multiple vegetation parameters, any pairwise comparisons would overlook the relationships between them. Therefore, this study employed multivariate analysis, which compares multiple parameters together to look for significant relationships within the data set as a whole (Cody 1981, Cody 1985).

The options for multivariate analysis we looked at included discriminant function analysis (DFA), multivariate analysis of variance (MANOVA), and canonical correlation analysis (CCA). DFA
and MANOVA both require data to be grouped in some way, such as by occupied and unoccupied sites, high density and low density plots, or successful and unsuccessful nests (Whitmore 1981, Thomas Wray and Whitmore 1979, Cody 1981). MANOVA detects significance between the mean values for parameters within each group, while DFA looks for trends in data that indicate that a variable can be relied upon to discriminate between multiple groups (French et al. 2008, Poulsen and French 2008). Additionally, these tests constrain the data to analysis of one species at a time (Whitmore 1981). We sought to determine whether parameters measured within occupied territories differed significantly from their surrounding areas for each bird species, and so we utilized MANOVA (French et al. 2008). MANOVA generated Wilk’s lambda and P values, which indicated significance when P < 0.05 (Tacq and Tacq 1997).

We also examined statistical analysis that can be applied to bird densities, which reflect a series of values rather than defined groups. This study primarily utilized CCA to study the relationship between vegetation measurements and bird population densities. This method of analysis combines variables from multiple groups into two axes and examines their correlation when data is expected to have unimodal distribution (Thompson 1984). For this analysis to be significant, the number of data points, in this case the number of sites, should be double the amount of dependent variables, in this case the vegetation parameters (Palmer 1993). This is a particularly effective way of analyzing vegetation, as it is likely that the different measures are related in some way (Thompson 1984, Cody 1985). This analysis combines data points from two groups, in this case bird populations and vegetation parameters, into 3 axes and generates a score that represents how strongly correlated each variable is to the other variables in the group (Hammer 2016). Variables that have scores of the same sign are considered to be correlated to some degree (Hammer 2016). Two types of scaling types are possible, where type I determines axis scores based on independent variables and type II determines axis scores based on dependent variables (Palmer 1993). We chose scaling type II for analysis based on its ability to produce higher axis scores from the data obtained in this experiment (Palmer 1993). Eigenvalues are also generated, which represents how much of the
variation between measurements each axis accounts for (Thompson 1984, Palmer 1993). Bird
density values were log transformed before running CCA to account for the variation in species
abundance (Beauchame and Olson 1973). This adjusted the variation in density values to be similarly
scaled so that each species contributed equally to the variation accounted for in axes scores
(Beauchame and Olson 1973). An additional permutation test was generated to determine the
significance of relationships detected by CCA (Hammer 2016). This test assigns random numbers to
the parameters being studied and calculates the probability that the numbers included in the study
are more correlated than the random values (Hammer 2016). This test is dependent on the N value,
which represents the number of random sets tested (Hammer 2016). P values generated from this
indicated significant findings when P < 0.05 (Palmer 1993). The analysis for this study was completed
using Version 3.13 of PAST software.
Chapter 2

Abstract

In response to grassland bird decline caused by loss of suitable habitat, management practices aim to preserve land which caters to their habitat preferences. In 2016, we studied 6 grassland sites in Worcester County to identify features of vegetation which characterize preferred habitat for Bobolinks, Grasshopper Sparrows, Vesper Sparrows, and Savannah Sparrows. We analyzed the results of spot mapping and behavioral observations to determine bird densities and territory locations and conducted vegetation surveys to measure vegetation structure and composition. We found no statistically significant correlations between bird densities and vegetation measurements site-wide or between territory location and vegetation measurements within occupied sites, but did see significance in correlation between territory location and vegetation measurements across all sites. We discovered positive relationships between Grasshopper Sparrows and Vesper Sparrows with bare ground cover, litter depth, and woody vegetation, as well as positive relationships between Bobolinks and Savannah Sparrows with increased vegetation density, height, and thickness. The significance of these results and their difference from past studies highlighted the need for local studies like this one to continue. We used this information to make species-specific management recommendations for promoting local population growth.

Introduction

Grassland bird populations have seen significant declines in recent years, thought to be caused in great part by habitat change and loss (Vickery et al. 1995, National Audubon Society 2016). Increases in human populations have both directly and indirectly caused changes in grassland composition and availability, mainly by limiting disturbances which keep grasslands from undergoing succession (Best and Rodenhouse 1984, Foster et al. 2002). Current management practices and recommendations typically focus on retaining soil nutrients and increasing plant biomass while limiting the growth of woody vegetation (Grace 1999, Vickery et al 1995, Conant et al. 2001). These
practices typically include prescribed burning about every 5 years and delaying agricultural field tilling until the end of grassland bird breeding season (Grace 1999, Vickery et al 1995). However, management practices that target certain species sometimes decrease overall wildlife diversity because of some species’ habitat preferences (Grace 1999). Therefore, it is necessary for management tactics to be developed on a species specific basis so that threatened wildlife can be emphasized in these practices (Vickery et al. 1995).

This project studied the habitat selection of four grassland bird species: Grasshopper Sparrows (*Ammodramus savannarum*), Vesper Sparrows (*Poecetes gramineus*), Savannah Sparrows (*Passerculus sandwichensis*), and Bobolinks (*Dolichonyx oryivorus*), all of which have experienced significant population declines in the Northeast from 1966-2013 (Sauer et al. 2014). These declines have caused concern for species survival, leading to Grasshopper Sparrows and Vespers Sparrows being declared threatened in the state of Massachusetts which warrents direct conservation action (Commonwealth of Massachusetts 2016). Because of their relatively small size, grassland birds are particularly affected by changes in vegetation structure, as it highly affects food availability and the birds’ ability to forage, nest, and attract mates (Cody 1968, Cody 1981). Parameters describing vegetation structure have been explored extensively for each bird species in this study, usually comparing bird density, territory occupation, breeding success, or nest success, with only some studies comparing the effects of vegetation on more than one of these at the same site (Vickery et al. 1992). Additionally, these comparisons are typically done pairwise, with one bird species compared to one vegetation parameter at a time, not considering possible relationships between species or the parameters.

The goals of this study were to identify measurements vegetation structure and composition that showed correlation with grassland bird populations (1) among sites by comparing their densities to vegetation measurements within sites, and (2) within territories by determining the difference between vegetation within occupied and unoccupied spaces. This was done with the intention of identifying key vegetation characteristics that can be used to determine appropriate grassland
management tactics. It was hypothesized that selected habitat for grassland birds would be based on both site wide and territory specific vegetation parameters and reflect their individual behaviors. We predicted that (1) vegetation measurements related to vegetation structure, including bare ground cover, vegetation height, and vegetation density, would show the greatest significance in analysis, (2) each bird species would show unique relationships to vegetation characteristics, and (3) analysis of vegetation measures and site bird densities as well as the analysis between measurements in occupied and unoccupied spaces within selected sites would show statistically significant relationships.

Methods

Study Site

We used six study sites to collect grassland bird population data for this study: Chestnut Hill Farm (4.3 ha), Dexter Drumlín (15.0 ha), Doyle Reservation and Community Park (19.7 ha), Bolton Flats Wildlife Management Area (24.0 ha), Wachusett Meadow Wildlife Sanctuary (3.3 ha), and Breakneck Hill Conservation Land (16.0). These sites were located in 5 cities in Worcester County (Figure 2). Sites are owned and managed by the Trustees of Reservations, the Massachusetts Division of Fisheries and Wildlife, Mass Audubon, and the town of Southborough. Each of these groups prioriterizes the conservation of grassland birds through delayed tillage, with the town of Southborough also fostering the creation of more grassland habitat (Southborough Stewardship Committee 2016).
Figure 2: Map of study sites located in Worcester County (image retrieved from Google Maps)

Bird Surveys

 Territory Maps

To gather detailed location data for each adult male bird, we surveyed each site looking at the 4 grassland bird species, Grasshopper Sparrow (GRSP), Vesper Sparrow (VESP), Savannah Sparrow (SAVS), and Bobolink (BOBO), from 23 May – 24 June 2016 to create spot maps. We created maps overlain with gridlines 50m apart using ArcMap 10 and calculated the time it would take to survey each site using a rate of 20-26 grid squares per hour (Bibby 2000, Wheater et al. 2011). Three of our sites, Chestnut Hill, Dexter Drumlin, and Doyle Reservation, had additional regulations for walking in the fields. We surveyed these sites at the same rate, but limited walking paths to pre-existing, manmade ones. Additionally, Bolton Flats was too large to be surveyed entirely in one outing, and so was split into north and south halves. We recorded the presence and behavior of each bird weekly between 0700 and 1100 using the standard conventions developed by the British Trust for Ornithology (Bibby 2000). At the end of the season, we compiled the data for all visits on maps for
each species to determine the number of adult male birds of each species present and delineate their territories (Bibby 2000).

**Time Budgets**

We recorded behavioral observations of male Bobolinks at each site they occupied from 7 June – 8 July 2016 to obtain information about the birds’ time budget at each site. A random number generator was used to select a grid square where the nearest male Bobolink was observed for approximately 15 minutes (Verner 1965, Wiens 1969). Observations included when the birds flew to a new location, when they arrived there, the type of vegetation the bird was perched on, and the number of times the bird called per minute and from each perch type (Verner 1965, Dwyer 1975).

**Vegetation Surveys**

We chose vegetation sample sites by splitting sites into 1 ha subplots based on the preexisting grid created for spot mapping surveys (Ambuel and Temple 1983). We selected the exact location of each sample using a random number generator to determine the distance north and east away from the southwest corner of each subplot the sample should be taken, resulting in approximately 1 sample taken per hectare (Wiens 1969, Ambuel and Temple 1983). For each sample, we took measurements in a 1m² plot delineated by a square of ½-in PCV pipe (Wiens 1969, Wheater et al. 2011). We classified and made density counts for each forb, grass, and shrub species present within each sample plot, and measured the tallest plant of each species within the plot using a tape measure (Weins 1969, Wheater et al. 2011, Fisher and Davis 2012). We visually estimated the proportion of the sample square that was covered by bare ground, litter, and each plant species within the plot on a 6 point scale using the Daubenmire method (Daubenmire 1959, Wheater et al. 2011). We measured the vegetation’s effective height at each of the plot’s 4 corners, and determined vegetation thickness at the middle of each plot by taking visual obstruction measurements from each cardinal direction using a Robel pole (Weins 1969, Robel et al. 1970, Fisher and Davis 2012).
Statistical Analysis

Sample Size Strength

To determine the statistical power of the vegetation sample size, we used two methods. First, we compared mean grass and forb densities at each site to their standard error and standard deviations. A mean larger than both of these values indicated that the sample size was sufficient for determining the difference in plant frequencies between sites (Ambuel and Temple, 1983, Coulloudon et al. 1999). Another test used a formula that determined the number of samples necessary to reach a desired confidence level in distinguishing mean plant densities within a site, shown below (Elzinga et al. 1998).

\[
n = \frac{(Z_\alpha)^2 s^2}{B^2}
\]

Where n= Uncorrected sample size
  \(Z_\alpha\)= Standard normal coefficient from Table 1 of Appendix I
  s = Standard deviation
  B= Desired precision level, calculated by multiplying the desired confidence level expressed as a decimal by the mean of the sample data set.

The actual sample number needed uses a more complex formula, the product of which can be determined based on the results of the formula above. The conversion between these formulas can be found in Table 2 of Appendix I.

Vegetation Parameter Correlation

Based on the vegetation measurements taken in each sample, we calculated average density, frequency, percent cover, and weighted average height for each species and some taxonomic or morphologically similar groups (forbs, grasses, hay, and woody vegetation) at each site (Fisher and Davis 2010). We selected parameters for further analysis based on three criteria. First, we looked at parameters that were most often found to show correlation with bird population measurements in previous studies, including litter depth, bare ground cover, vegetation thickness, and effective height (Fisher and Davis 2010). Next, we looked at parameters that characterized a large portion of the sample plots, including forb density and height, grass density, height, and cover,
and woody vegetation density (Fisher and Davis 2010). Finally, we considered measurements of vegetation that were commonly found being utilized during behavioral observations, including hay density and height, bedstraw density, frequency, and cover, and vetch density and frequency (Table 1). We used PAST software version 3.13 to run correlation analysis of these values, obtaining Spearman’s rank order correlation coefficient values \( r_s \) (Hauke and Kossowski 2011, Hammer 2016). We eliminated one of the parameters that made up each combination which had \( p < 0.05 \), combining parameters to reduce the number of measurements that would be compared to bird densities and territory occupancy (Hauke and Kossowski 2011).

**Bird Density and Site Vegetation Relationships**

We subjected site-wide vegetation parameter means retained after Spearman’s rank analysis to canonical correlation analysis (CCA) with site bird densities (Thompson 1984, Cody 1985). This analysis combined data into three axes based on how correlated they were, yielding scores for each species density, site, and vegetation measurement which represented how strongly correlated it was with others in the group (Thompson 1984, Hammer 2016). Bird densities were first log transformed to account for a greater abundance of Bobolinks (Beauchame and Olson 1973). We used triplot scaling type II, which placed data in the CCA plot based on the location of the vegetation measurements, to enhance the visibility of data trends and correlations (Palmer 1993). We considered scores that shared values of the same sign to be correlated, with values from axes with higher eigenvalues and with greater axis scores being seen as more meaningful (Thompson 1984). To determine the statistical significance of the relationships detected, we ran a permutation test, yielding a trace p value which indicates significance for resulting p values \(< 0.05\) (Hammer 2016).

**Territory Occupancy and Vegetation Relationships**

We ran multivariate analysis of variance (MANOVA) using vegetation data retained after Spearman’s rank correlation analysis, grouping data based on whether or not the sample was contained within territories occupied by adult males. For each species, analysis was completed to compare occupied territories to (1) unoccupied areas within sites where birds were detected and (2)
Bombard 42

unoccupied areas across all study sites. We used $p$ values derived from Wilk’s lambda to determine significance, with $p < 0.05$ representing significant differences in groups (Tacq and Tacq 1997).

Results

Analysis of Bird Surveys and Observations

Site visits throughout the breeding season produced 4-5 spot maps for each site. Territory maps created from these for each species at each site can be seen in Appendix II. We determined the number of adult males present at each site as follows: Chestnut Hill: 13 Bobolinks; Dexter Drumlín: 10 Bobolinks, 11 Savannah Sparrows; Doyle Reservation: 20 Bobolinks; Bolton Flats: 8 Grasshopper Sparrows, 3 Vesper Sparrows; Wachusett Meadow: 3 Bobolinks; Breakneck Hill: 1 Bobolink. These were used along with site sizes to determine densities (Figure 3). Bobolinks were the most widely distributed of the species we surveyed, occupying 5 out of 6 sites, while each of the other species only occupied one (Figure 3). Dexter Drumlín was the only site where Bobolinks shared territory with other grassland birds (density= 0.7 birds/ha) and was the only site occupied by Savannah Sparrows (density= 0.7 birds/ha) (Figure 3). Densities for Bobolinks ranged from 3.0 birds/ha (Chestnut Hill) to 0.06 birds/ha (Breakneck Hill) (Figure 3). Bolton Flats was unique in containing Grasshopper Sparrows (density= 0.3 birds/ha) and Vesper Sparrows (density= 0.1 birds/ha) (Figure 3).
Figure 3: Adult male grassland bird densities (birds/ha) for 4 bird species. Data was collected at six sites from 23 May – 24 June 2016.

We collected behavioral data for adult male Bobolinks at 4 sites (Doyle Reservation, Chestnut Hill, Dexter Drumlin, and Wachusett Meadow). We made 14 observations (Males observed per site: Doyle Reservation=6, Chestnut Hill= 5, Dexter Drumlin=2, Wachusett Meadow=1) for a total of 189.5 minutes of observation (Time per site: Doyle Reservation = 84.5 min, Chestnut Hill =59.5 min, Dexter Drumlin = 31.5 min, Wachusett Meadow =14 min). Bobolinks spent the greatest amount of time utilizing hay (42.5%), which included several different species such as Kentucky Bluegrass (*Poa pratensis*), Orchard Grass (*Dactylis glomerata*), and Redtop (*Agrostis alba*) (Table 1). The second largest amount of time was spent utilizing other types of grasses (23.8%), which were typically shorter and resulted in birds remaining mostly hidden from sight (Table 1). Most specific species of plants were unable to be identified because of the distance from which birds were observed was too great, as well as because observations were made before most flowers bloomed. However, two species, purple vetch (*Vicia Americana*) and rough bedstraw (*Galium asprellum*), were able to be identified as common perches, and so were subject to further analysis in correlation to bird populations (Table 1).
**Table 1: Time spent calling from or perching on different vegetation and perch types by adult male Bobolinks. Data is derived from 14 observations lasting a total of 189.5 minutes at 4 sites from 23 May – 24 June 2016.**

<table>
<thead>
<tr>
<th>Perch Type</th>
<th>Time Used (min)</th>
<th>Percent of total observation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hay</td>
<td>80.5</td>
<td>42.5%</td>
</tr>
<tr>
<td>Grass</td>
<td>45.0</td>
<td>23.8%</td>
</tr>
<tr>
<td>Unidentified forb</td>
<td>19.5</td>
<td>10.3%</td>
</tr>
<tr>
<td>Tree</td>
<td>19.0</td>
<td>10.0%</td>
</tr>
<tr>
<td>Vetch</td>
<td>11.0</td>
<td>5.8%</td>
</tr>
<tr>
<td>Bedstraw</td>
<td>9.5</td>
<td>5.0%</td>
</tr>
<tr>
<td>Fence</td>
<td>5.0</td>
<td>2.6%</td>
</tr>
</tbody>
</table>

**Vegetation Sample Size Analysis**

We determined vegetation sample strength using site-wide means, standard errors, and standard deviations for grass and forb density. Analysis revealed that both standard deviations and standard errors were smaller than means for all sites except for Bolton Flats, where the grass density standard deviation exceeded the mean (mean= 280.3, standard deviation=436.8) (Table 2). Other instances with relatively small differences between standard deviations and means were for forb density at Bolton Flats (mean= 25.4, standard deviation= 22.4), grass density at Doyle Reservation (mean= 500.8, standard deviation= 460.4), and forb density at Breakneck Hill (mean=51.5, standard deviation= 40.3) (Table 2). Relatively large differences in mean and standard deviation values existed for forb density at Chestnut Hill (mean= 199.3, standard deviation 77.6), grass density at Chestnut Hill (mean= 1036.5, standard deviation= 324.3), and forb density at Dexter Drumlin (mean= 141.1, standard deviation= 78.3) (Table 2). Relative differences between means and standard deviations and means and standard errors tended to follow similar trends (Table 2).
Table 2: Grass and forb density mean, standard deviation, and standard error at six sites. Data was collected by taking 1 sample/ ha in a 1m² square from 27 June – 9 July 2016.

<table>
<thead>
<tr>
<th>Site</th>
<th>Forb Density (plants/m²)</th>
<th>Grass Density (plants/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>Chestnut</td>
<td>199.3</td>
<td>77.6</td>
</tr>
<tr>
<td>Dexter</td>
<td>141.1</td>
<td>78.3</td>
</tr>
<tr>
<td>Doyle</td>
<td>152.0</td>
<td>107.6</td>
</tr>
<tr>
<td>Bolton</td>
<td>25.4</td>
<td>22.4</td>
</tr>
<tr>
<td>Wachusett</td>
<td>120.3</td>
<td>67.3</td>
</tr>
<tr>
<td>Breakneck</td>
<td>51.5</td>
<td>40.3</td>
</tr>
</tbody>
</table>

We also calculated the sample sizes necessary to reach 80% confidence in the difference in grass and forb densities between sites, which revealed that none of the sample sizes at any site were large enough to be statistically significant at this level (Table 3). Ideal sample sizes ranged from 9-110 samples, while actual sample sizes ranged from 3-20 (Table 3). Chestnut Hill was the closest to achieving this level of significance (6 samples taken, 11 needed for 80% confidence in forb density, 9 needed for 80% confidence in grass density), and Bolton Flats was the farthest, despite having the largest sample size (20 samples taken, 36 needed for 80% confidence in forb density, 110 needed for 80% confidence in grass density) (Table 3).
Table 3: Number of samples taken at each of 6 sites and the ideal number of samples needed to detect difference in mean forb and grass densities across sites. About one 1m² sample/ha was taken at each site, with the mean and standard deviation values of forb of forb and grass density used to calculate samples needed to reach 80% confidence in differentiating means.

<table>
<thead>
<tr>
<th>Site</th>
<th>Sample Size</th>
<th>Sample Size to reach 80% confidence in forb density</th>
<th>Sample Size to reach 80% confidence in grass density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chestnut</td>
<td>6</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>Dexter</td>
<td>9</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Doyle</td>
<td>11</td>
<td>29</td>
<td>45</td>
</tr>
<tr>
<td>Bolton</td>
<td>20</td>
<td>36</td>
<td>110</td>
</tr>
<tr>
<td>Wachusett</td>
<td>3</td>
<td>19</td>
<td>15</td>
</tr>
<tr>
<td>Breakneck</td>
<td>11</td>
<td>31</td>
<td>23</td>
</tr>
</tbody>
</table>

Vegetation Measurement Correlation Analysis

Average vegetation measurements for each study site and their standard errors can be found in Appendix III. Correlation analysis using Spearman’s rank correlation coefficients and correlation probabilities yielded several statistically significant results, allowing us to reduce the number of parameters used in analyses with bird populations. We chose to retain some values which showed multiple significant correlations, such as litter depth, bare ground cover, and visual obstruction measurements, because they were common indicators of significant relationships with bird populations in previous studies (Table 4). These relationships led to the elimination of grass density, grass cover, grass height, forb density, forb height, bedstraw density, bedstraw frequency, vetch density, and vetch frequency from further analysis with bird densities and territory occupation (Table 4). A full table of $r_s$ and $p$ values can be found in Appendix IV.
Table 4: Significantly correlated vegetation parameters, probability of correlation ($p$), and Spearman’s rank coefficient ($r_s$). Significance was determined by $p$ values <0.05. Derived from measurements taken at 6 sites from 27 June – 9 July 2016.

<table>
<thead>
<tr>
<th>Parameter 1</th>
<th>Parameter 2</th>
<th>$p$</th>
<th>$r_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Litter Depth</td>
<td>Grass Density</td>
<td>&lt;0.01</td>
<td>-1.0</td>
</tr>
<tr>
<td>Bare Ground Cover</td>
<td>Grass Cover</td>
<td>0.03</td>
<td>-0.9</td>
</tr>
<tr>
<td>Bare Ground Cover</td>
<td>Forb Density</td>
<td>0.03</td>
<td>-0.9</td>
</tr>
<tr>
<td>Bare Ground Cover</td>
<td>Bedstraw Density</td>
<td>0.01</td>
<td>-1.0</td>
</tr>
<tr>
<td>Robel Pole</td>
<td>Grass Height</td>
<td>0.02</td>
<td>0.9</td>
</tr>
<tr>
<td>Robel Pole</td>
<td>Forb Height</td>
<td>0.02</td>
<td>0.9</td>
</tr>
<tr>
<td>Robel Pole</td>
<td>Vetch Density</td>
<td>&lt;0.01</td>
<td>1.0</td>
</tr>
<tr>
<td>Robel Pole</td>
<td>Vetch Frequency</td>
<td>&lt;0.01</td>
<td>1.0</td>
</tr>
<tr>
<td>Grass Cover</td>
<td>Forb Density</td>
<td>&lt;0.01</td>
<td>1.0</td>
</tr>
<tr>
<td>Grass Cover</td>
<td>Bedstraw Density</td>
<td>&lt;0.01</td>
<td>0.9</td>
</tr>
<tr>
<td>Grass Cover</td>
<td>Bedstraw Cover</td>
<td>&lt;0.01</td>
<td>0.9</td>
</tr>
<tr>
<td>Grass Height</td>
<td>Forb Height</td>
<td>0.02</td>
<td>0.9</td>
</tr>
<tr>
<td>Grass Height</td>
<td>Vetch Density</td>
<td>0.02</td>
<td>0.9</td>
</tr>
<tr>
<td>Grass Height</td>
<td>Vetch Frequency</td>
<td>0.02</td>
<td>0.9</td>
</tr>
<tr>
<td>Forb Density</td>
<td>Bedstraw Density</td>
<td>&lt;0.01</td>
<td>0.9</td>
</tr>
<tr>
<td>Forb Density</td>
<td>Bedstraw Cover</td>
<td>&lt;0.01</td>
<td>0.9</td>
</tr>
<tr>
<td>Forb Height</td>
<td>Vetch Density</td>
<td>0.02</td>
<td>0.9</td>
</tr>
<tr>
<td>Forb Height</td>
<td>Vetch Frequency</td>
<td>0.02</td>
<td>0.9</td>
</tr>
<tr>
<td>Bedstraw Frequency</td>
<td>Hay Height</td>
<td>0.03</td>
<td>0.9</td>
</tr>
<tr>
<td>Bedstraw Density</td>
<td>Bedstraw Cover</td>
<td>0.03</td>
<td>0.7</td>
</tr>
<tr>
<td>Vetch Density</td>
<td>Vetch Frequency</td>
<td>&lt;0.01</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Bird Density and Vegetation Parameter Correlation

We used CCA to examine the relationship between male bird densities for each species at each site and vegetation parameters averaged by site (Figure 4, Table 5). Eigenvalues indicated that Axis 1 accounted for 87.36% of variation between data, Axis 2 accounted for 12.62%, and Axis 3 (not pictured) accounted for 0.02% (Eigenvalues: Axis 1 = 0.339, Axis 2 = 0.049, Axis 3 = 8.26*10^-5). Scores from Bobolinks and Savannah Sparrows showed positive values on Axis 1 (BOBO = 3.20, SAVS = 0.27), whereas Grasshopper Sparrows and Savannah Sparrows showed negative values (GRSP = -0.59, VESP = -0.47) (Figure 4, Table 5). Additionally, all sites except for Bolton Flats (-1.32) and Breakneck (-0.14) showed positive scores on Axis 1 (Range: 0.25-0.46) (Table 5). Vegetation parameters showing the highest positive scores on Axis 1 were effective height (0.96) and bedstraw cover (0.92) (Figure 4, Table 5). Parameters showing the most negative scores for Axis 1 were woody density (-0.95) and bare ground cover (-0.82) (Figure 4, Table 5). Axis 2 revealed a positive score for Savannah Sparrows (1.50) and negative scores for Bobolinks (-1.25), Grasshopper Sparrows (-0.58), and Vesper Sparrows (-0.56) (Figure 4, Table 5). Parameters showing the highest positive scores on Axis two were effective height (0.25) and hay density (0.42), and parameters showing the most negative values were litter depth (-0.30) and hay height (-0.65) (Figure 4, Table 5). However, these values were determined to be statistically insignificant by a permutation test (p = 0.518, N=999).
Figure 4: CCA scatter plot with scaling type II for log transformed Bobolink (BOBO), Grasshopper Sparrows (GRSP), Vesper Sparrows (VESP), and Savannah Sparrows (SAVS) adult male densities and vegetation parameters across 6 sites, Chestnut Hill (CHE), Dexter Drumlín (DEX), Doyle Reservation (DOY), Bolton Flats (BOL), Wachusett Meadow (WAC), and Breakneck Hill (BRE), measured from 23 May-9 July 2016.
Table 5: CCA scores for Axis 1 and 2 comparing adult male grassland bird densities for 4 species, Bobolink (BOBO), Grasshopper Sparrows (GRSP), Vesper Sparrows (VESP), and Savannah Sparrows (SAVS), and values and vegetation parameters across 6 sites, Chestnut Hill (CHE), Dexter Drumlın (DEX), Doyle Reservation (DOY), Bolton Flats (BOL), Wachusett Meadow (WAC), and Breakneck Hill (BRE), measured from 23 May – 9 July 2016.

<table>
<thead>
<tr>
<th>Species</th>
<th>Axis 1</th>
<th>Axis 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOBO</td>
<td>3.20</td>
<td>-1.25</td>
</tr>
<tr>
<td>GRSP</td>
<td>-0.59</td>
<td>-0.58</td>
</tr>
<tr>
<td>SAVS</td>
<td>0.27</td>
<td>1.50</td>
</tr>
<tr>
<td>VESP</td>
<td>-0.47</td>
<td>-0.56</td>
</tr>
<tr>
<td>CHE</td>
<td>0.46</td>
<td>-0.20</td>
</tr>
<tr>
<td>DEX</td>
<td>0.41</td>
<td>0.54</td>
</tr>
<tr>
<td>DOY</td>
<td>0.27</td>
<td>-0.12</td>
</tr>
<tr>
<td>BOL</td>
<td>-1.32</td>
<td>0.00</td>
</tr>
<tr>
<td>WAC</td>
<td>0.25</td>
<td>-0.12</td>
</tr>
<tr>
<td>BRE</td>
<td>-0.14</td>
<td>0.04</td>
</tr>
<tr>
<td>Litter Depth</td>
<td>-0.66</td>
<td>-0.30</td>
</tr>
<tr>
<td>Bare Ground Cover</td>
<td>-0.82</td>
<td>0.03</td>
</tr>
<tr>
<td>Robel Pole</td>
<td>0.61</td>
<td>0.05</td>
</tr>
<tr>
<td>Effective Height</td>
<td>0.96</td>
<td>0.25</td>
</tr>
<tr>
<td>Woody Density</td>
<td>-0.95</td>
<td>-0.04</td>
</tr>
<tr>
<td>Hay Density</td>
<td>0.66</td>
<td>0.42</td>
</tr>
<tr>
<td>Hay Height</td>
<td>0.57</td>
<td>-0.65</td>
</tr>
<tr>
<td>Bedstraw Cover</td>
<td>0.92</td>
<td>-0.09</td>
</tr>
</tbody>
</table>
Analysis of Vegetation Parameters and Territory Occupation

We completed MANOVA analysis of vegetation measurements based on their means across occupied territories and unoccupied spaces. Mean measurements for these groups can be seen in Appendix V. We completed analysis of vegetation samples within territories and the unoccupied spaces within sites where the species was detected for 3 out of 4 species. This analysis was not completed for Savannah Sparrows because they occupied every sample plot within their occupied site. This analysis revealed a lack of statistical significance between sample groups (Bobolinks: Wilks’ lambda= 0.727, $F_{8,31} = 1.45$, $p = 0.214$, Grasshopper Sparrows: Wilks’ lambda= 0.718, $F_{8,11} = 0.54$, $p = 0.804$, Vesper Sparrows: Wilks’ lambda= 0.675, $F_{8,11} = 0.66$, $p = 0.715$). However, in comparing sample measurements within occupied territories to sample measurements within unoccupied spaces across all sites, significant $p$ values were determined for 3 out 4 species, with Savannah Sparrows being the only species that did not show significant values (Bobolinks: Wilks’ lambda= 0.455, $F_{8,51} = 7.65$, $p < 0.001$, Savannah Sparrows: Wilks’ lambda= 0.736, $F_{8,51} = 2.28$, $p = 0.036$, Grasshopper Sparrows: Wilks’ lambda= 0.532, $F_{8,51} = 5.61$, $p < 0.001$, Vesper Sparrows: Wilks’ lambda= 0.821, $F_{8,51} = 1.39$, $p = 0.223$).

Discussion

Site Vegetation Structure and Bird Density Analysis

The goal of this study was to identify vegetation structure and composition measurements that were associated with increases in bird density or territory occupancy. Results from CCA and Spearman’s rank analysis were combined to form two groups of bird species and vegetation measurements showing correlation. Grasshopper Sparrow and Vesper Sparrow densities were positively related to litter depth, bare ground cover, and woody vegetation density. Conversely, Bobolink and Savannah Sparrow populations showed positive relationships with visual obstruction, effective height, hay density and height, forb density and height, vetch frequency and density, grass density, height, and cover, and bedstraw frequency, density, and cover. We considered these relationships, which were described by Axis 1 of the CCA plot, to be the most significant because of
the axis’ higher eigenvalue and the relatively higher axis scores for vegetation parameters. We predicted that vegetation measures reflecting qualities of overall vegetation structure would show the highest correlation. The vegetation measurements with the highest axis scores here were effective height, woody vegetation density, and bedstraw cover. Effective height is a common measure associated with vegetation structure, as it describes the overall height of the vegetation in a sample, taking into account relative abundances of species when determining the height which encompasses 90% of individual plant (Weins 1969, Fisher and Davis 2010). Changes in woody vegetation density are also associated with difference in structure, as an environment in a stage of succession which allows for this growth can be much different from areas that are dominated by grasses (Vickery et al. 1995, Motzkin and Foster 2002). However, given the small number of sites included in this study, it is difficult to know the ability of woody vegetation density to predict overall vegetation structure. This study could be expanded to more sites in the future to help determine this. Bedstraw cover’s ability to reflect vegetation structure is difficult to determine since the specific plant species comprising grasslands are highly variable (Eriksson and Jakobsson 1998). It also carries less confidence, given that the behavioral observations were not detailed enough to see exactly how vegetation that was commonly used by Bobolinks was beneficial to them. However, the strength of correlation to bird densities in this study could warrant more research into its benefits or harms to grassland birds as well as its effect on overall vegetation structure. Further research could also be directed towards analyses containing a larger number of vegetation variables, since the limited number of parameters included in our analysis leaves the possibility that some vegetation composition measurements not considered could show significant correlation to bird densities. Despite this, the data above generally supports the prediction that structure variables were more highly correlated with bird densities. Because vegetation structure has such a large effect on a grassland birds’ ability to feed, breed, and nest, it follows that natural selection would favor the reproductive success of individuals that prioritize those characteristics in the process of habitat
selection (Krausman 1999). Because habitat selection drives habitat preferences, it makes sense that bird densities would be more greatly affected by this type of measure (Krausman 1999).

**Species Specific Habitat Preferences**

We determined species specific habitat preferences based on the vegetation parameters showing the highest magnitude CCA axis scores. We considered these parameters biologically significant despite the trace p value indicating that they were not statistically significant because the number of compared vegetation parameters exceeded the recommended amount for this type of analysis (Palmer 1993). Future studies may consider splitting CCA between measures of vegetation structure and composition to reduce the effects of this problem and increase the analyses' statistical power (Palmer 1993. We predicted that each bird species would show specific habitat preferences that related to their behaviors. To assess this, we compared our results for species habitat preferences to those of similar studies for each species present.

Grasshopper Sparrows showed a positive relationship with bare ground cover and negative relationship with grass cover, which has been previously documented and likely relates to the birds’ need for open space to forage (Weins 1969, Whitmore 1981). This study also indicated a positive relationship between Grasshopper Sparrows and woody vegetation. Grasshopper Sparrows require tall vegetation for perching to defend territory, which makes this possible habitat preference beneficial for these birds (Weins 1969, National Audubon Society 1963). This behavior could also account for the negative relationship between Grasshopper Sparrows and forb density shown in this study, which contradicts the findings of some past studies (Weins 1969, Weins 1963). Since woody vegetation is uncommon in grassland habitats, most studies of Grasshopper Sparrow habitat have likely taken place in areas where it was not available for perches, revealing a species preference for forbs instead (Moog et al. 2002, Mass Audubon 2016). Grasshopper Sparrows in this study also show a negative relationship to effective height. Previous studies have shown mixed height preferences for different types of vegetation (Weins 1969, Weins 1973, Whitmore 1981). The preference for shorter vegetation here is likely a reflection of effective height’s relationship to vegetation structure,
especially given the small number of sites sampled in this study and the structural differences between the site occupied by Grasshopper Sparrows and other sites (Cody, 1985).

Vesper Sparrows showed similar habitat preferences to Grasshopper Sparrows. Increased litter depth and woody vegetation density have been previously seen to be positively correlated with increases in Vesper Sparrow habitat use (Thomas Wray and Whitmore 1979, Best and Rodenhouse 1984). While increased litter depth could impede foraging, it could also play a role in Vesper Sparrow nesting, providing material and necessary cover (Whitmore 1981, National Audubon Society 2016). Vesper Sparrow behavior reflects the preference for increased woody vegetation density increases available perches for defending territories (Thomas Wray and Whitmore 1979, National Audubon Society 2016). One previous study showed correlation between decreased bare ground exposure and increased Vesper Sparrow density, whereas this study showed the opposite (Wray and Whitmore 1979). This demonstrates that bare ground exposure can be a trade-off, as it allows for easier foraging but increases exposure to predators (Cody 1981, National Audubon Society 2016).

Vesper Sparrows also showed a negative relationship to hay density. Similar to Grasshopper Sparrows’ negative relationship to forb density, this also likely reflects woody density’s presence as a possible perching location and the small site sample size’s effect on certain parameter’s ability to reflect overall differences in vegetation structure.

Savannah Sparrows showed much different relationships with vegetation parameters than Grasshopper and Vesper Sparrows in this study. These differences in developed preferences indicate that Savannah Sparrows have different foraging abilities, or possibly evolved in a habitat with different food availability or predator populations (Krausman 1999). Additionally, ours and previous studies have shown correlation between Savannah Sparrows habitat preference and overall vegetation height (Wiens 1973, Cody 1981). Like Grasshopper and Vesper Sparrows, Savannah Sparrows require perches to sing from to attract mates and defend territories (Weins 1973, National Audubon Society 2016). The preference for taller perches again represents a trade-off, as while taller perches may be more effective in territory defense they are also leave birds more subject to
predation. Savannah Sparrows may trade this possible disadvantage for other habitat structure features that come with increased height. The need for perches could also explain Savannah Sparrows’ positive relationship with hay density, since we saw Bobolinks commonly perching on hay during behavioral observations. Hay density could also contribute to Savannah Sparrows’ relationship to overall vegetation density and thickness, as this can still provide advantages in protection from predators and greater insect availability (Cody 1981). Past studies have shown Savannah Sparrows occupying areas with relatively medium to high litter depth (Welsh 1975, Weins 1973). This makes sense given these birds’ need for nest material, yet we found Savannah Sparrows having a negative relationship with litter depth in this study (Weins 1973, Winter et al. 2005). This could be beneficial to birds in allowing easier movement on the ground when foraging, and could be different from past studies in that they took place in areas with different food availability and levels of predation (Winter et al. 2005). This would cause different foraging techniques to be favored, and habitat preference to evolve which would optimize the efficiency of these techniques (Krausman 1999, Winter et al. 2005).

Bobolinks showed similar habitat preferences to Savannah Sparrows, despite Savannah Sparrows being more closely related to Grasshopper and Vesper Sparrows. Past studies have also shown Bobolink habitat occupancy to be positively related to vegetation height, which this study more specifically related to hay height (Weins 1973, Winter et al. 2005). Whether this is a result of Bobolinks receiving specific benefits from hay or a coincidence based on the fields available for Bobolink nesting in this area, it emphasizes the need for delayed tilling practices, since agricultural practices can lead to Bobolink nest destruction and long term species survival (Vickery et al. 1995). Bobolinks also showed a positive relationship with grass cover, along with a negative relationship with bare ground cover, which has been indicated in past studies (Weins 1969, Cody 1981). This could be beneficial to Bobolinks in providing more nesting material and foraging opportunities (Cody 1981). Comparing Bobolink preferences to those of Grasshopper and Vesper Sparrows, which showed opposite preferences for bare ground and grass cover but preferred high litter depth, shows
that preferences which aid in behaviors like nest building are highly variable between grassland bird species and indicates the need for species-specific management practices (Wray and Whitmore 1979, Cody 1981).

Habitat preference fell into two main groups, with Grasshopper and Vesper Sparrows showing generally showing positive relationships to vegetation parameters that Bobolinks and Savannah Sparrows showed negative relationships. This can be explained in a number of ways, the first of which is competition. Interspecific competition is one of the leading drivers of habitat selection not considered in this study, which can lead to weaker competitors occupying a greater variety of habitats which may be of lower quality (Cody 1985, Krausman 1999). This could be the case here, as declining amounts of suitable habitat would increase competition for remaining available spaces (Foster et al. 2002). Furthermore, since habitat preferences exist as a result of evolution, natural selection could be driving these species to be habitat specialists rather than generalists (Vickery et al. 1992, Krausman 1999). This makes them better adapted to their particular habitat, creating a cycle that drives their preferences even farther apart (Vickery et al. 1992, Krausman 1999). Site sample size likely affects the significance of these correlations, in that three out of the four species were only present at one available site, making it difficult to draw conclusions about more widespread preferences. Additionally, Bobolinks are subject to over-counting while spot mapping, which could have affected the determined densities, and could be improved by supplementing with banding or nest counting (Bollinger et al. 1988). Despite these limitations, the difference between our study and past studies indicate the development of different habitat preferences among local populations (Winter et al. 2005).

Analyses of Vegetation Preferences and Territory Occupation

We predicted that differences between vegetation measurements from occupied territories and measurements from unoccupied spaces would be significant, but found them to be insignificant when compared just within occupied sites. This is surprising, given that several studies have used both of these measures in determining the relationship of bird populations to vegetation
measurements in the past (Weins 1973, Vickery et al. 1992, Winter et al. 2005). This could have occurred here because birds often utilize habitat outside of their designated territories, which would be especially likely if competition between species for limited habitat resulted in some being forced to use habitat to which they are not historically adapted (Cody 1985). To further explore this, it may be beneficial to study the relationship between vegetation parameters and territory size, as changes in territory size also indicate increasing interspecific competition for suitable habitat across sites (Cody 1985). Additionally, the position of the vegetation samples may not have corresponded exactly to the locations of territories, since they were chosen randomly within relatively large subplots. This created the possibility that while a subplot contained occupied territory, the exact location of the sample did not. In the future, a more strategic method of selecting sample plots could allow for closer coordination with bird territory location. To add even more certainty to the location of territories, nest searching could take place and vegetation sample locations could be planned around nest locations.

While there was no statistical significance in the difference between vegetation within and outside of occupied territories at only occupied sites, there was statistical significance in the difference between these groups when all sites were included in the analysis. This could reflect the manner in which migratory birds such as the grassland birds considered select sites. Since birds select sites by first flying over fields and choosing to look for suitable habitat within them, birds cannot determine areas of highest quality within sites until after they have settled (Hoover 2003). The energy required to then move to a different site may be too great, potentially influencing birds to stay at a site regardless of the sites’ ability to provide territory that is better in some areas than others (Hoover 2003). This is reflected in our data by showing significance in the first, more influential step of habitat selection and not the second. The difference in statistical significance could also suggest that sites are being managed well enough that more habitat of higher quality exists within sites, but that bird densities are not high enough to fill these areas. Another possible explanation is the small vegetation sample size. Analysis of site vegetation heterogeneity showed
that while there were enough samples taken to make accurate assumptions about the site as a whole, we were not able to detect differences between the mean grass and forb densities within sites at 80% confidence. This, coupled with a relatively small number of sites containing each species, makes this type of analysis less powerful than the site-wide density analysis. We recommend that future studies limit the measurement detail within each vegetation sample in order to increase the total number of samples that can be taken. Furthermore, while vegetation samples did not include any invasive plant species, some species, such as purple loostrife and bush honeysuckle, have been known to exist at these sites (Center for Invasive Species and Ecosystem Health 2016). Future studies may consider additional analysis of these plant types to study their effects on both how the bird densities and vegetation measurements are affected by their presence.

**Recommendations for Management and Future Studies**

The potential habitat preferences determined by the vegetation measurement and bird density analysis have implications for management practices, and we recommend management tactics for sites be chosen based on each species’ vegetation preferences. Typically, recommendations for grassland bird-focused land management include limiting the growth of woody vegetation and maintaining low litter depth to decrease forb density and increase grass density (Mass Audubon 2016). According to the bird density analysis results of this study, these management tactics cater mainly to the habitat preferences of Bobolinks and Savannah Sparrows, and not Grasshopper Sparrows or Vesper Sparrows. The differences in species’ habitat preferences indicate that management recommendations should be catered to specific species. Additionally, differences in habitat preference detected here and those detected in previous studies at other locations demonstrate a need for management recommendations specific to local populations, and for studies of bird habitat preference to continue as local ecosystems change (Winter et al. 2005).

Because sites vary in the habitat preference of the species being conserved, as well as the use of the land in general, several options for grassland management exist (Mass Audubon 2016). We recommended chosen tactics aim to maintain site-wide averages for vegetation measurements.
for sites where each species was present. These values were used for recommendations since the number of sites sampled was too small to determine the normal distribution of vegetation characteristics in relation to bird densities. Additionally, the results of the MANOVA analysis of occupied territories within occupied sites indicated that sites contain more than sufficient amounts of optimal habitat, indicating that our sites contain vegetation that can support increases in bird density and can serve as models for management. At sites being managed for Grasshopper Sparrows and Vesper Sparrows, we recommend management tactics that increase litter depth (greater than 5.5 cm) and bare ground exposure (greater than 25% of total plot area), as well as allow for the growth of some woody vegetation (density greater than 6.2 plants/ m²) while limiting overall vegetation height (effective height less than 24.1 cm) and density (visual obstruction measurement less than 21.9 cm). At sites aiming to conserve Savannah Sparrows or Bobolinks, we recommend tactics that encourage the growth of grass (percent cover greater than 50%) while limiting the growth of woody vegetation (density greater than 6.2 plants/ m²), as well as decrease the amount of litter accumulation (less than 5.5 cm). Management should also allow for the growth of hay (density greater than 18 plants/ m²) and for greater vegetation density (visual obstruction measurements greater than 21.9 cm) and height (effective height greater than 30.0 cm).

We also identified additional factors which can be explored in order to best plan for site management. Site size should be taken into account, as past studies have demonstrated its effects on the bird density a sites is able to support (Fletcher and Koford 2003, Bollinger and Gavin 2004). Additionally, our study did not take into account site surroundings, which sometimes included additional patches or uninhabitable area which can affect bird density and survival (Fletcher and Koford 2003). Additionally, past studies have disagreed on the ability of territory occupancy and density to predict breeding success, and that vegetation measurements within territories can be highly variable and inconsistently accurate in determining optimal habitat (Vickery et al. 1992, Winter et al. 2005). Therefore, future studies should look at nest success as a measure of bird populations to ensure the determined preferences allow for species persistence (Vickery et al. 1992,
Winter et al. 2005). These factors, along with the recommended vegetation measures, should be explored and prioritized at sites in order to allow for the continued survival of these grassland bird species.
References


AMBUEL, B., AND S. A. TEMPLE. 1983. Area-dependent changes in the bird communities and


KRAUSMAN, P. R. 1999. Some basic principles of habitat use. Grazing behavior of livestock and wildlife 85-90.


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  evapotranspiration, energy balance and surface conductance in a northern temperate
  grassland. Agricultural and Forest Meteorology 112: 31-49.

  Sons.

WHITMORE, R. C., 1981. Structural characteristics of grasshopper sparrow habitat. The Journal of

  birds. Ornithological monographs, pp.1-93.


WINTER, M., D.H. JOHNSON, AND J.A. SHAFFER. 2005. Variability in vegetation effects on density and

WITTENBERGER, J. F. 1980. Vegetation structure, food supply, and polygyny in bobolinks (Dolichonyx
Appendices

Appendix I: Sample Calculation Coefficient and Sample Size Adjustment Tables

Table 1: Standard Normal Coefficients ($Z_\alpha$) for Varying Confidence Levels

<table>
<thead>
<tr>
<th>Confidence level</th>
<th>Alpha ($\alpha$) level</th>
<th>($Z_\alpha$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80%</td>
<td>0.20</td>
<td>1.28</td>
</tr>
<tr>
<td>90%</td>
<td>0.10</td>
<td>1.64</td>
</tr>
<tr>
<td>95%</td>
<td>0.05</td>
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</tr>
<tr>
<td>99%</td>
<td>0.01</td>
<td>2.58</td>
</tr>
</tbody>
</table>

Source: Elzinga et al. 1998. Values of $Z_\alpha$ are used in the equation described earlier based on the selected confidence level to calculate necessary sample sizes.
Table 2: Sample Size Adjustment for Estimating Difference in Population Total Means at 80% Confidence

<table>
<thead>
<tr>
<th>n*</th>
<th>80% confidence level</th>
<th>n</th>
<th>n*</th>
</tr>
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<td>51</td>
<td>65</td>
<td>60</td>
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<td>6</td>
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<tr>
<td>16</td>
<td>150</td>
<td>167</td>
<td>159</td>
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</tbody>
</table>

Source: Elzinga et al. 1998. The sample size calculated using the formula described earlier is found in the left column, and the corresponding adjusted sample size based on the more complex formula is round on the right, given a desired confidence level of 80%.
Appendix II: Completed territory maps for each bird species present at each site. Spot mapping surveys conducted 23 May - 24 June 2016, notation follows standard conventions developed by the British Trust for Ornithology, with letter representing different visits. Large circles represent suspected adult male territories.

*Figure 1: Composite map of Bobolinks observed at Chestnut Hill Farm.*

*Figure 2: Composite map of Bobolinks observed at Dexter Drumlín.*
Figure 3: Composite map of Savannah Sparrows observed at Dexter Drumlín.

Figure 4: Composite map of Bobolinks observed at Doyle Reservation.
Figure 5: Composite map of Grasshopper Sparrows observed in southern part of Bolton Flats.

Figure 6: Composite map of Vesper Sparrows observed in southern part of Bolton Flats.
Figure 7: Composite map of Grasshopper Sparrows observed in northern part of Bolton Flats.

Figure 8: Composite map of Vesper Sparrows observed in northern part of Bolton Flats.
Figure 9: Composite map of Bobolinks observed at Wachusett Meadow.

Figure 10: Composite map of Bobolinks observed at Breakneck Hill.
Appendix III: Mean (SE) of vegetation parameters subject to correlation analysis for 6 sites, Chestnut Hill (CHE), Dexter Drumlin (DEX), Doyle Reservation (DOY), Bolton Flats (BOL), Wachusett Meadow (WAC), and Breakneck Hill (BRE), measured from 23 May – 9 July 2016.

<table>
<thead>
<tr>
<th>Site</th>
<th>Litter Depth (cm)</th>
<th>Bare Ground (cm)</th>
<th>Robel Pole (cm)</th>
<th>Effective Height (cm)</th>
<th>Grass Density (plants/m²)</th>
<th>Grass Cover (Scale 1-6)</th>
<th>Grass Height (cm)</th>
<th>Forb Density (plants/m²)</th>
<th>Forb Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHE</td>
<td>3.2 (0.9)</td>
<td>1.0 (0.4)</td>
<td>25.0 (3.1)</td>
<td>36.8 (6.4)</td>
<td>1036.5 (166.3)</td>
<td>5.2 (0.3)</td>
<td>25.9 (8.2)</td>
<td>199.3 (31.7)</td>
<td>28.9 (5.3)</td>
</tr>
<tr>
<td>DEX</td>
<td>2.8 (0.3)</td>
<td>1.0 (0.3)</td>
<td>48.2 (21.5)</td>
<td>45.5 (21.4)</td>
<td>1184.6 (219.8)</td>
<td>4.6 (0.3)</td>
<td>37.3 (6.5)</td>
<td>141.1 (26.1)</td>
<td>59.4 (6.3)</td>
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<tr>
<td>DOY</td>
<td>5.5 (1.0)</td>
<td>0.4 (0.2)</td>
<td>55.2 (8.3)</td>
<td>42.3 (7.6)</td>
<td>500.8 (136.9)</td>
<td>4.9 (0.3)</td>
<td>58.5 (6.5)</td>
<td>152.0 (32.6)</td>
<td>72.6 (10.0)</td>
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<tr>
<td>BOL</td>
<td>5.7 (0.9)</td>
<td>2.4 (0.4)</td>
<td>144.1 (21.1)</td>
<td>10.7 (97.7)</td>
<td>280.3 (120.3)</td>
<td>2.4 (0.2)</td>
<td>28.6 (4.4)</td>
<td>25.4 (5.3)</td>
<td>58.6 (5.9)</td>
</tr>
<tr>
<td>WAC</td>
<td>2.7 (0.7)</td>
<td>1.3 (0.9)</td>
<td>71.3 (18.2)</td>
<td>37.3 (15.4)</td>
<td>1623.3 (445.5)</td>
<td>4.0 (0.6)</td>
<td>44.0 (13.1)</td>
<td>38.9 (11.3)</td>
<td>77.3 (11.3)</td>
</tr>
<tr>
<td>BRE</td>
<td>3.6 (0.7)</td>
<td>2.0 (0.9)</td>
<td>32.0 (11.4)</td>
<td>33.8 (15.4)</td>
<td>838.3 (445.5)</td>
<td>3.9 (0.6)</td>
<td>34.8 (13.2)</td>
<td>51.5 (15.0)</td>
<td>65.4 (23.2)</td>
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</table>

<table>
<thead>
<tr>
<th>Site</th>
<th>Woody Density (plants/m²)</th>
<th>Hay Den (plants/m²)</th>
<th>Hay Height (cm)</th>
<th>Bedstraw Density (plants/m²)</th>
<th>Bedstraw Frequency (Plots)</th>
<th>Bedstraw Cover (Scale 1-6)</th>
<th>Vetch Density (plants/m²)</th>
<th>Vetch Frequency (Plots)</th>
</tr>
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<tbody>
<tr>
<td>CHE</td>
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<td>168.7 (4.2)</td>
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Appendix IV: Spearman’s correlation coefficient ($r_s$), and probability that values are not correlated ($p$) for vegetation parameters based on site averages of samples collected at 6 sites from 27 June - 9 July 2016. $r_s^2$ values are presented in the lower left triangle, and $p$ values in the upper right.

<table>
<thead>
<tr>
<th>Litter Depth</th>
<th>Bare Ground</th>
<th>Robel Pole</th>
<th>Effective Height</th>
<th>Grass Density</th>
<th>Grass Cover</th>
<th>Grass Height</th>
<th>Forb Density</th>
<th>Forb Height</th>
</tr>
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<tbody>
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<td>0.56</td>
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<td>0.8</td>
<td>&lt; 0.01</td>
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<td>Forb Density</td>
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<td>0.2</td>
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<td>Hay Density</td>
<td>Hay Height</td>
<td>Bedstraw Density</td>
<td>Bedstraw Frequency</td>
<td>Bedstraw Cover</td>
<td>Vetch Density</td>
<td>Vetch Frequency</td>
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</table>
Appendix V: Vegetation measurements averaged between samples taken in occupied and unoccupied territories for each bird species, within sites where the species was present. Measurements were obtained at 6 sites between 27 June – 9 July 2016 and made into occupied and unoccupied groups based on territory map results for each species, seen in Appendix II.

<table>
<thead>
<tr>
<th>Species</th>
<th>Sample location</th>
<th>Litter Depth</th>
<th>Bare Ground Cover</th>
<th>Robel Pole Height</th>
<th>Effective Height</th>
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<tbody>
<tr>
<td>BOBO</td>
<td>territory</td>
<td>3.6 (0.4)</td>
<td>0.9 (0.2)</td>
<td>43.8 (7.7)</td>
<td>43.7 (7.3)</td>
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<tr>
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<td>4.1 (0.9)</td>
<td>2.0 (0.4)</td>
<td>42.5 (5.7)</td>
<td>39.9 (6.5)</td>
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<td>2.2 (0.3)</td>
<td>22.0 (3.5)</td>
<td>19.5 (3.1)</td>
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<tr>
<td>SAVS</td>
<td>territory</td>
<td>2.3 (0.3)</td>
<td>1.1 (0.3)</td>
<td>55.2 (21.5)</td>
<td>55.8 (21.4)</td>
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<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
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<td>1.7 (0.2)</td>
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<td>31.4 (4.7)</td>
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<td>1.8 (0.5)</td>
<td>17.0 (4.5)</td>
<td>10.1 (2.9)</td>
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<td>3.3 (0.7)</td>
<td>10.6 (4.2)</td>
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<td>1.4 (0.2)</td>
<td>37.3 (4.8)</td>
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<tr>
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<td>territory</td>
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<td>1.7 (0.8)</td>
<td>22.1 (7.6)</td>
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<td>2.7 (0.5)</td>
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<td>4.2 (0.4)</td>
<td>1.6 (0.4)</td>
<td>35.6 (4.8)</td>
<td>34.6 (4.6)</td>
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<table>
<thead>
<tr>
<th>Species</th>
<th>Sample location</th>
<th>Woody Density (plants/ m²)</th>
<th>Hay Density (plants/ m²)</th>
<th>Hay Height (cm)</th>
<th>Bedstraw Cover (scale 1-6)</th>
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<tbody>
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<td>BOBO</td>
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<td>N/A</td>
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<td>territory</td>
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<td>95.4 (12.6)</td>
<td>73.9 (6.6)</td>
<td>1.5 (0.2)</td>
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