Factors affecting habitat use and abundance patterns of birds in a grassland-savanna-woodland habitat mosaic

Submitted by

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I. INTRODUCTION AND OBJECTIVES

Since European settlement, many North American vegetation types have been altered, or lost from the landscape (Whitney 1994). In the eastern portion of the American Midwest, in an area classified as the prairie-oak transition, situated between the open grasslands to the west and deciduous forests to the east (Curtis 1959), human land-use changes has severely reduced the extent of native prairie and savanna (Nuzzo 1986, Savage 2004). In addition, loss of disturbance from the landscape (e.g., fire and grazing) has changed grasslands and savannas by allowing succession toward climax communities that differ in both their plant community composition (florisitcs) and their vegetation structure (physiognomy) (Larsen 1953, Abrams 2000, Wolf 2004, Nowacki and Abrams 2008, Rogers et al. 2008). In southern Wisconsin, this process has led to a change in the dominant tree species. Oak (*Quercus sp.*) has declined in dominance, while shade-tolerant species like maple (*Acer sp.*) have increased in dominance (Rogers et al. 2008).

These successional changes in trees are likely to affect bird distributions. Vegetation floristics, physiognomy, and resource availability are influential in partitioning assemblages of bird species within and between habitats (MacArthur and MacArthur 1961, Rotenberry and Wiens 1980, Cody 1981, Wiens and Rotenberry 1981, Rotenberry 1985, MacNally 1990, Rodewald and Abrams 2002). In Wisconsin grasslands and savannas, 58 species of breeding birds are known to be grassland or savanna associates with 26 listed as species of management concern (Sample and Mossman 1997). Furthermore, many more species of neartic-neotropical migrants utilize habitats found in Wisconsin during migration (Ewert and Hamas 1996). However, it is unclear what specific proximate settlement cues and ultimate resource elements within Wisconsin's varied habitat types are important for migrant birds.

During spring migration birds must locate resources to replenish energy losses (Lindström 1991, McWilliams et al. 2004, Chernetsov 2006). Flowering trees have been shown to cue migrating birds to the availability of herbivorous arthropods in Illinois woodlands (Graber and Graber 1983, Strode 2004) and Arizona riparian habitat (McGrath et al. 2008). Some arthropod species synchronize their hatch period to that of plant bud-burst and leaf out events in order to maximize their use of the nitrogen-rich young vegetative material available (Hunter and Lechowicz 1992, Hunter 1992, Quiring and McKinnon 1999). In Wisconsin, it is unclear whether arthropod resources available to foraging migratory birds differ among tree species. Additionally, whether migratory birds display plasticity in their use of tree species in response to the shifting phenological stages they encounter during spring migration has been little explored (Strode 2004). These questions are of particular concern given the shift in dominant tree species over much of the upper Midwest (Leach and Givnish 1999).

To manage and conserve species of concern, as well as monitor migrating birds, efficient techniques are required for measuring factors affecting avian habitat use. Ornithologists have developed many techniques for measuring resources as well as floristic and physiognomic features of habitat that are thought to influence bird distribution patterns. Such methods include assessing resource use (Cooper and Whitmore 1990, Johnson 2000, Johnson and Sherry 2001), quantifying vegetation structure with measures such as foliage-height diversity (MacArthur and MacArthur 1961) or visual obscurity (Robel et al. 1970), and using plot-level inventories of vegetation composition (Daubenmire 1959, James and Shugart Jr 1970, Noon 1981). These ground-based data collection methods are valuable in their ability to characterize habitat on small scales.

However, they are labor intensive and expensive, making large scale avian-habitat monitoring problematic. Habitat mapping with remotely sensed landcover data offers a solution and has been successfully applied to numerous species and habitat types (Aspinall and Veith 1993, Turner et al. 2003).

Remote sensing analysis has been successfully used to monitor correlates of avian species and diversity patterns. Investigators have integrated remote sensing data with ground-collected data to answer ecological questions throughout the world (Pidgeon et al. 2003, Laurent et al. 2005, Hale 2006, Duro et al. 2007, Pasher et al. 2007, St-Louis et al. 2006, St-Louis et al. 2008). Whereas ground-based studies are spatially precise, remote sensing methods are often more efficient but may sacrifice spatial precision depending on the grain of the remote sensing data. Remote sensing approaches traditionally map vegetation types which are then linked to distributional patterns of species of interest. An alternative method, image texture analysis, has been used to measure vegetation patterns and fine scale distributions of bird species in heterogeneous vegetation types including eastern deciduous and conifer forests, sparsely vegetated desert grasslands, shrublands, and woodlands, and South American grasslands (Hepinstall and Sader 1997, St-Louis et al. 2006, Tuttle et al. 2006, St-Louis et al. 2008, Bellis et al. 2008). However, the degree of flexibility of image texture in other habitat types is not known, and it is unclear if image texture is correlated with vegetation structure in a prairie-savanna-woodland habitat system, or if it is a useful predictor of avian abundance patterns in that ecosystem.

Effective management and conservation of neotropical bird species requires understanding resource and habitat use during all aspects of their annual cycle, including spring migration (Robins et al. 1989, Askins, 1990, 2002, Sillett and Holmes 2002). Quantifying bird species abundance across the prairie, savanna, woodland continuum can yield insight into the importance of these vegetation types for migrants. Furthermore, accurate and efficient mapping is also important for monitoring and management within these habitats. Image texture analysis is a method that may allow mapping large areas of the prairie-to-woodland continuum efficiently, with a focus on vegetation structure.

The overarching goal of this dissertation is to measure factors affecting habitat use and abundance patterns of birds in grasslands, savannas, and woodlands at Fort McCoy Military Installation using both remotely sensed and ground-measured data across varying spatial scales.

This dissertation addresses five objectives related to the overarching goal. **1)** I will examine tree-species preferences and arrival times of neotropical migrants in Wisconsin savannas and woodlands. **2)** I will test two competing hypotheses of drivers of neotropical migrant passerine use of stop-over habitats: tree phenology versus vegetation structure. **3)** I will investigate whether neotropical migrants follow a selective or an opportunistic strategy during refueling at a stop-over site**. 4)** I will examine the use of image texture as a tool for predicting vegetation structure and mapping vegetation types. **5)** I will investigate the use of image texture as a tool for predicting bird species abundance across varying vegetation types.

The five major objectives will be addressed in five chapters:

CHAPTER 1: Tree-species use and arrival times of insectivorous migratory birds in Wisconsin savannas and woodlands. It is not clear which tree species or which cues insectivorous neotropical migrants use to select resources in forests in southern Wisconsin. I propose to investigate whether some tree species are selected as foraging substrates during migration with greater frequency than they occur, through use of foraging observations. This chapter will provide insight into whether successional changes within the historic range of oak, toward more mesic species, have implications for migratory bird foraging resources. Looking to the future, and tree range shifts in response to global climate change (Iverson and Prasad 1998, Visser 1998, Harrington et al. 1999, Visser 2001, Strode 2003, Visser and Both 2005), this study will give insight into how a change in floristics may affect spring migrants during stop-over.

CHAPTER 2: Tree flowering versus vertical vegetation structure as cues for foraging migrant birds. In Wisconsin, passerine birds use a variety of tree-dominated habitats as stop-over sites during spring migration, ranging from savannas, to dense forest (Ewert and Hamas 1996). Oak savanna habitat, which used to be a dominant vegetation type in southern Wisconsin, is characterized as a mixture of low density, open grown oaks with a grass and forb dominated herbaceous layer (Curtis 1959). Open grown oaks situated in savanna tend to have larger, broader crowns than closed canopy woodland oaks which tend to have smaller, narrower crowns (personal observation). Furthermore, oaks are wind pollinated (Sharp and Chisman 1961, Sharp and Sprague 1967). Because of this, oaks that are situated in savanna that are exposed to more sun and wind may allocate more resources to flower development thus having more densely packed catkin bundles (Givnish 2007, pers. comm.).

It is well known that high vegetation vertical complexity is correlated with high bird species diversity (MacArthur and MacArthur 1961, Cody 1981, Cody 1985). I believe that oak woodland habitat has greater vertical vegetation complexity (i.e., foliage height diversity) than savanna. Yet, it is not clear if migrant birds use vertical vegetation complexity or high flower abundance as cues for selecting stop-over locations. In this chapter, I propose to test two competing hypothesis of drivers of habitat selection for neotropical migrants: that birds use tree phenology as a cue, and that birds use vegetation structure as a cue. First, I will compare tree flower abundance and associated food resources on trees in oak savanna with tree flower abundance and associated food resources in closed canopy woodlands and assess the strength of the association with bird presence and abundance with these explanatory factors. Second, I will compare the power of foliage height diversity in savanna and closed woodland to explain bird presence and abundance. This chapter will be the first study to quantify the importance of oak flowers versus vegetation structure to neartic-neotropical spring migrants.

CHAPTER 3: Stop-over foraging patterns of neotropical migrants: selective or opportunistic. Resource use has not been quantified for migrating warblers during spring migration in oak dominated vegetation types in southern Wisconsin. I propose to identify food items used by spring neartic-neotropical migrants in oak savanna and woodland vegetation types during migration and to compare what they eat (through stomach content analysis) with what is available to them, to determine whether their use of food items is selective or opportunistic.

CHAPTER 4: The use of image texture as a tool for predicting and mapping vegetation structure. Image texture analysis has recently been used to explore woody plant encroachment in African savannas (Hudak and Wessman 1998, Hudak and Wessman 2001) map saltcedar (*Tamarix parviflora)* distribution in California (Ge et al. 2006), investigate image texture differences due to phenology (Culbert et al. *in review*), and to improve vegetation classifications in various systems throughout the world (Moskal and Franklin 2001, Zhang and Franklin 2002, Coburn and Roberts 2004). Although these studies successfully employed texture measures to investigate questions related to vegetation patterns and distributions, they did not specifically evaluate or make use of image texture to quantify vegetation structure. Vegetation structure, quantified using a foliage-height diversity method (MacArthur and MacArthur 1961), is an important ecological characteristic of vegetation communities as well as a correlate of occurrence patterns for many wildlife species (Cody 1981). In this chapter, I propose to explore the use of remotely sensed image texture as a tool for predicting and mapping vegetation structure. This analysis will be important for advancing knowledge about remotely analyzing vegetation structure, and about the potential of mapping patterns of vegetation structure over broad geographic ranges.

CHAPTER 5: The potential of image texture for predicting bird species abundance. Image texture analysis has been used to predict bird species richness (St-Louis et al. 2006, St-Louis et al. 2008), compare breeding bird territory sizes (Tuttle et al. 2006), and to map bird habitat quality(Bellis et al. 2008). A strength of image texture analysis is the ability to characterize fine scale ecological patterns such as spatial variation in vegetation while simultaneously covering broad areas and multiple vegetation types. Although image texture analysis shows promise for predicting avian habitat, it is still a relatively new technique. The aim of this chapter is to investigate the ability of image texture to predict patterns of bird abundance in a prairie, savanna, woodland matrix.. The findings of this chapter will be useful in understanding how well image texture predicts bird distribution patterns across an open to closed tree canopy continuum.

STUDY AREA:

The study area for this dissertation is Fort McCoy Military Installation, located in the driftless area of southwestern Wisconsin, USA, in Monroe County (Fig 1.). Fort McCoy was selected for this study due to the range of vegetation types from open sand prairie, to savanna, to closed canopy woodlands and forest that are representative of southern Wisconsin. Dominant trees, shrubs and grasses at Fort McCoy include Black Oak (*Quercus velutina*), Northern Pin Oak (*Q. ellipsoidalis*), Bur Oak (*Q. macrocarpa*), Jack Pine (*Pinus banksiana*), Black Cherry (*Prunus serotina*), Red Oak (*Q. alba*), White Oak (*Q. alba),* Red Maple (*Acer rubrum*), Big-toothed Aspen (*Populus gradidentata*), Quaking Aspen (*P. tremuloides*), Red Pine (*P. resinosa*), White Pine (*P. strobus*), Blueberry (*Vaccinium angustifolium*), American Hazelnut (*Corylus americana*), Black Huckleberry (*Gaylussacia baccata*), Big Bluestem (*Andropogon gerardi*) and Little Bluestem (*Schizachyrium scoparium*).

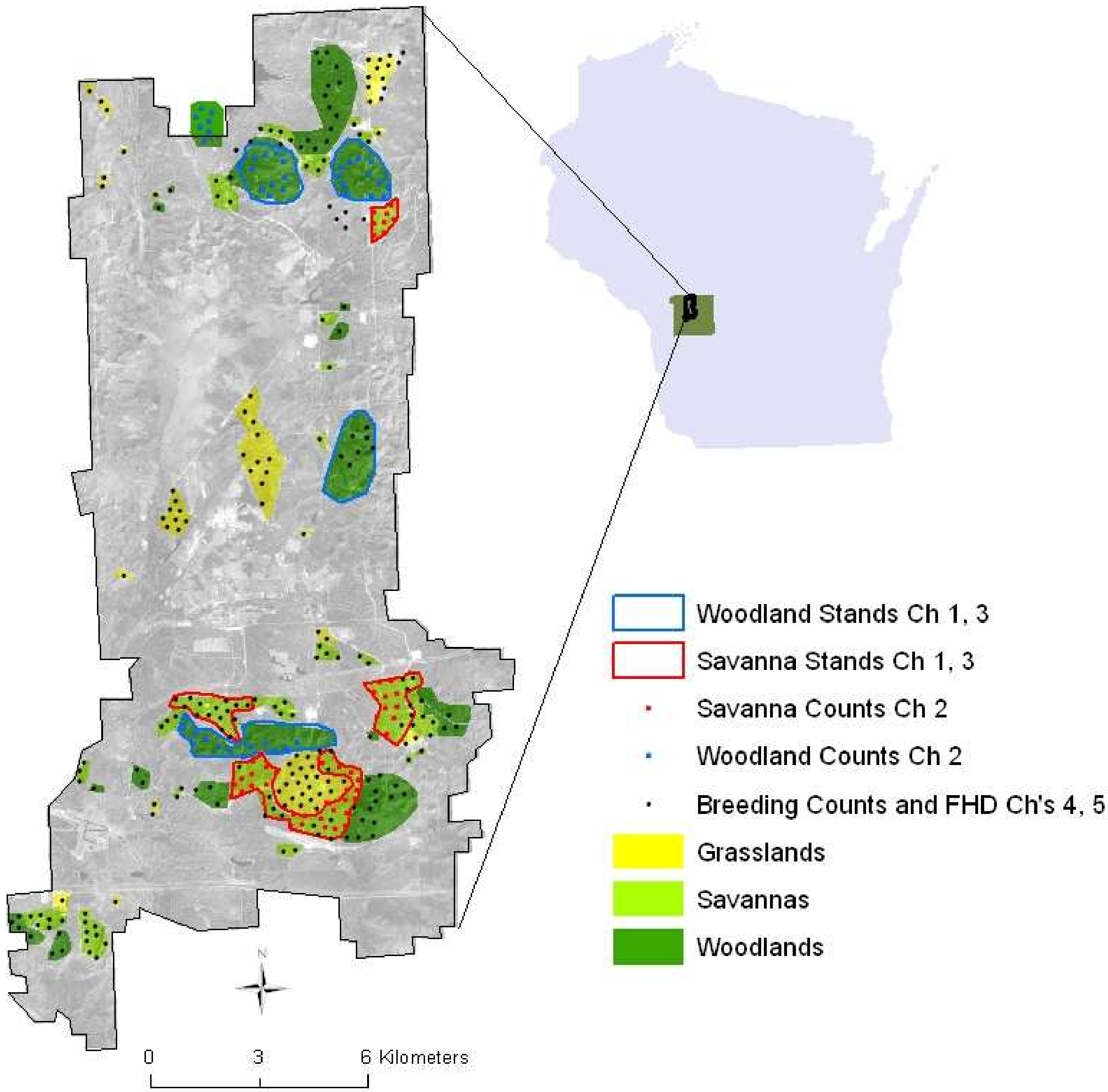

Figure 1. Fort McCoy Military Installation displaying sampling design for all Chapters. **Chapter 1, 3:** Distribution of eight sample stands for stop-over use patterns of neotropical migrant bird species study. Red outlined polygons represent savanna sample stands. Blue outlined polygons represent woodland sample stands. **Chapter 2:** Distribution of 83 randomly selected sample points. Red squares represent savanna sample points. Blue squares represent woodland sample points. **Chapter 4 and 5:** Distribution of 330 breeding season sample points displayed as black squares. Grassland, savanna, and woodland vegetation types that are available for sampling are highlighted.

Chapter 1: Tree-species use and arrival times of neotropical migrants in Wisconsin savannas and woodlands.

I. Background:

Spring migration is a taxing time in the life cycle of migratory bird species (Lack 1968, Alerstam and Högstedt 1982, Hutto 2000, Newton 2004, Greenberg and Marra 2005, Newton 2006, Hedenström 2008). Amid the many challenges birds face, such as predator avoidance (Lindström 1990, Schmaljohann and Dierschke 2005, Lind and Cresswell 2006), inhospitable weather (Rappole and Warner 1976, Richardson 1978), and inter and intra-specific competition (Moore and Yong 1991), birds must make critical decisions regarding resource selection at stop-over sites (Hutto 1985, Moore et al. 2005, Chernetsov 2006, Buler et al. 2007, Smith et al. 2007). Stop-over habitat can be defined as "…areas with the combination of resources (e.g., food, cover, water) and environmental conditions (e.g., precipitation, presence and absence of competitors and predators) that promotes site occupancy by a given species and allows individuals to survive…" (Morrison et al. 2006). Optimal stop-over locations may allow birds to refuel (i.e. forage) efficiently , and thus to depart quickly to the next stop-over location or breeding area (Loria and Moore 1990, Moore and Yong 1991, Moore and Simons 1992, Moore et al. 1995, Smith and Moore 2003, Schaub et al. 2008). Since migration involves risks and energy demands, determining what habitat to use during stop-over is a critical decision affecting fitness and survival of individuals of all migratory species (Berthold and Terrill 1991, Moore et al. 2005).

Birds are hypothesized to use proximate cues that vary over spatial scales to aid in their selection of stop-over habitat (Hutto 1985). In the central portion of North America, birds move northward along the Mississippi flyway from southern Texas and Louisiana along the Mississippi River Valley, and spreading out across most of the upper Midwest and boreal regions of Canada. Within this flyway, stop-over selection occurs in a mosaic of habitats that differ both in their vegetation composition (floristics) and their vegetation structure (physiognomy) including grasslands, savanna, woodlands, forest, shrublands, edge communities, riparian zones, and wetlands (Ewert and Hamas 1996, Petit 2000). During each stop-over period, birds must find food resources to replenish energy stores that are used during long migratory flights (Moore and Yong 1991, Smith and Moore 2003, Moore and Kerlinger 1987, Sandberg and Moore 1996, Smith and Moore 2005, Németh and Moore 2007). Although Hutto's hypothesis was put forth more than 20 years ago, it is still unclear which proximate cues birds use within Midwestern oak dominated habitats during their spring journeys.

One proximate cue birds may use to select stop-over habitat during spring migration is plant flowering phenology (Marra et al. 2005, Rodewald and Brittingham 2007, McGrath et al. 2008). The timing of egg hatch of many arthropod species coincides with bud-burst of plant species and thus, the new larvae can feed on the nitrogen rich young vegetation materials (Hunter 1987, Wolda 1988, Hunter and Willmer 1989, Hunter 1990, Huntly 1991, Hunter 1992, Quiring 1993, Jordano and Gomariz 1994, Ivashov et al. 2002, Russell and Louda 2004, Mjaaseth et al. 2005, van Asch and Visser 2006, Forkner et al. 2008). In Illinois woodlands, migratory warbler arrival times in spring have been observed to coincide with peak caterpillar abundance (Graber and Graber 1983, Strode 2002, Strode 2004). In a desert-riparian system, spring migratory birds preferentially select heavily flowering honey mesquite (*Prosopis glandulosa*) as a cue for the high energy resource of arthropods that are present (McGrath et al. 2008). However, the relationship or arrival times of birds to tree flowering phenology, and the patterns of tree species use by birds during stop-over, have not been explored in southern Wisconsin.

II. GOALS, OBJECTIVES, AND HYPOTHESES:

The overarching goal for this chapter is to identify foraging habitat substrates selected by neartic-neotropical migrants at stop-over sites.

The two chapter objectives I propose are to **(1)** determine the relationship between arrival time of neartic-neotropical warblers and flowering phenology of dominant tree species in a savanna, woodland matrix in southwestern Wisconsin, and to **(2)** determine if certain tree species are selected as foraging substrates with greater frequency than they occur.

H1: ARRIVAL TIMES OF NEOTROPICAL BIRDS RELATED TO TREE FLOWERING PHENOLOGY: Bird species use tree flowering phenology as a settlement cue to help time their migration to match the resources available. If this is true, then I will find high correlations between tree flowering phenology and bird arrival.

H2: TREE SPECIES USE: Certain flowering tree species are used by migrant warblers with greater frequency than their proportional availability in the. If this is true, then I will find higher correlation between migratory warbler presence on a selected tree species than if use of the tree species was neutral. The proportion of migrants observed on trees of the selected species will be a larger number than the proportion of that tree species to total trees in the landscape.

III. METHODS:

ARRIVAL TIMES SAMPLE POINTS:

To select sample points to investigate arrival times of migrating birds related to flowering trees, four savanna and four woodland stands at Fort McCoy were digitized using a 0.25 m resolution Black and White air photograph taken in August of 2006. In each of the savanna and woodland areas, 83 random points separated by greater than 300 m from each other, were selected from an original set of 200 randomly generated points using the Hawth's Tools extension (Beyer 2004, Fig. 1).

FOCAL TREE SAMPLING DESIGN:

At the 83 random sample points, an observer will select a random direction and walk to the first tree of the following seven species: Black or Pin Oak, Red Oak, White Oak, Bur Oak, Red Maple, Black Cherry, or Jack Pine. That tree will be flagged as a focal tree. All trees within 25 m of the focal tree will be tallied by species. Only two trees of the same species will be marked as a focal tree at each random point. Returning to the set of randomly generated points, this process will be repeated until 20 trees of each species are tagged for a total of 140 focal trees. According to this design the maximum possible number of focal trees per random point would be 14.

TREE MEASUREMENTS:

At each of the 83 randomly selected points following similar methods to Holmes and Robinson (1981), Gabbe et al. (2002), and Hartung and Brawn (2005), I propose to use a point-center quarter technique (Cottam and Curtis 1956) to gain information on tree species composition. In addition to the point-center quarter method, I propose to measure diameter at breast height (dbh), density, and frequency for all trees of 2.5 cm dbh within each sub-plot. Importance values (IV) for each tree species will be calculated: IV = relative frequency + relative density + relative cover (i.e., basal area per hectare); where relative frequency = number of species x/number of total trees, relative density = number of species x/area sampled, in ha, and relative cover = absolute cover (i.e., basal area per hectare)/total cover.

TREE SPECIES PHENOLOGY:

At each of the focal trees, an observer will monitor tree bud-burst phenology using the following methods developed at the Harvard Forest:
http://harvardforest.fas.harvard.edu/data/p00/hf003/hf003.html.
A tree phenology score will be assigned based on the proportion of the focal tree that is observed, through binoculars, in the following states: 1) no bud, 2) flower bud tip showing, 3) full bud emergence, 4) flower emerging, 5) light flowering, 6) heavily flowering, 7) flowers wilted (e.g., pollen released), 8) leaves < 2 cm, 9) leaves >2 cm, and < 6 cm leaves, 10) leaves > 6 cm. In addition, I will score flower intensity using a modification of tree flowering quantification from McGrath et al. (2008) where each observer will monitor the proportion of the tree that is in light (< 5 catkins per bundle), medium (5-15 catkins per bundle), and heavily flowering (>15 catkins per bundle).. Trees will be visited two times per week from mid-April, to early June. All tree flowering phenology data will be pooled per tree species and assigned a date specific "phenology index" (average tree species phenology score).

ARRIVAL TIMES OF WARBLERS RELATED TO TREE SPECIES PHENOLOGY:

I will to focus on common insectivorous spring neotropical migrants found throughout Wisconsin (Table 1). During each phenology assessment of a focal tree, a three minute observation will be completed where an observer will document any insectivorous migratory songbird that uses the tree. Each tree will be visited two times per week throughout the study period. All tree flowering phenology and

Table 1. Fifteen potential study species. Asterisks (*) indicate local breeder.

Common Name	Scientific Name
Tennessee Warbler	*Vermivora peregrina*
Blue-winged Warbler*	*V. pinus*
Golden-winged Warbler*	*V. chrysoptera*
Nashville Warbler*	*V. ruficapella*
Northern Parula	*Parula americana*
Chestnut-sided Warbler*	*Dendroica pennsylvanica*
Magnolia Warbler	*D. magnolia*
Cape-may Warbler	*D. tigrina*
Blackburnian Warbler	*D. fusca*
Black-throated Green Warbler	*D. virens*
Blackpoll Warbler	*D. striata*
Bay-breasted Warbler	*D. castanea*
American Redstart*	*Setophaga ruticilla*
Canada Warbler	*Wilsonia canadensis*
Wilson's Warbler	*W. pusilla*

migratory bird data will be pooled per tree species and assigned a date specific "phenology" (average tree species phenology score) and "migratory bird species index" (mean number of focal migratory warblers per tree).

BIRD FORAGING OBSERVATIONS:

To gain information on foraging behavior of migrant warblers related to tree species use, an observer will systematically walk throughout one of the eight study stands at a selected starting point and actively search for foraging flocks of neotropical migrant warblers using standardized methods (Holmes and Robinson 1981, Remsen and Robinson 1990). Once a flock is found, the observer will choose an individual of a focal species and will follow and document the bird's activities and movements for as long as possible up to five minutes within the boundaries of the study stand. Using a digital recorder and a stopwatch, the observer will document the following data on: species, sex, time spent in each tree, number of perch changes (e.g. hops or flights), frequency of prey attacks, type of attack (1. flower glean, 2. flower eating 3. leaf glean, 4. bark glean, 5. hover, 6. hawk, 7. sally, and 8. flush-chase), tree species, and tree phenology state (see Harvard Forest methods above). All data will be transcribed into a database that afternoon.

STATISTICAL ANALYSIS:

Unless otherwise noted, all analyses for this dissertation will be completed using the R statistical software package (R Development Core Team 2005).

The following statistical tests will be used to specifically address each hypothesis.

H1: ARRIVAL TIMES OF NEOTROPICAL BIRDS RELATED TO TREE FLOWERING PHENOLOGY: A date and sample point specific "migratory bird species index" will be regressed against average tree "phenology index" levels. I will to use non-parametric tests to compare arrival times of migrant warblers to their frequency of occurrence on flowering trees across a time gradient from early April to early June. These results will be plotted, with date on the x-axis and peak occurrence of neotropical migrant warblers, plus peak flowering time of species-specific trees within the study stands on two y-axes.

H2: TREE SPECIES USE: Two indices, a "search index" and an "attack rate index" will be derived from the foraging observations (Robinson and Holmes 1982). These indices will be statistically related to tree species and "tree phenology index" in a mixed effects modeling framework.

To investigate whether birds forage on each tree species in proportion to their availability, I propose to compare observed frequencies with expected frequencies. Expected frequencies will be calculated, by tree species, by multiplying the IV of the tree species by the total number of observations of individual migrant birds on the tree species. This will be repeated for each focal bird species and for the focal group collectively. I propose to use a chi-square goodness-of-fit analysis to investigate the preference index of each foraging bird species for each tree species following methods of Holmes and Robinson (1982).

IV. Sampling strategy:

I will collect tree phenology, and bird observation data in 2009 and 2010 from early April continuing through early June to fully capture the temporal differences of the earliest to the latest neotropical migrants.

V. Expected and preliminary results:

In 2007 and 2008, maple flowered earliest at Fort McCoy, in early April. Trees in the Red Oak group (e.g., Black, Pin, and Red) flowered during the middle of May, whereas trees in the White Oak group (e.g., Bur and White) flowered at the end of May terminating their flowering period in early June (personal observation). Neartic-neotropical migrants passed north during this same period.

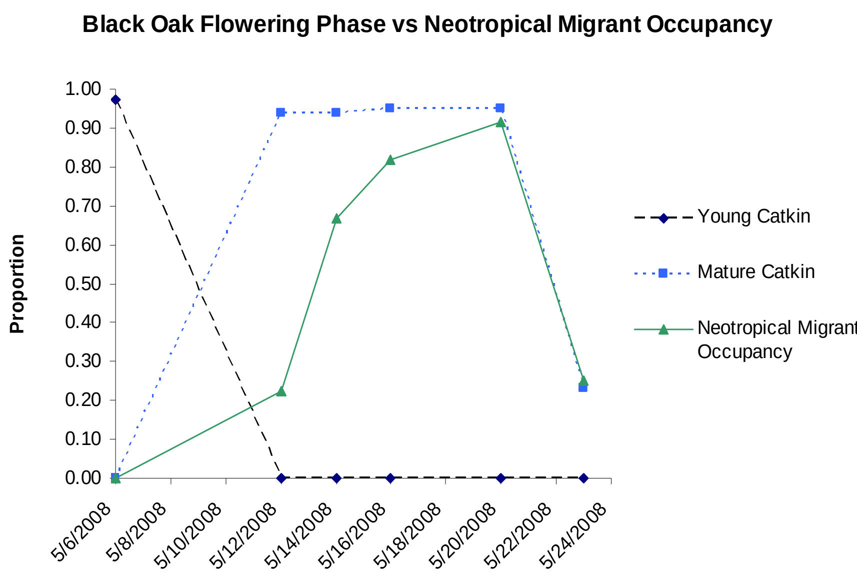

Figure 2. The relationship of the spring phenology events of tree flowering versus neotropical bird arrival and departure. Information about the proportion of young catkins (early flowering), and mature catkins (peak flowering) were gathered from 48 replicate Black Oak trees located at 12 sample points within a stand of savanna during six visits from May 6, 2008 to May 23, 2008. The proportion of each of these trees that had greater than 10% of young or mature catkins for that date are displayed. During these six visits, 100 m fixed radius bird point counts for Neotropical migrant occupancy were completed. The proportion of the 12 sample sites that had at least one of the neotropical study species (see Chapter 1, Table 1) detected are displayed.

Exploratory field work was carried out in the spring of 2008 to investigate when oaks situated in savanna are in flower, and when neotropical migrants arrive and depart . At 12 sample sites, 48 Black Oak trees were located and visited on six different occasions from May 6 to May 23. During each of these visits, observers collected information on flowering stage, in categories including young flower emergence, mature flower emergence, and young and mature leaf emergence. During each of these visits, observers also carried out a five minute, 100 m fixed radius bird point count, gathering information on all birds seen or heard within the 100 m radius boundary. The proportion of each of the 48 Black Oak trees that had at least 10% of either young catkins, or mature catkins was assessed on each of the six visits. In addition the proportion of sites that had at least one of the neotropical migrant study species (see Table 1) detected during each of the six counts was also assessed. There is a clear relationship between the timing of mature flowering of Black Oak trees and the arrival of neotropical migrants (Fig. 2). Furthermore, there is strong coincidence between the fading of flowers and the departure of birds (Fig. 2). I seek to expand on these results by sampling birds and flowering phenology on more tree species and more stands during the 2009 and 2010 spring migration seasons.

Exploratory field work was carried out in the spring of 2008 to investigate the foraging behavior of birds during stop-over. Results suggest that migrant birds clearly use flowers over other physiognomic areas of an oak (e.g., the leaf or bark) (Table 2). Furthermore, birds meticulously hop along oak branches, as evidenced by the high hop to search ratio, searching catkin bundles for food items. Our results do not indicate that these warbler species are using other portions of the tree in high frequency. Although these results do not determine tree selection by warblers, it is clear that more data needs to be collected to determine factors associated with settlement and tree species preferences.

VI. SIGNIFICANCE:

The character of southern Wisconsin forests is changing. In order to ensure that habitat for neotropical migrants is available in sufficient quantity, it is necessary to understand selection and use of specific tree species as stop-over habitat. Understanding the connection between migrant arrival times and tree flowering is also imperative. This study will add to our understanding of migration and stop-over ecology, including insights about factors motivating migrant behavior, and insights into the ramifications for migrants, of climate change, and the associated shift in tree species, in Wisconsin.

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Table 2. Foraging behavior of six neotropical warbler species in oak savanna habitats at Fort McCoy from May 12 to May 23, 2008. Mean and standard deviation scaled to document each search tactic or attack per minute for each species. Sample size (*n*), total seconds for each species monitored (s), the search tactics of hops (H), and flights (F), perch changes, a hop to flight ratio, oak catkin flower attacks, leaf attacks, and total attacks shown. Bark attack, hover gleaning, and sally attack information was collected but not included in this table due to birds choosing these attack preferences in very low frequency throughout the study.

Species	*n*	(s)	Hops (H)	Flights (F)	Perch Δ (H+F)	H/F ratio	Flower Attack	Leaf Attack	Total Attacks
Tennessee Warbler	40	6381	5.5 (3.9)	1.1 (1.0)	6.7	4.8	5.0 (5.6)	0.1 (0.5)	5.1
Blackburnian Warbler	12	2039	10.9 (8.2)	1.1 (1.2)	12.0	10.2	4.0 (3.1)	0.1 (0.3)	4.1
Cape-may Warbler	11	2065	12.1 (9.7)	1.3 (0.9)	13.4	9.2	9.4 (8.1)	0.02 (0.1)	9.6
Bay-breasted Warbler	8	1322	10.1 (4.8)	1.9 (2.0)	12.0	5.3	2.4 (2.2)	0.1 (0.1)	2.6
Magnolia Warbler	5	1433	7.1 (3,2)	1.8 (2.4)	8.9	4.0	3.2 (1.7)	0.1 (0.1)	3.5
Blackpoll Warbler	4	968	1.0 (0.7)	6.1 (2.0)	7.1	6.1	2.0 (1.8)	0.2 (0.4)	2.2

CHAPTER 2: Tree flowering versus vertical vegetation structure as settlement cues for foraging migrant birds

I. BACKGROUND:

Since European settlement, many North American vegetation types have been severely diminished in area, altered, or lost from the landscape (Whitney 1994). In the American Midwest, one of the most endangered vegetation types in North America, oak savanna, previously covered an area from Texas northwards along the Mississippi flyway into Manitoba (Nuzzo 1986, Anderson et al. 1999, Leach and Givnish 1999). Savanna vegetation types are classified as having a low tree density, ranging from 5% up to 50% tree cover, with a diverse herbaceous layer composed of grasses and forbs (Curtis 1959, Taft 1997, Anderson et al. 1999). In Wisconsin, two types of oak savanna previously occupied large portions of the area south of the tension zone: oak openings dominated by Bur Oak, and oak barrens dominated by Black and Northern Pin Oak (Curtis 1959).

The primary reasons oak savannas are nearly absent from the central North American landscape are conversion for anthropogenic uses and disturbance suppression (e.g., suppression of fires) (Dorney 1981, Lorimer 1985, Hicks Jr 1997, Abrams and Nowacki 2008). Without disturbance, succession changes savanna into woodlands and ultimately forests (Sousa 1984, McCune and Cottam 1985, Wolf 2004). Once shade is abundant in these woodlands, maple (*Acer spp*.) and other late successional climax species become established and create conditions that eventually shade out species of shade-intolerant oaks thus altering the vegetation composition and structure of the savanna community (Larsen 1953, Hix and Lorimer 1991, Lorimer et al. 1994, Abrams 1998, Fei and Steiner 2007, Abrams and Nowacki 2008, Nowacki and Abrams 2008, Rogers et al. 2008).

Previous studies have shown that a shift in the floristics of oak dominated woodlands to late successional forests has negative effects on oak associated migratory and breeding bird species (Rodewald and Abrams 2002, Rodewald 2003). As the overall floristics of a stand change, so does the physiognomy of the oak trees that grow under the new conditions. Oaks are wind pollinated (Sharp and Chisman 1961, Sharp and Sprague 1967). In open savanna, oaks tend to have larger, broader crowns due to increased wind and sun exposure. As succession changes the floristics of an oak savanna into a climax community composed of mesic species such as maple and American Basswood (*Tilia americana*.), the lower branches of oaks are shed in order to allocate resources to growing taller in search of sun and wind (Givnish 2007, pers. comm.), and new oak that are established under woodland conditions have less well developed lateral branches. In 2007 and 2008, I observed oaks in savanna that were flowering on all branches, whereas in woodlands, I only observed flowers on the highest branches of oaks. Thus, these successional changes directly influence amount of flowers per tree which may influence use by migratory birds

Ecologists have long recognized the importance of vegetation structure in shaping bird communities and distributions (Cody 1981). I believe dense oak woodlands have more vertical vegetation structural diversity than oak savannas. This study proposes to compare neotropical migrant abundance as well as resource abundance between open canopy savannas and closed canopy oak woodlands. This project will specifically test which of vegetation structure or resource availability of oaks occurring in savanna versus woodland are more influential to birds in selecting stop-over locations. This will be the first study to quantify the importance of oak flowers and resource availability in central North American oak savannas to neotropical spring migrants.

II. Goals, Objectives, and Hypotheses:

The overarching goal of this chapter is to test two competing hypotheses of drivers of neotropical migrant passerine use of stop-over habitats: phenology versus foliage height diversity.

The four chapter objectives are to investigate: **(1)** if there are differences in flower intensity between oaks in savanna versus woodlands, **(2)** if there are differences in arthropod resources between savannas and woodlands, **(3)** if there are differences in foliage-height diversity measurements between savanna and woodlands, and finally, **(4)** to compare the strength of association between avian abundance and foliage-height diversity, flowering intensity, and arthropods.

H1: FLOWERING INTENSITY: Open grown oaks in savannas flower more heavily, i.e. each tree has a greater number of flowers, than oaks in woodland stands.

H2: ARTHROPOD RESOURCES: Arthropods are more abundant on oaks in flower than on oaks without flower, and the more mature the flowers, the more abundant the arthropods are.

H3: FOLIAGE-HIEGHT DIVERSITY: Oak woodlands have greater vertical structural diversity than oak savannas.

H4: RESOURCES VS VEGETATION STRUCTURE: Insectivorous neartic-neotropical migrant birds select foraging substrates based on their arthropod abundance rather than their structural diversity. If this is true, then I will find a stronger association between avian abundance and arthropod abundance than between avian abundance and foliage height diversity.

III. Methods:

Migrant Bird Point Counts Sample Points:

From Chapter 1 I will use the four savanna and four woodland stands within which 83 random points were identified, as point count stations.

Migrant Bird Point Counts:

I will conduct standard 50 m fixed-radius bird point counts (Hutto et al. 1986, Ralph et al. 1995) at the 83 randomly selected sample points to document relative abundance of migrant songbirds from early April to early June. I will have three field assistants. Counts will begin at sunrise and continue until 9:30 a.m in favorable weather conditions. Observers will visit sample points two to three times per week from early April to early June to repeatedly document relative abundance of migrant species. To distribute observer bias, observers will be rotated daily between sample points throughout the counting season. In addition, sample points will be grouped into routes and walked in opposite direction on alternate visits (e.g., visit one: sample points 1→10; visit two sample points 10→1). Only birds detected within a 50 m radius boundary will be analyzed for this study due to lower detectability rates of migrant bird species compared to breeding bird species. Distance from observer to bird will be recorded for all detected species.

FLOWERING TREE SAMPLING:

At the 83 point count sample points, each observer will perform a detailed assessment of tree phenology within the 50 m radius counting circle. For sample points that are dominated by a homogenous stand composed of a single tree species, four randomly selected trees of the homogenous species will be sampled. The tree closest to the bird point count center point, will be sampled along with one in a random distance (to 50 m) within each of the three sectors 0-120°, 120-240°, 240-360° (Fig. 3). For sample points that fall within a heterogeneous stand of trees, the methodology will be modified as follows; two of each representative tree species (e.g., Bur Oak, White Oak, Red Oak, Red Maple) will be sampled. For example, if a stand is dominated by Red Oak, Red Maple, and White Oak, the flowering stage of two Red Oaks, two Red Maples, and two White Oaks will be recorded at this sampling point. Each randomly selected tree will be flagged and gps'ed, and visited on each subsequent point count. A date specific "phenology index" for each counting station averaged over all the assessed trees, will be developed. Tree phenology data will be collected immediately following point counts using the Harvard Forest method described in Chapter 1.

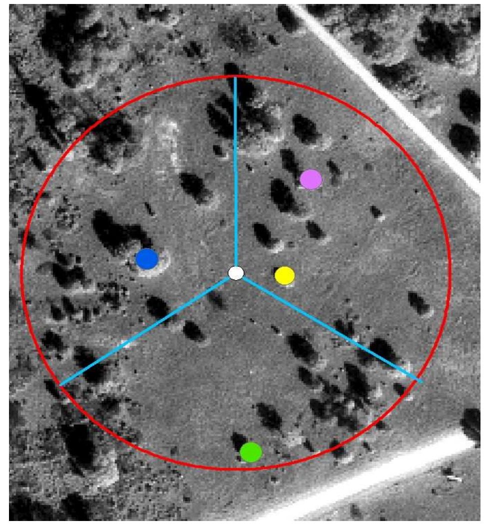

Figure 3. Proposed sampling design for monitoring tree phenology and arthropod sampling: bird point count center point (white) with a 50 m radius boundary (red boundary) located in a homogenous savanna stand of black oak. Four trees are randomly selected based on the tree closest to the bird point count center point (yellow), and one in a random distance and bearing falling within the following bearing ranges: 0-120° (purple), 120-240° (green), and 240-360° (blue).

ARTHROPOD AVAILABILITY COLLECTION:

I will sample availability of arthropods at the same trees where flowering phenology assessments are collected. .A modified 'active branch bagging' sample method will be used (Cooper and Whitmore 1990, Johnson 2000, Ozanne and Leather 2005). A 12 m tall telescoping pole with 2 foot-circular metal ring with a sack firmly attached will be used for all sampling. The modification is that rather than actively sampling only where birds forage I will sample the study trees at four different locations on each tree once each in the lower 1/3 of canopy, middle 1/3 of canopy, and upper 1/3 of canopy, randomly choosing one of the cardinal directions for each sample. All vegetation (e.g., flower catkins, leaves) located on a "sampled" area of a tree will be clipped and removed in the sack.

All materials will be placed in a plastic bag and sorted. All arthropods will be identified to order using a stereomicroscope, measured to the nearest millimeter, and tallied by morpho order (after Johnson 2000).

FOLIAGE-HEIGHT DIVERSITY MEASUREMENTS:

Foliage height diversity measurements will be collected at each of the 83 sample points to gain site specific information of vegetation structure (MacArthur and MacArthur 1961). At the sample point center point, and at three randomly selected sub-plots within the 50 m radius sample point boundary (following the procedure for selecting trees; see Fig. 3 above) observers will use a 12 m tall telescoping pole partitioned into segments of 30 cm to document foliage height diversity. From the center of each of the four sub-plots, an observer will walk 5 m in each of the cardinal directions and record any vegetation that intersects the pole at a specific height category. This will yield four measurements at each of the four sub-plots totaling 16 random foliage height profile measurements within each bird point count sample point. These values will then be pooled and used to calculate foliage height diversity for the plot, using the Shannon Index (Equation 1; Shannon 1948, Krebs 1989) for total hits of vegetation at different height segments for each of the 83 sample points.

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Equation 1. Shannon Index , a measure of the complexity of vertical vegetation at a plot, as calculated from the proportion of vegetation hits within each height segment (e.g., < 30 cm, 30-60 cm, 60-90 cm, etc) at 16 sample points per plot.

STATISTICAL ANALYSIS:

Simple summary statistics (e.g., box plots, descriptive tables, etc…) will be generated for all data collected, described above, comparing savanna versus woodland.

Furthermore, the following tests will be used to specifically address each hypothesis.

H1, H2, H3: For HI, H2, and H3 detrended correspondence ordination analysis (Hill 1979) will be used to investigate differences in tree flowering, arthropod resources, and foliage-height diversity across a tree canopy cover gradient.

H4: RESOURCES VS VEGETATION STRUCTURE: A mixed-modeling framework will be used to investigate correlations between avian abundance and flowering intensity, arthropod abundance, and foliage-height diversity. Interactions between these three predictors will also be investigated in models.

IV. SAMPLING STRATEGY:

Pilot bird point count and tree phenology data was collected during the 2008 field season from April 21 to early June. I propose to collect two more seasons of migration, tree phenology, and arthropod data in 2009 and 2010 beginning earlier in the season (e.g., early April) continuing to early June for to fully capture the temporal range of variability from earliest to latest arriving neotropical migrants.

V. EXPECTED AND PRELIMINARY RESULTS:

In 2008, flowering intensity appeared greater in savanna stands than woodland (Fig. 4). Woodland trees had higher apparent medium flowering intensity than savanna.

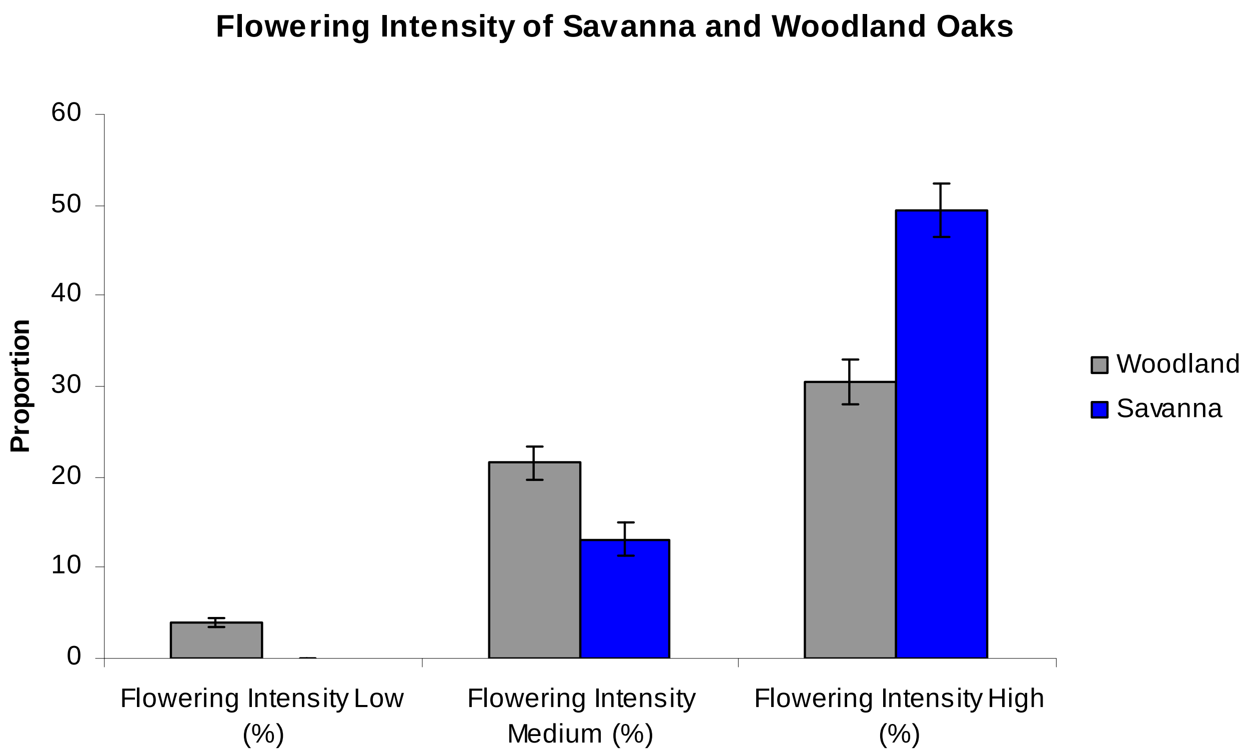

Figure 4. Average proportion of flowering intensity (see tree phenology methods Chapter 1) with standard error bars during the period May 15 to May 26 of 92 Black Oak trees located in savanna, and 166 Black, Red, and White Oak trees located in woodlands. Low = % of flowering portion of tree with < 5 catkins per bundle; Medium = % of flowering portion of tree with 5-15 catkins per bundle. High = % of flowering portion of tree with >15 catkins per bundle.

In 2008, foliage-height diversity data was collected at 12 woodland sample points, and 90 savanna sample points. When foliage-height diversity is expressed as the Shannon Index, there appears to be more vegetation structure complexity in woodland stands than in savanna (Fig. 5). Foliage-height diversity measurements have been collected at all savanna sample points. Not all woodland sample points have been sampled. Once all field data is collected at the remaining woodland sample points, I expect there will be a greater separation between current savanna and woodland Shannon index values.

In 2008, 100 m fixed radius point counts were conducted at the 83 sample points. All sample points were visited at least six times from May 5 to May 26. Preliminary data suggests that warbler richness, neotropical warbler richness, neotropical warbler abundance, and Tennessee Warbler (TEWA) abundance are all greater in savanna stands than woodland stands. I expect similar results from 2009 and 2010 data (Fig. 6).

Although I did not collect arthropod abundance data in 2008, I expect data from 2009 and 2010 will show more arthropods in savanna than woodland stands. I also expect stronger correlations between regression models of flower intensity, arthropod abundance, and migratory warbler abundance. I expect that the results from this chapter will provide support for the "resource availability" hypothesis I put forth explaining warbler distribution patterns more than the "vegetation vertical structure" hypothesis.

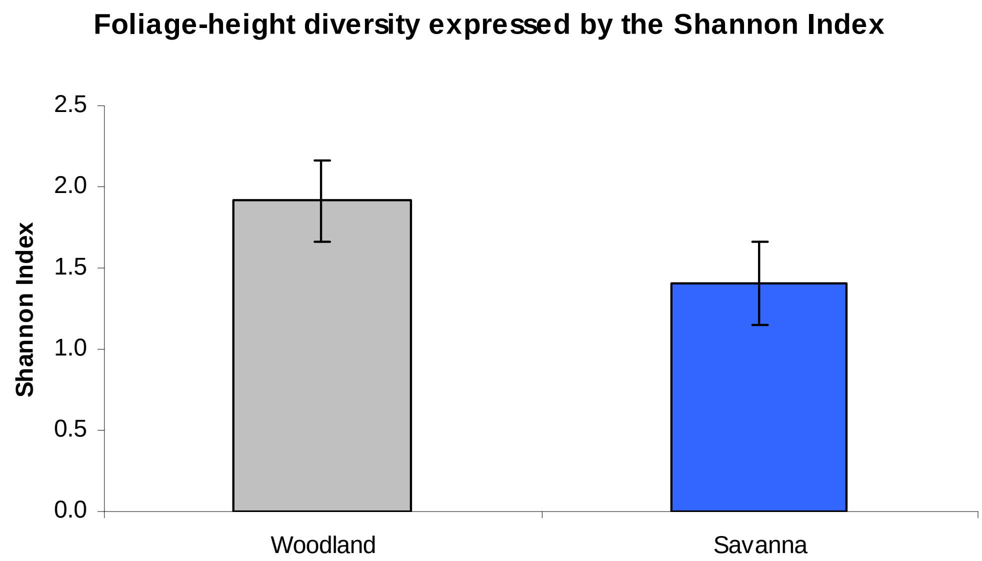

Figure 5. Average foliage-height diversity measurements with standard error bars expressed as the Shannon index for 12 woodland sample points and 90 savanna sample points

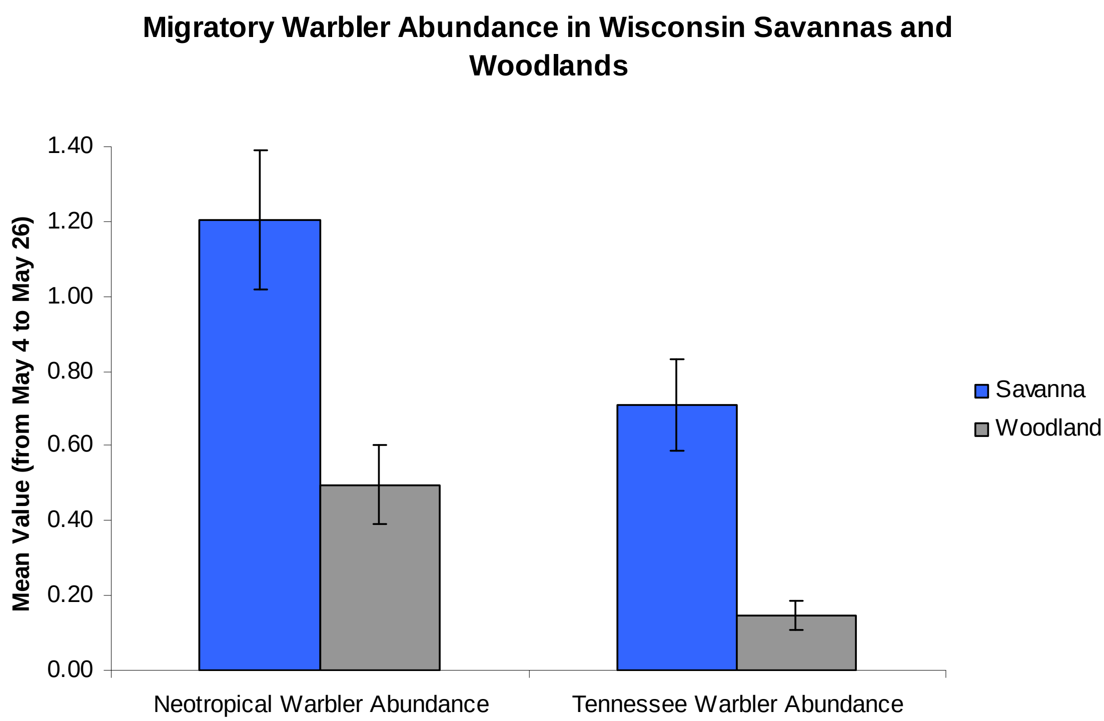

Figure 6. Mean neotropical warbler abundance and Tennessee Warbler abundance with standard error bars collected at 83 sample points distributed equally between savanna and woodland. At each point a 100 m fixed radius point count was completed. Each point was visited on at least six occasions from May 5 to May 26, 2008.

VI. SIGNIFICANCE:

Oak species are recognized for their importance to wildlife. Yet, few studies have quantified use of oak savanna by migrant birds (Grundel and Pavlovic 2007). This study will evaluate two competing hypothesis about drivers of avian patterns in spring, refining our understanding of the role of tree flowers, arthropods, and vegetation structure as determinants of distribution patterns of migratory warblers in Wisconsin savannas and woodlands. These results are expected to clarify the relative importance of savanna to migratory birds.

CHAPTER 3: Stop-over resource use by neotropical migrants: selective or opportunistic.

I. BACKGROUND:

During migration, birds must locate food resources quickly and efficiently at stop-over locations. High-quality stop-over habitat with abundant food resources may allow birds to rapidly refuel and thus make quick departures to the breeding grounds (Moore and Kerlinger 1987, Sandberg and Moore 1996). Poor quality stop-over habitats with limited food resources negatively influence refueling rates thus potentially affecting migration time and possibly breeding success (Moore and Francis 1991, Moore and Yong 1991, Smith and Moore 2003, Smith and Moore 2005, Moore et al. 2005). Food availability has been hypothesized to be an important intrinsic (within-habitat) factor governing the distribution of migratory birds (Hutto 1985). However, the relationships between resource use and neotropic migratory bird foraging behavior is not well understood in oak dominated habitats in southern Wisconsin.

Oaks have long been known to be a major resource for birds, and wildlife generally, for the foods supplied (e.g., acorns) and shelter (e.g., cavities) provided (Webb 1977, Block et al. 1992, Rodewald 2003, Somershoe and Chandler 2004, McShea et al. 2007). Furthermore, birds may use the flowering stage of oaks (e.g., bud burst) as a proximate cue to ultimate resource availability (e.g., moth larvae) (Visser 2001,Both and Visser 2005, Both et al. 2006, Both and te Marvelde 2007). In English woodlands, resident Great Tits *(Parus major)* time their egg laying dates to match the flowering and leafing phenology of Pendunculate Oak *(Q. robur)* (Van Noordwijk et al. 1995, Visser 1998, Buse et al. 1999). As Pendunculate Oaks flower and leaf out, the larvae of Winter Moth *(Operophtera brumata)* emerge to feed on the highly palatable vegetation material. The Great Tit feeds Winter Moth larvae to their chicks. In addition to the Great Tit, the long distance migratory Pied-Flycatcher (*Ficedula hypoleuca*) closely times its first laying date upon arrival at the breeding grounds to that of the bud-burst patterns of Pendunculate Oaks to also take advantage of lepidopteron abundance as a food source for its young (Both and Visser 2005, Both et al. 2006, Both and te Marvelde 2007). Although these breeding/resource-use relationships have been well studied in the United Kingdom, there have been few studies investigating migrant bird resource use at stop-over sites in North America (Graber and Graber 1983, Strode 2004, Rodewald and Brittingham 2007, McGrath et al. 2008).

I propose to gain insight into ultimate resources birds use during stop-over. Specifically, in this chapter I will investigate what food items neotropical migrants use when they refuel in oak savanna and woodland vegetation types. I will determine whether their use of food items is selective or opportunistic.

II. GOALS, OBJECTIVES, AND HYPOTHESES:

The overarching goal of this chapter is to determine whether neotropical migrants follow a selective or an opportunistic foraging strategy at a stop-over site.

The **two chapter objectives** I propose are **(1)** to investigate what food items neotropical migrants use when they refuel in savanna and wooded vegetation types and to **(2)** determine whether their use of food items is selective or opportunistic during stop-over.

H1: FOOD RESOURCE USE: Relative abundance of morpho taxa of arthropods found in stomach contents of migratory warblers will be highly correlated with abundance of arthropod morpho taxa present on flowering oak trees.

H2: FOOD RESOURCE AVAILABILITY: Foraging birds are selective in their choice of arthropod prey species. If this is true, then I will find differences in arthropod obtained from active branch sampling at foraged section of trees versus samples from non-foraged sections of trees

III. METHODS:

FOOD RESOURCE USE ASSESSMENT:

Analysis of food consumed by birds is required to understand how selective migrants are, and to relate use to availability. To gain information on avian diet, birds will be captured using mist nets and given an emetic to obtain stomach contents. All mist netting will take place in one of the eight study stands. I will erect nets in locations within stands that have the best chance of catching the highest number of potential study species.

I will erect arrays of both ground and canopy nets (Ralph et al. 1993) and use call/song playbacks of focal species played continuously at locations near nets (Johnson and Sherry 2001). For all study species captured, a non lethal emetic, Ipecac$_c$ (Diamond et al. 2007) will be administered to acquire stomach contents following an animal use protocol approved by the Research Animal Resources Center (#A1361). This is necessary to understand resource selection of migrants related to resource availability. Each sample will be visually inspected using a stereroscope for arthropod parts, and if possible, these parts will be identified to order following methods of McGrath et al. (2008). For all birds captured that are not part of the stomach contents study, we will release the birds at the net without a band since all personnel resources will be needed for processing focal birds.

ASSESSING ARTHROPOD AVAILABILITY AND USE BY BIRDS:

ACTIVE BRANCH SAMPLING:

To assess food resource use, this study proposes to use an "active branch sampling" technique to quantify arthropod use related to foraging warblers (Johnson 2000). Active branch sampling is used for sampling the arthropods on specific portions of a tree. A 12 m telescoping pole with a two foot-radius circular metal ring with a cloth bag (e.g., pillow case) firmly attached will be used for all arthropod branch sampling. One observer will walk through one of the eight study stands (e.g. savanna or woodland) and actively search for a flock of migrating warblers. After a flock is found, the observer will raise the telescoping pole to a portion of the tree where the birds are actively foraging, place the pole and bag around the branch, and clip all vegetation (e.g., flowers and leafs) into the cloth bag. All arthropods captured will be moved into a plastic bag, identified and measured to the nearest millimeter (after Johnson 2000).

In order to gain information on what arthropods are available to foraging birds, during the same sampling event, an area of the tree equivalent to the site where birds were observed foraging (e.g., similar aspect and height, and distance from trunk) will be selected where birds were not observed foraging. Arthropods will be collected, using the same method.

Statistical Analysis:

H1: FOOD RESOURCE USE: Use versus availability of invertebrate prey food items will be assessed through a comparison of occurrence and abundance of invertebrate taxa in the stomach contents to invertebrates captured during the use versus availability active branch sampling. A chi-square framework will be used for this analysis.

H2: FOOD RESOURCE ABUNDANCE: To test whether foraging birds remove a quantity of arthropods large enough to be detected, and thus to assess food resource use versus availability, Analysis of Variance tests will be used to compare insect samples obtained from active branch sampling at foraged section of trees versus samples from non-foraged sections of trees.

IV. Sampling strategy:

I propose to conduct these sampling efforts during the spring and early summer of 2009 and 2010.

V. Expected and preliminary results:

I expect that there will be positive correlations between the arthropods in migratory bird's stomach contents and arthropod resources found on sections of trees where warblers are observed to be foraging and that these correlations will be stronger than the correlation between foraging and non-foraging locations.

VI. Ecological and Theoretical Significance:

Quantifying use of resources by birds in migration will contribute to our knowledge of migration ecology, and resource selection of insectivorous neotropical migratory birds

CHAPTER 4: The use of image texture as a tool for predicting and mapping vegetation structure.

I. BACKGROUND:

Wildlife ecologists regularly use ground-based sampling to assess vegetation characteristics that are thought to influence biodiversity patterns (Mueller-Dombois and Ellenberg 1974, Morrison et al. 2006). A common field method used to gather data on vegetation structure is foliage-height diversity (MacArthur and MacArthur 1961). Foliage-height diversity measurements are designed to quantify heterogeneity in vegetation vertical structure within a habitat patch. These measurements are flexible in that they can be used in systems ranging from sparse grasslands to dense forests. Since these methods were introduced by MacArthur and MacArthur (1961) many studies have successfully employed foliage-height diversity measurements as a correlate to bird occurrence (Tramer 1969, Wiens and Rotenberry 1981, Cody 1981, 1985, Patterson and Best 1996, Estades 1997, Greenberg et al. 1997, Johnson and Sherry 2001, Poulsen 2002, Smith et al. 2008).

Although measures derived from ground data, such as foliage-height diversity, are useful predictors of birds, they are labor intensive to collect. Furthermore, these methods generally provide little information across broad scales, thus making large scale prediction of biodiversity, or monitoring of habitat, problematic. In addition, many regions of the globe are difficult to access for long term ground-based field monitoring (Noss et al. 1997). Remotely sensed data offers at least a partial solution for ecological prediction and monitoring.

The analysis of remotely sensed data is used to investigate broad scale biodiversity patterns (Roughgarden et al. 1991, Stoms and Estes 1993, Innes and Koch 1998, Jensen 2000, Nagendra 2001, Turner et al. 2003, Wulder et al. 2004, Gottschalk et al. 2005, Tweddale and Melton 2005, Duro et al. 2007, Xie et al. 2008). Ecologists use remote data sources ranging from fine grained aerial photography to coarse grained satellite imagery to elucidate broad scale patterns of landscape configuration (Turner et al. 2001), and biodiversity assessments (Roughgarden et al. 1991, Turner et al. 2003). Remote sensing methods are especially useful for distinguishing between broad landcover classes. However within landcover classes, or in broad ecotone areas, there is substantial heterogeneity in the amount of cover. Use of remotely sensed data to characterize areas that differ in relatively fine scale features like vertical vegetation structure has, until recently, been little explored.

Vegetation structure can differ substantially within a landcover class, and image texture analysis.has been used to characterize this heterogeneity indirectly, and to predict biodiversity patterns based on the heterogeneity (St. Louis et al 2006). Image texture analysis has been used to characterize vegetation ranging from woody plants in African savannas (Hudak and Wessman 1998, Hudak and Wessman 2001) to invasive plant distributions (Tsai et al. 2005, Ge et al. 2006). However, a direct connection between image texture and vertical diversity has not been established, to my knowledge.

IMAGE TEXTURE:

Tone and texture are the two principle properties of raster based image sources. Tone refers to the high and low brightness values (or digital numbers) of pixels in an image, whereas texture refers to the spatial distribution of digital numbers throughout an image source. Tone and texture are not independent qualities of an image. Some images are dominated by tone (homogenous digital numbers across an image) whereas others are dominated by texture (heterogonous digital numbers across an image).

Image texture is quantified using first-order (occurrence) and second-order (co-occurrence) statistics. First-order statistics, such as variance, mean, range, minimum, maximum and entropy do not consider pixel neighbor relationships (Haralick et al. 1973, Haralick 1979). Rather, in an area of interest, gray tone values are assigned to each specific cell then summarized based on a chosen first-order statistic giving a total value for that area of interest. Second-order statistics, such as angular second moment, second-order variance, contrast, correlation, and entropy (see Haralick 1973 for additional ten second-order statistics) consider associations and relationships between neighboring cells (Haralick et al. 1973, Haralick 1979, Hall-Beyer 2007). To quantify these neighboring relationships, the digital numbers are first translated into a gray-level co-occurrence matrix (GLCM) which is the basis of the calculation (Hall-Beyer 2007).

Using image texture analysis high-resolution data sources, such as air photos, may be used to estimate within-habitat vegetation patterns such as the spatial arrangement of trees (Fig. 7). The scale at which vegetation heterogeneity is quantified can be varied by using imagery with different grain size, and by summarizing texture measures within windows of different sizes.

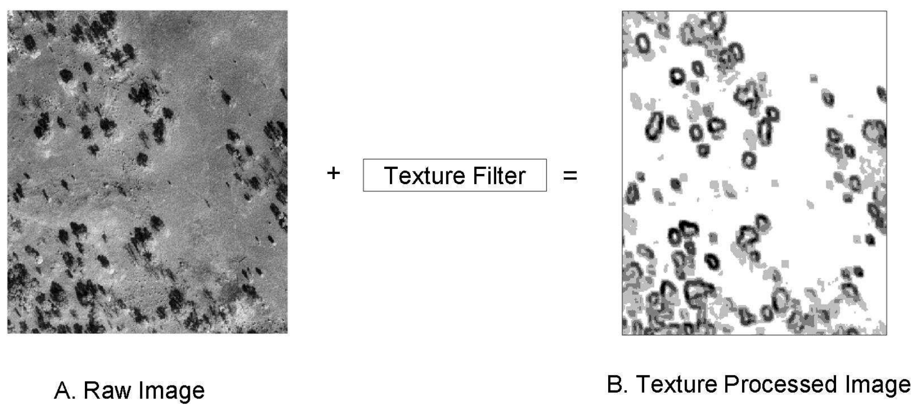

Figure 7. An example of applying a texture filter to a high resolution air photo depicting a savanna ecotone at Fort McCoy Military Installation, WI, USA. A raw aerial photograph (A.) is processed using a texture filter yielding the raw photo processed for (B.) texture.

II. GOALS, OBJECTIVES, AND HYPOTHESES:

The overarching goal of this chapter is to investigate the use of image texture as a tool for predicting vegetation structure and for mapping grassland, savanna, and woodland.

I propose to address the following **two main objectives** related to the overarching goal. **(1)** Is image texture a good proxy for vertical vegetation structure? **(2)** Can image texture be used to distinguish between and map grassland, savanna, and woodland?

H1: RELATIONSHIP BETWEEN VEGETATION STRUCTURE AND IMAGE TEXTURE USING HIGH RESOLUTION AIR-PHOTOS: Image texture derived from high-resolution air photos is a correlate to within-habitat vertical vegetation structure. If this is true I expect to find positive correlation between foliage-height diversity and measures of image texture.

H2: RELATIONSHIP BETWEEN VEGETATION STRUCTURE AND IMAGE TEXTURE DERVIED FROM FINE AND MEDIUM-GRAIN IMAGE SOURCES: Image texture derived from fine-grained image sources will be better correlated with foliage-height diversity measurements than image texture measures derived from medium-grain image sources.

H3: MAPPING VEGETATION TYPES USING IMAGE TEXTURE ANALYSIS: Image texture derived from fine grained imagery (i.e. ~ 1 m resolution) will more accurately differentiate between vegetation types (e.g., grassland versus savanna) than image texture derived from medium grained (i.e. 30 m resolution) imagery.

III. Methods:

Sample Points:

Potential sample point locations were selected within a grid of permissible survey locations, stratified by grassland, savanna and woodland dispersed throughout Fort McCoy. To refine my universe of interest, using a leaf-on, infrared aerial photograph taken in late August 2006, polygons were manually digitized including all areas falling within four dominant vegetation types at Fort McCoy: 1. open grassland, 2. sparse canopy savanna 3. closed canopy woodlands, and 4. human modified landscapes (e.g., mowed firing ranges). Human modified landscapes were not considered further. Within polygons of grassland, savanna and woodlands, 600 random sample points were generated using the Hawth's Tools extension (Beyer 2004) in ArcGIS 9.3 (ESRI, Redlands, California, USA 2008). Points for sampling were selected from this group so as to construct efficient walking routes, with points separated by at least 300 m but not more than 400 m. This resulted in a total of 330 points, distributed throughout my study area. Vegetation is assessed within 100-m radius of the center point (see Chapter 1, Fig. 1).

Foliage-Height Diversity Measurements:

Following the methodology described in Chapter 2, measures of vertical structure at four subplots will be collected at each of the 330 sample points (MacArthur and MacArthur 1961). In addition to using this data for estimating foliage height diversity, I will also estimate horizontal diversity, calculated as the standard deviation of the highest vegetation 'hit' at each of the four sampling points within each of the subplots. Thus a total of 16 vegetation tallies will go into each sample point measure of ground-based vegetation structure.

Remote Data Sources:

I will use air photos and satellite imagery for image texture analysis (Table 3).

Remote Sensing Analysis:

Image texture will be calculated at a range of scales. All images will be processed for texture in various window sizes ranging from small to large to encompass the area of the 100 m radius boundary sample point circle using the ENVI software package (Research Systems Inc., Boulder, Colorado).

Table 3. Imagery used for Fort McCoy texture analysis study. Ideally both air-photo and satellite imagery will be available from summer months (leaf-on) and the spring months (leaf-off). In addition to aerial photos and Landsat TM, data Aster (15 m resolution)may also be analyzed.

Imagery Source	Date	Resolution
Air-photos		
Black-and-white Infrared	August 2006, Leaf-on	0.25 m
Panchromatic	April 2005, Leaf-off	0.50 m
Satellite		
Landsat TM	Not yet acquired	30 m

As a window moves through an image, a measure of texture is calculated and assigned to the central pixel of that window size. This process is then repeated for each pixel across the image. To summarize texture within an area of interest (e.g., 100 m radius circle), the mean or standard deviation of all texture values within the area of interest is calculated. Since different scales (as represented by window sizes) may by more strongly correlated with foliage height diversity at the scale of the ground measurements different window sizes will be used for different image sources. Air-photos will be processed in a 3x3, 9x9, 15x15, 31x31, and a 61x61 window. The 61x61 window corresponds to approximately 15 meters of area for the 2006 Black-and-white image. Image texture from Landsat TM imagery will be processed in 3 x 3 windows, 5 x 5, and 7 x 7 windows, which corresponds to the diameter (200 m) of the buffer.

I will focus on measures which, in recent studies, have been useful in characterizing vegetation distribution patterns (Hudak and Wessman 1998, Hudak and Wessman 2001, Chan et al. 2003, Coburn and Roberts 2004, Kuplich et al. 2005, Lu and Batistella 2005, Tuominen and Pekkarinen 2005, Ge et al. 2006, Dobrowski et al. 2008, Culbert *in review*). The first-order measures to be used include variance, mean, and entropy. See Table 4 for a list of second-order statistics to be used.

STATISTICAL ANALYSIS:

H1: RELATIONSHIP BETWEEN VEGETATION STRUCTURE AND IMAGE TEXTURE USING HIGH RESOLUTION AIR-PHOTOS: I will use simple and multiple linear regression to investigate correlations between image texture and vegetation structure. Since numerous first and second-order statistics will be generated from each image, correlation matrices will be built to investigate collinearity between texture metrics. If there is a high degree of collinearity between texture metrics, only one of the texture metrics will be chosen for a particular model.

H2: RELATIONSHIP BETWEEN VEGETATION STRUCTURE AND IMAGE TEXTURE DERVIED FROM VARYING IMAGE SOURCES: Similar statistical methods will be used to **H1.**

H3: MAPPING VEGETATION TYPES USING IMAGE TEXTURE ANALYSIS: Correspondence between image texture and the three vegetation types (grasslands, savannas, woodlands) will be assessed.. Texture, extracted from each sample point will be used in a Generalized Linear Modeling (GLM) framework to assess which imagery and which texture measure offers the strongest differentiation among the three habitat types based on their structural differences.

Table 4. Eight GLCM second-order statistics used to summarize image texture with description of statistic measurement used for Chapter's 3 and 4 analysis. * Table adopted and modified from (Guo et al. 2004).

Second-order statistic	Statistic Description of Behavior
1. Homogeneity	Homogeneity is high when GLCM concentrates along the diagonal. This occurs when the image is locally homogeneous such as in a grassland.
2. Contrast	This is the opposite of Homogeneity. It is a measure of the amount of local variation in the image. We might expect this to be higher in a heterogeneous landscape such as a savanna.
3. Dissimilarity	Similar to Contrast. High when the local region has a high contrast.
4. Mean	Average grey level in the local window.
5. Variance	Grey level variance in the local window. High when there is a large grey level variance in the local region. This statistic may be higher in savanna, lower in grasslands.
6. Entropy	High when the elements of GLCM have relatively equal values. Low when the elements are uniform in the window.
7. Angular Second Moment	This is the opposite of Entropy. It is high when the GLCM has few entries of large magnitude, low when all entries are almost equal. This is a measure of local homogeneity.
8. Correlation	Measures the linear dependency of grey levels of neighboring pixels.

IV. Sampling strategy:

Foliage-height diversity measurements have been collected during the 2007 and 2008 field seasons. Currently, 180 of the 330 sample points have been sampled. From mid-May to mid-July of 2009 I will collect data at the remaining points.

Image texture analysis on the air-photos has been completed. The satellite imagery (Landsat and potentially ASTER) will be acquired during the 2009 calendar year.

V. Expected and preliminary results:

Preliminary results suggest image texture derived from high resolution air photos can be used to map vegetation structure with relatively high accuracy (Table 5). I expect similar results when using other first and second order texture measures derived from different window sizes. However, since I am measuring vegetation structure on a small scale (e.g., within a 100 m radius circle) it is expected that coarse grained satellite imagery will not predict vegetation structure as well as high resolution air photography.

Table 5. Linear Regression Models: Image Texture vs. Shannon-diversity Index and Horizontal Diversity. Window Sized used to generate image texture values, image texture summary statistic (e.g., standard deviation, mean, range), r^2 value, and associated p-values for each regression test are shown in subsequent columns for one image source: Black and White Infrared air photo, leaf-on, taken August 2006.

	Shannon-Diversity Index		Horizontal Diversity	
Window Size	r^2	*p-value*	r^2	*p-value*
7x7 Mean	0.48	<0.001	0.60	<0.001
7x7 Standard Dev.	0.63	<0.001	0.68	<0.001
7x7 Range	0.49	<0.001	0.57	<0.001

Preliminary results also suggest raw image texture values are successful at differentiating between grasslands and either savanna or woodlands vegetation types using the standard deviation of first-order standard deviation texture derived from a high-resolution infrared photo (Fig. 8). However, the relationship becomes less clear when using texture to distinguish between savanna and woodland. This project will further evaluate the use of texture to predict fine scale vegetation characteristics such as vegetation structure as well evaluate using texture to map vegetation types across a prairie to woodland continuum of using both first and second-order texture measures derived from different image sources. Furthermore, I expect varying levels of model fit based on image source, image texture statistic used, window size, and habitat type (Table 6).

VI. SIGNIFICANCE:

In this chapter I will advance understanding of the relationship between ground-measured foliage height diversity and image texture. Understanding this relationship is important because vegetation structure is a property of that is strongly linked to habitat quality. This chapter will provide a theoretical foundation for the use of image texture as a predictor of vegetation vertical structure, in ecological studies.

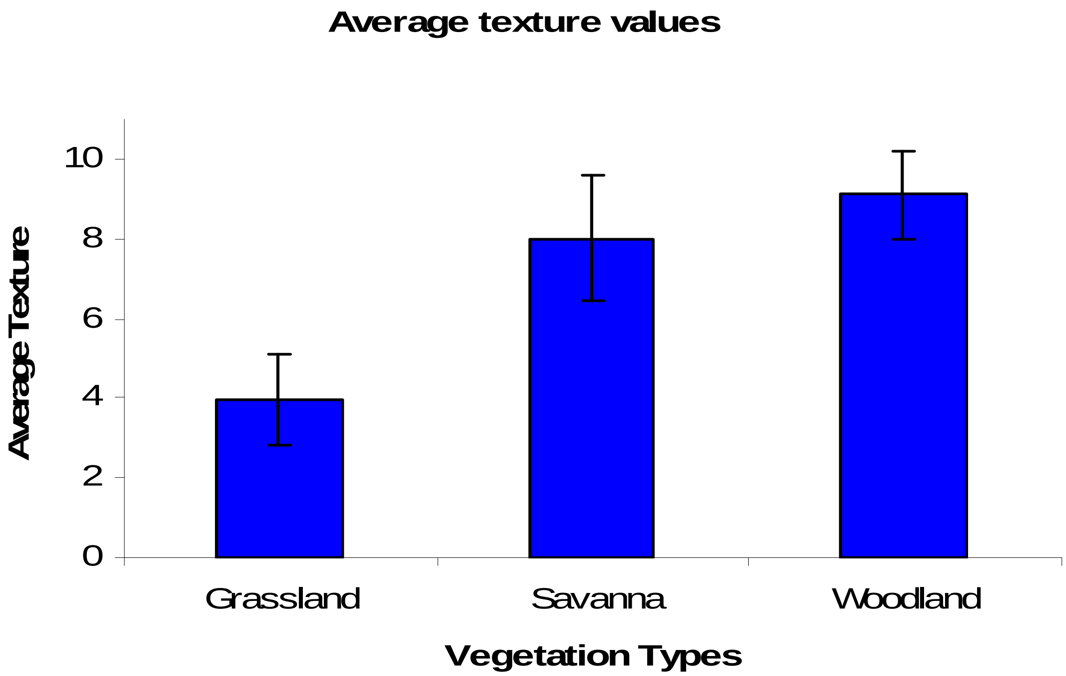

Figure 8. Average texture values for all sample points that occur in grassland, savanna, and woodland. Texture was calculated by first-order variance using a 7x7 moving window on a black-and-white Infrared leaf on, 0.25 m resolution air-photograph. At each sample point, texture values were summarized as the standard deviation of all 1^{st} order variance values within a 100 m radius buffer.

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Table 6. List of 1rst and 2nd-order statistics and expected model performance for texture versus vegetation structure for four different image sources. Low correlations = $r^2 < 0.2$; medium correlations = r^2 0.2 - 0.4; high correlations = $r^2 > 0.4$.

1rst-Order Statistic	**Black-and-white Infrared 0.25 m**	**Panchromatic 0.50 m**	**ASTER 15 m**	**Landsat 30 m**
1. Variance	High correlations for most window sizes in prairie-savanna. Lower correlations in woodlands.	High correlations for most window sizes in prairie-savanna. Lower correlations in woodlands.	Medium strength correlations for smaller window sizes in prairie-savanna. Low correlations in woodlands.	Medium strength correlations for smaller window sizes in prairie-savanna. Low correlations in woodlands.
2. Mean	Lower correlations in prairie-savanna than Variance. Low correlations in woodlands.	Lower correlations in prairie-savanna than Variance. Low correlations in woodlands.	Lower correlations than Variance in prairie-savanna. Low correlations in woodlands.	Lower correlations than Variance in prairie-savanna. Low correlations in woodlands.
2nd-Order Statistic				
1. Homogeneity	High-correlations in grassland-savanna for all window sizes. Low correlations in woodlands.	High-correlations in grassland-savanna for all window sizes. Low correlations in woodlands.	Medium strength correlations in grassland-savanna in small window sizes. Low in woodlands.	Medium strength correlations in grassland-savanna in small window sizes. Low in woodlands.
2. Contrast	Medium strength correlations in grassland-savanna for smaller window sizes. Low in woodlands.	Medium strength correlations in grassland-savanna for smaller window sizes. Low in woodlands.	Medium strength correlations in grassland-savanna in small window sizes. Low in woodlands.	Medium strength correlations in grassland-savanna in small window sizes. Low in woodlands.
3. Dissimilarity	High correlations in grassland-savanna. Low in woodlands.	High correlations in grassland-savanna. Low in woodlands.	Medium correlations in grassland-savanna. Low in woodlands.	Medium correlations in grassland-savanna. Low in woodlands.

4. Mean	Low correlations in grassland-savanna. Low in woodlands.	Low correlations in grassland-savanna. Low in woodlands.	Low correlations in grassland-savanna. Low in woodlands.	Low correlations in grassland-savanna. Low in woodlands.
5. Variance	Medium strength correlations in grassland-savanna. Low in woodlands.	Medium strength correlations in grassland-savanna. Low in woodlands.	Low correlations in grassland-savanna. Low in woodlands.	Low correlations in grassland-savanna. Low in woodlands.
6. Entropy	Medium strength correlations in grassland-savanna. Low in woodlands.	Medium strength correlations in grassland-savanna. Low in woodlands.	Low correlations in grassland-savanna. Low in woodlands.	Low correlations in grassland-savanna. Low in woodlands.
7. Angular Second Moment	Medium strength correlations in grassland-savanna. Low in woodlands.	Medium strength correlations in grassland-savanna. Low in woodlands.	Low correlations in grassland-savanna. Low in woodlands.	Medium correlations in grassland-savanna. Low in woodlands..
8. Correlation	Medium strength correlations in grassland-savanna. Low in woodlands.	Medium strength correlations in grassland-savanna. Low in woodlands.	Medium correlations in grassland-savanna. Low in woodlands.	Medium correlations in grassland-savanna. Low in woodlands.

CHAPTER 5: The potential of image texture for predicting bird species abundance

I. BACKGROUND:

Avian ecologists traditionally use ground based data in studies ranging from monitoring demographic parameters (Williams et al. 2002) to sampling bird species occurrence and abundance (Rosenstock et al. 2002, Scott et al. 2002, Morrison et al. 2006). Ornithological studies involving passerine birds generally follow two broad approaches. First, ornithologists employ census techniques using direct counting (Järvinen and Väisänen 1975, Anderson et al. 1979, Hutto et al. 1986, Ralph et al. 1995, Johnson 1995, Ralph et al. 1998), banding (Silkey et al. 1999, Dunn and Ralph 2004, Nur et al. 2004, Ralph et al. 2004), nest searching (Martin and Geupel 1993) and territory or spot mapping (Verner and Ritter 1988). Second, features of a habitat that are thought to influence bird fitness or occurrence are measured, or experimentally manipulated (MacArthur and MacArthur 1961, Robel et al. 1970, James and Shugart Jr. 1970, James 1971, Mueller-Dombois and Ellenberg 1974, Noon 1981). Data from these approaches are then analyzed together to investigate occurrence patterns or habitat correlations.

Although ground based data is extremely valuable for the information provided, studies requiring these data collection methods often require considerable resources of personnel and field equipment. Furthermore, these studies are oftentimes focused on small scale ecological phenomena rather than broad landscape regions. Studies conducted over broad areas yield different ecological insights than small scale studies, and the results of broad scale studies are more congruent with the scale at which land management and conservation typically operates (Burley 1988, Szaro and Johnston 1996, Sutherland 2000). Because of this, researchers have explored and developed image based remote sensing methods as a cost-effective approach to monitoring biodiversity over broad spatial scales (Roughgarden et al. 1991, Stoms and Estes 1993, Nagendra 2001, Turner et al. 2003).

Image texture analysis is a remote sensing method that has recently been successfully used to predict patterns of avian distributions (Hepinstall and Sader 1997, St-Louis et al. 2006, Tuttle et al. 2006, Bellis et al. 2008, St-Louis et al. 2008). Although this method has shown promise as a tool for characterizing avian habitat this is a relatively new application that has not been evaluated in a range of habitat types.

Estimating the abundance of bird species is a common practice in ornithological studies (Emlen 1971, Emlen 1977, Johnson 1995, Silkey et al. 1999, Burnham et al. 1980, Reynolds et al. 1980, Nichols et al. 2000, Bart and Earnst 2002, Thomas et al. 2002, Norvell et al. 2003, Moore et al. 2004, Kissling et al. 2006, Alldredge et al. 2007). Furthermore, avian ecologists often use abundance data to construct wildlife-habitat relationship models, searching for associations between site specific habitat variables and avian abundance to estimate habitat distribution patterns and habitat quality (Manel et al. 1999, Maurer 2002, Kery et al. 2005, Pearce and Boyce 2006, Thogmartin et al. 2006). Many avian species are associated with distinct vegetation communities (Morrison et al. 2006). Furthermore, bird species diversity, abundance, and richness are correlated with vertical vegetation heterogeneity (MacArthur and MacArthur 1961, Cody 1981, 1985). Therefore, it may be possible to use image texture to quantify vegetation patterns which can then be used as an index to species abundance.

II. Goals, Objectives, and Hypotheses:

The overarching goal of this chapter is to investigate the use of image texture as a tool for predicting bird species abundance across varying vegetation types.

The **three main objectives** related to the chapter goal are**: (1)** are there relationships between image texture and bird abundance in grassland, savanna, and woodland? **(2)** What is the best image source (panchromatic or multi-spectral, fine or medium grain) for predicting bird species occurrence at Fort McCoy? **(3)** How do predictions of bird abundance based on image texture measures differ from predictions based on ground-based vegetation measures?

H1: IMAGE TEXTURE AS A TOOL TO PREDICT ABUNDANCE PATTERNS OF INDIVIDUAL BIRD SPECIES ASSOCIATED WITH GRASSLANDS, SAVANNA, AND WOODLANDS: I believe that image texture derived from high-resolution air photos will accurately predict abundance patterns of birds in a prairie, savanna, woodland mosaic.

H2: DO DIFFERENT IMAGE SOURCES VARY IN THEIR ABILITY TO PREDICT BIRD ABUNDANCE? Image texture derived from high-resolution air photos will predict bird abundance more accurately than coarse gained imagery.

H3: IMAGE TEXTURE VERUS EMPRICAL VEGETATION DATA IN PREDICTING BIRD SPECIES ABUNDANCE: Image texture derived from both high resolution and coarse grained imagery will not accurately predict bird species abundance as accurately as ground collected vegetation data.

III. METHODS:

We will use breeding season bird point count data collected from 330 randomly stratified sampling points dispersed in open canopy prairie, savannas, and closed canopy woodlands to characterize the avian community (Fig. 9).

STUDY BIRDS:

Nine study species will be selected for this study (Fig 10.). These species were chosen because they exhibit specialized habitat use patterns of either grassland or savanna habitats. I will not model bird species that are associated with dense woodland and forest habitat because image texture does not pick up information below the tree canopy level such as shrub cover which may influence bird species abundance.

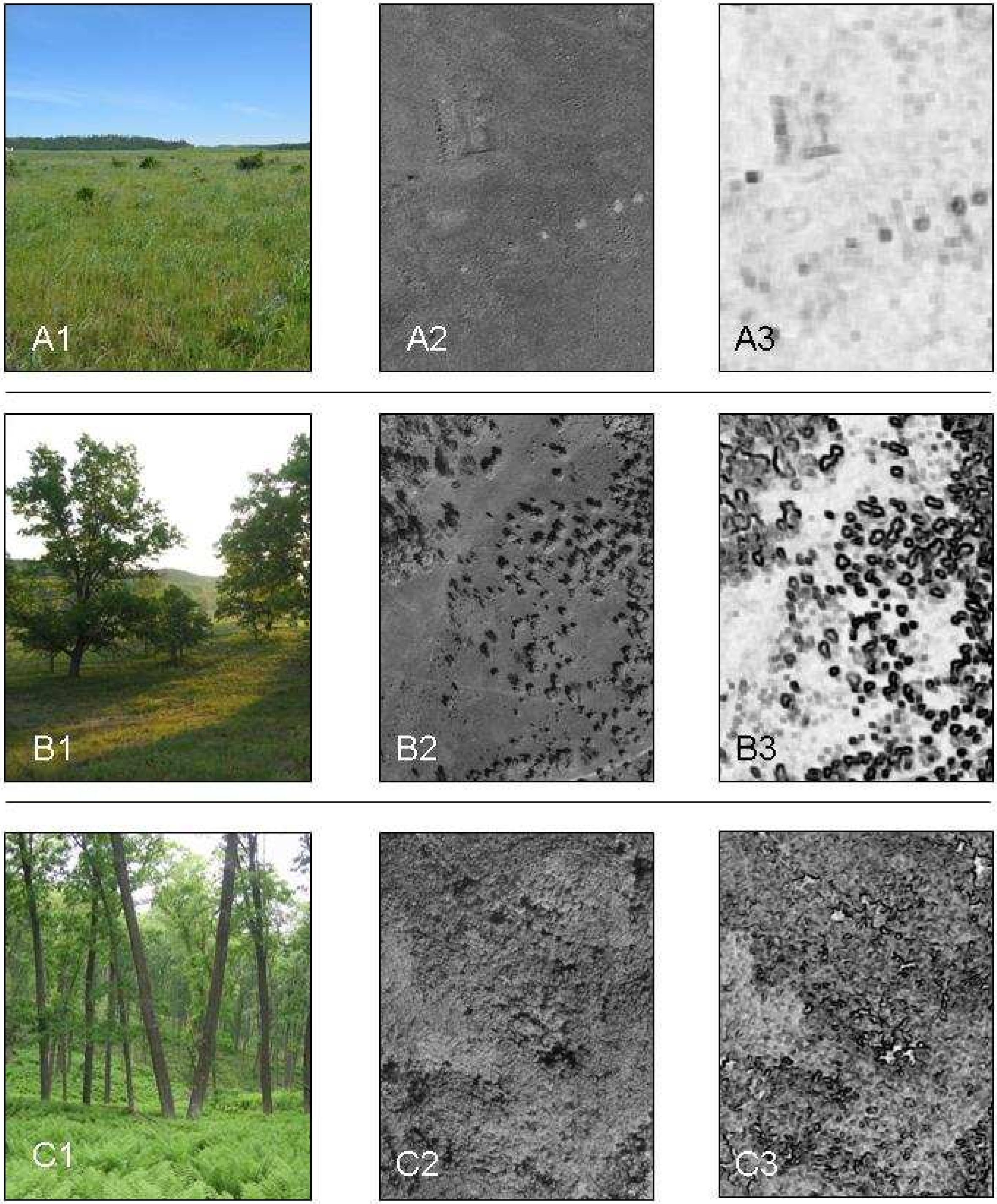

Figure 9. Three vegetation types across an open to closed tree canopy continuum: A) Grassland, B) Savanna, and C) Woodland. Each vegetation type depicted with a 1) ground photograph, an 2) infrared air-photograph, and an 3) infrared air-photograph processed for first-order variance in a 7x7 moving window.

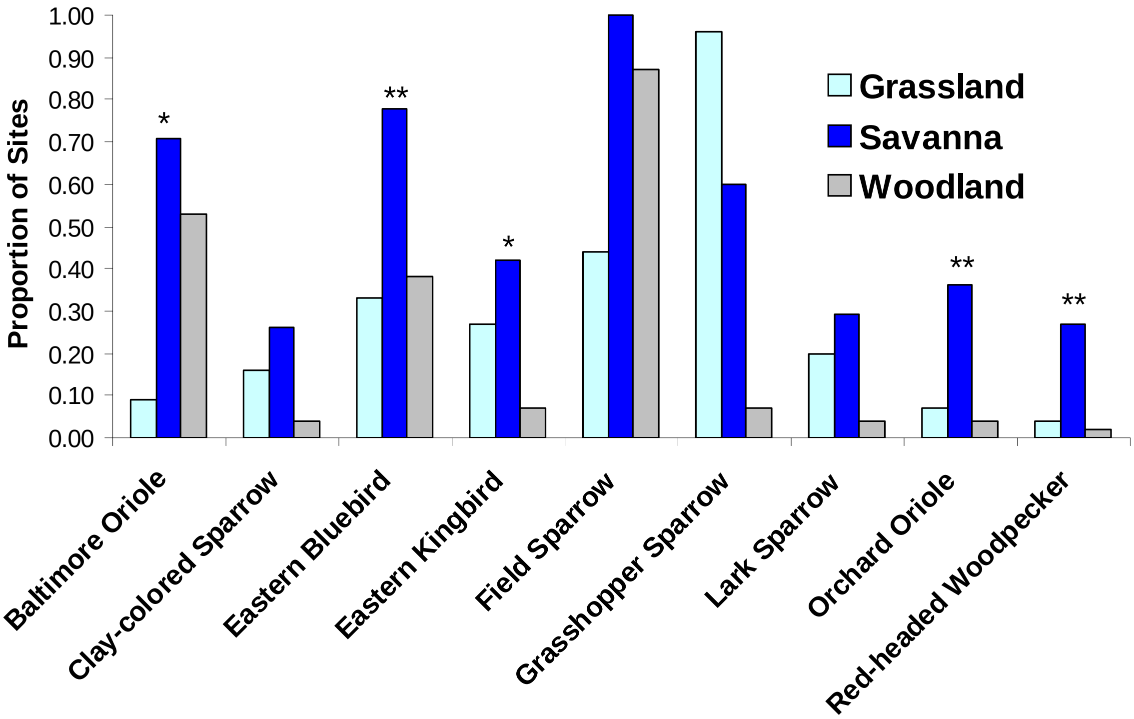

Figure 10. Proportion of sites where at least one individual was detected, for nine species surveyed during the 2007 field season at Fort McCoy. Significance of difference in species use of savanna, prairie, or woodland is based on 3x3 chi-square analysis and is indicated by asterisks (* 0.01 – 0.05, **, < 0.01).

AVIAN POINT COUNTS:

At each of the 330 sample points, four 100 m, standardized fixed radius point counts will be collected from 25 May to 4 July from 2007 to 2009 to characterize the bird community during the breeding season (Hutto et al. 1986, Ralph et al. 1995, Johnson 1995). Sample points are spaced > 300 m (Barker and Sauer 1995). To distribute observer variability, the four observers will each perform one of the counts at each sample point. Sample points will be visited in a fixed order made up of 11-15 sample points (e.g., 1→ 11) designated as a point counting route. For the first point counting route visit, an observer will walk in an ascending order (e.g., 1 → 11). For the subsequent visits the order will alternate (e.g., 11 → 1). This methodology will help to distribute counting effort among the morning hours, which is important because birds tend to sing more vigorously in the early morning thus increasing detectability (Hutto et al. 1986, Ralph et al. 1995, Dawson et al. 1995, Wolf et al. 1995, Huff et al. 2000). At each sample point, a five minute duration bird point count will be completed with the first count of the morning beginning within 10 minutes of sunrise. Counts will be conducted for three to three and a half hours after sunrise allowing one full point counting route (e.g., 11 – 15 sample points) to be visited per day. Bird observations will be limited to those occurring within the 100 m radius sample point boundary. Distance to detected bird will be recorded, and I will use both flagging and laser rangefinders to assess distance.

Remote Data Sources and Image Texture Analysis:

Air photos and satellite imagery will be the basis of image texture measures.

Table 7. Imagery used for Fort McCoy bird species richness versus texture analysis study. Varying window sizes shown indicating moving window in which texture will be quantified.

Black-and-white Infrared 0.25 m August 2006, Leaf-on	**Panchromatic 0.50 m April 2005, Leaf-off**	**ASTER 15 m Leaf-on**	**Landsat 30 m Leaf-on**
Window Size	Window Size	Window Size	Window Size
3x3	3x3	3x3	3x3
7x7	7x7	7x7	7x7
15x15	15x15	15x15	15x15
31x31	51x51	31x31	
101x101	101x101		
201x201			

Image texture will be calculated within several scales (approximated by different sizes of moving windows; Table 7), ranging from 3x3 to 201x201 for air-photos, 3x3 to 31x31 for 15 m resolution ASTER imagery, and 3x3 to 15x15 for 30 m resolution Landsat imagery using the ENVI software package (Research Systems Inc., Boulder, Colorado). First-order metrics to be used are variance and mean. Eight second-order statistics will be used for this study (see Chapter 4, Table 4).

This study will focus on the relationships between texture derived from within the 100 m radius sample point as well as vegetation components beyond the 100 m radius boundary. To achieve this, image texture will be processed using window sizes that fall beyond the boundaries of the 100 m sample point. For example, as the different sized moving windows for each image source scan across an image processing texture values, gray tone information from outside of a 100 m radius circle around a sample point (e.g., savanna sample point with an abrupt forested edge just outside of the 100 m radius buffer) will be calculated and included in cells that are located within the sample point. These cells will then be summarized into final texture values for a specific sample point. Edge associated bird species are known to use > 1 habitat type near their preferred edge locations (Whitcomb et al. 1981). Therefore, I expect more edge associated species to occur in sample points that are close to habitat edges.

Vegetation data:

Vegetation data will be collected at the 330 sample points following methods adapted from the Breeding Biology Research and Monitoring Database (BBIRD) protocol (Martin et al. 1997). The protocol accommodates both grassland and woodland sampling. For grasslands, vegetation sample sub-plots can be limited to a one meter radius whereas in wooded sites (e.g., savanna, woodlands, and forests) the vegetation sample sup-plot extends to a five meter radius boundary to adequately capture characteristics of the vegetation community.

Vegetation sub-plots are selected in a manner similar to the foliage-height diversity subplots used in Chapter 2. At the sample point center point, and three randomly selected sub-plots within the 100 m radius sample point boundary (chosen using a random distance and bearing within the bearing ranges: 0-120°, 120-240°, 240-360°) four sup-plots will be selected for all vegetation measurements.

Data from each of the four sub-plots will then be averaged or combined together to come up with a total vegetation description for each sample point.

In grasslands, two specific sets of measurements will be used: visual obscurity and biomass of grass will be measured using a Robel Pole (Robel et al. 1970), and foliage-height diversity for grasslands will be calculated using a Wien's Pole (Wiens and Rotenberry 1981). Additional data collected include slope, aspect, and elevation, cover estimates for ground (e.g., bare, rock, leaf litter, moss, fern), herbaceous materials (e.g., grass, forb, sedge, rush), woody materials (e.g., small shrub), litter depth, downed logs, coarse woody debris, litter depth, and heights of tallest grass/woody plant. Within each sub-plot, all woody stems will be tallied. All live vegetation that is estimated for cover within a sup-plot will be identified to species. Therefore, a floristic list of all live species will be developed.

In tree-dominated sample points, similar vegetation data will be collected in four, five meter radius sub-plots. Visual obscurity and grass biomass will not be collected since the methodology is not intended for wooded vegetation types. All height diversity profiles will be collect using foliage-height diversity. Foliage-height diversity and Wien's pole measurements can easily be scaled to one-another for comparison purposes. Tree data to be collected are diameter-breast height (dbh) for all live trees as well as snags, number of small, medium, and large stems, and average crown diameter for all trees. A complete floristic list will be tallied for all species within each sup-plot.

STATISTICAL ANALYSIS:

Before performing any analysis related to bird species abundance, raw point count data will be adjusted for differences in detectability between species (Rosenstock et al. 2002, Bart et al. 2004) by using distance-sampling to estimate species density (Buckland et al. 2001, Buckland et al. 2004). Distance sampling methods used for point count survey data rely on the validity of three key assumptions:

1) Detection probability at the plot center is 1 (or a known value).
2) Birds do not move in response to the observer prior to detection (e.g., flushing of a covey of quail).
3) Distance to each detected bird is recorded accurately. (Buckland et al. 2001, Buckland et al. 2004)

The following analysis will be carried out for each of the three hypotheses.

H1: IMAGE TEXTURE AS A TOOL TO PREDICT ABUNDANCE PATTERNS OF SPECIFIC BIRD SPECIES ASSOCIATED WITHIN GRASSLANDS, SAVANNA, AND WOODLANDS: Regression models will be built to investigate correlations between image texture derived from high-resolution air photos and bird species abundance. Numerous first and second-order statistics will be generated from each image. Therefore, correlation matrices will be built to investigate collinearity between texture metrics. If there is a high degree of collinearity between texture metrics, only one texture metric will be chosen for a particular model set. Once texture metrics are chosen, best-subsets regression will be used to examine relationships between image texture and bird species abundance.

H2: DO DIFFERENT IMAGE SOURCES VARY IN THEIR ABILITY TO PREDICT BIRD ABUNDANCE? A similar procedure will be followed to the statistical analysis for H1. However, the best models from H1 will be compared to additional image sources (see Chapter 4, Table 3). These additional image sources will be processed for texture and regressed against bird species abundance. Top ranking models built using texture metrics derived from satellite images will then be compared to top models from texture derived from high-resolution air photos in H1

H3: IMAGE TEXTURE VERUS EMPRICAL VEGETATION DATA IN PREDICTING BIRD SPECIES ABUNDANCE: Although image texture may adequately predict bird species richness in a desert ecosystem (St-Louis et al. 2006, St-Louis et al. 2008), it is not clear if image texture can be used to predict bird species abundance with as strong a predictive power as ground based vegetation data. To investigate this, vegetation data will be regressed against bird species abundance using best-subsets regression. The top vegetation covariates selected from the best-subsets regression will then be included in a model set with the best performing texture metrics derived from both high-resolution air-photos and coarse grained satellite images regressed against bird species abundance.

IV. SAMPLING STRATEGY:

Bird point count data has already been collected during the 2007 and 2008 field seasons which are approximately from late May to early July. Furthermore, vegetation data has been collected at 180 out of 330 sample points. We will collect a third season of data in a similar time range in 2009 (Appendix A and B).

V. EXPECTED AND PRELIMINARY RESULTS:

Preliminary results suggest image texture can be used to predict bird species richness in an ecosystem of grassland and savanna (Table 8). Using bird species richness data collected in 2007 and 2008, the 2006 Black-and-white Infrared 0.25 m resolution air photo performed better than the 2005 Black-and-white Panchromatic 0.50 m resolution air photo based on higher r^2 values in predicting bird species richness. The 2006 image, which was taken in the summer, is leaf-on while the 2005 image was taken in early spring and is leaf-off. Furthermore, the air photos are taken using different films or image sensors. The infrared photo is sensitive to infrared light, therefore letting infrared pass through the camera sensor, but blocking all or most of the visible light. The panchromatic photo differs in that it is sensitive to all wavelengths of visible light therefore letting all pass through the camera sensor. These two differences, seasonality of photo, and difference in film/sensor along with differences in grain size may have caused the differences in the model performance between the two photos. Furthermore, models built using the 2007 data performed better than the 2008 data suggesting possible temporal variation in bird species richness between the years.

However, it is unclear whether image texture may be used to model specific bird species abundances.

VI. SIGNIFICANCE:

This project will advance the use of image texture analysis as a remote sensing tool to predict bird species abundance across varying vegetation types. This is significant in three ways: First, fine-scale, within habitat (i.e., vegetation structure) characterization of habitat structure that is possible using image texture may have significant usefulness for broad scale bird monitoring. Furthermore, image texture may be useful to predict breeding habitat for species of concern that use heterogeneous vegetation types during the breeding season (e.g., Kirtland's Warbler (*Dendroica kirtlandii*) breeding in young Jack Pine barrens). In addition, the advancement of image texture analysis may also be useful for broad scale monitoring of other taxa.

Table 8. Linear regression models of 1rst order standard deviation image texture vs. bird species richness. 100 m fixed radius, breeding bird point count data collected during the breeding seasons of 2007 and 2008 at 128 bird point count sample points distributed along a grassland to savanna continuum at Fort McCoy Military Installation, WI, USA. Two 0.5 m resolution air-photos were processed for 1rst order variance image texture in ArcGIS 9.2. The images were a Black and White Infrared air photo (taken late August, leaf-on) and a Black and White Panchromatic air photo (taken spring, leaf-off). Description of window size (e.g., 7x7), summary metric (e.g., standard deviation or mean) used to summarize texture values within a 100 m radius circle around each bird point count sample point, year bird data collected, r^2 value, and associated *p-values* for each regression test are shown in subsequent columns.

Black and White Infrared 2006					**Black and White Panchromatic 2005**				
	2007		2008			2007		2008	
Window Size and Summary Metric	r^2	*p-value*	r^2	*p-value*	Window Size and Summary Metric	r^2	*p-value*	r^2	*p-value*
7x7 Mean	0.43	<0.001	0.37	<0.001	7x7 Mean	0.31	<0.001	0.12	<0.001
7x7 Standard Dev.	0.54	<0.001	0.53	<0.001	7x7 Standard Dev.	0.21	<0.001	0.23	<0.001
11x11 Mean	0.46	<0.001	0.39	<0.001	11x11 Mean	0.30	<0.001	0.23	<0.001
11x11 Standard Dev.	0.52	<0.001	0.52	<0.001	11x11 Standard Dev.	0.24	<0.001	0.07	<0.001
31x31 Mean	0.51	<0.001	0.44	<0.001	31x31 Mean	0.31	<0.001	0.20	0.526
31x31 Standard Dev.	0.31	<0.001	0.33	<0.001	31x31 Standard Dev.	0.11	<0.001	0.00	<0.001

Ecological, Technical, and Conservation Contributions

From an **ecological perspective**, this dissertation will contribute to our scientific understanding of insectivorous neotropical migrant stopover ecology in the upper Midwestern U.S. More specifically, the first three proposed chapters will highlight the importance of proximate and ultimate resources used by birds during stop-over (e.g., tree flowers, food resources).

From a **technical perspective**, my research will broaden our understanding of how widely the relationship between image texture and vegetation vertical structure is. This has broad appeal since vertical vegetation structure is a correlate to wildlife diversity patterns globally. Furthermore, in addition to predicting avian species diversity, is image texture correlated with avian abundance patterns?

This dissertation will contribute to **conservation science** by investigating the importance of different tree species as well as the potential significance of savanna habitats to migratory birds. Specifically I am addressing the question of whether the replacement of oak by maple in the landscape is likely to lead to a cascading effect on migrant passerines. This study may be early enough in the process that if my findings suggest there will be effects, there is still time for conservationists to work toward stabilizing or reversing the trend.

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Appendix A. Field season schedule for all proposed field methods. The field season will run from April 7 to July 15. The first two weeks in April are for crew training. Two months in advance of the field season, I have sent, detailed bird lists, bird song cd's and other training materials to my field technicians. During the training period in April. Furthermore, we will field test arthropod trapping methods and practice other field techniques as needed. For each month, a schedule for carrying out each field method is shown. Work will run on a six day on, one day off schedule throughout the study. Breeding season point counts will run from early June, when migration work is completed, until July-4. Vegetation quantification will be carried out until July-15.

Field Method	April	May	Early June	June - July 4	Time of Day
Tree Phenology and Migratory Bird Monitoring	M,W,F	M,W,F, Sun	M,W,F		Morning
^ Foraging Observations (Phenology Assessments)	M,W,F	M,W,F, Sun	M,W,F		Morning/Afternoon
^ Migrant Point Counts (Phenology Assessments)	T,R,S	M,W,F, Sun	T,R,S		Morning
Arthropod Trapping (Use)	M,W,F	M,W,F, Sun	M,W,F		Morning/Afternoon
Arthropod Trapping (Availability)	M,W,F	M,W,F, Sun	M,W,F		Morning/Afternoon
Mist-netting (Emetic Administration)		T,R,S			Morning
Breeding Season Point Counts				M-S	Mornings
Vegetation Quantification				M-S (until July 17)	Afternoons

^ Phenology assessments will be collected while montoring birds during point counts and foraging obseravations.

* Branch exclosure experiement will be constructed during the month of April. Check = times during the month that each tree will be sampled for arthropods.

Appendix B. Proposed Timeline