INFLUENCE OF VEGETATION STRUCTURE AND LANDSCAPE FEATURES ON MIGRATORY BIRDS IN NORTHERN LAKE MICHIGAN

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ABSTRACT

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by Heather Shaw

Recent declines in forest dwelling migratory bird populations have motivated research involving breeding and wintering habitat availability and quality, yet little information has been documented on coastal migratory stopover locations, which act as stepping stones while migrants move between breeding and wintering areas. Understanding where migrants may be most vulnerable throughout all stages of the annual cycle is critical for the development of a comprehensive conservation strategy. As such, research surrounding stopover habitat composition and structure is gaining momentum. Stopover locations are prolific along a major migratory corridor in Lake Michigan, and little is known about what factors may drive migratory landbird use of these sites. Stopover locations vary between coastal mainland locations in Michigan and offshore islands, such as the Beaver Archipelago. The overall objectives of this study were to determine which forest dwelling migratory landbird species utilize coastal and island stopover locations within the northeast region of Lake Michigan, and to determine whether structural composition of varying stopover habitat influences species use, as well as to determine whether landscape scale factors influence nocturnal migratory pathways. Acoustic monitoring devices were placed on offshore and coastal areas of varying habitat complexity where diurnal and nocturnal flight periods were recorded continuously through spring and fall migration. Overall, there may be a synergy between forested and shoreline attributes driving species use in this region.

Results indicate that there is a strong positive correlation between habitat structure and bird species presence, and that migrant species groups utilize stopover locations of differing ecological complexity. Long distance migrants indicated a propensity to legacy structures found in mature forests, where short distance migrant presence was associated with shade tolerant forest composition and increased mid story structural diversity indicative of young forests. Associations between nocturnal bird use and landscape features were less pronounced, suggesting that adjacency of intact forested cover to the shoreline may play a larger role in the presence of a major migratory route. These results should better inform management strategies and include important structural features which should not be disregarded within the framework for landscape.

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CHAPTER I

INTRODUCTION

Neotropical migratory birds are those which migrate long distances to breed within North America and overwinter in Mexico, Central America, South America, and the Caribbean (New World Tropics), whereas nearctic migratory birds migrate shorter distances to breed and overwinter in North America. Populations of forest dwelling nearctic-neotropical migratory birds have been declining over recent decades, and several studies suggest that these declines may be due to challenges faced during migration (Robbins et al. 1989, Askins et al. 1990, Sherry and Holmes 1995, Duncan et al. 2002, Sillett and Holmes 2002, Gehring et al. 2010). Migrants spend an average of 25-33% of their annual cycle en route (Bonter et al. 2009). Identifying challenges during these massive migration events may be critical to properly directing conservation strategies (Mehlman et al. 2005).

Neotropical birds are known to migrate long distances over ecoregional and political boundaries where significant ecological barriers such as mountain ranges or large bodies of water exist. During such an exhaustive journey, birds require stopping at staging locations referred to as stopover sites. the availability of suitable stopover locations may be influential in the current use of migratory routes (Hutto 1995). These stopover locations allow migrants to replenish fat stores in order to meet energy needs, avoid challenging weather conditions, and rest. Typically, the amount of time spent at a stopover site outlasts flight time and can be a large factor in the overall duration of a migratory event (Alerstam 1993), thus having a likely role in limiting migratory populations (Sherry and Holmes 1995).

Survival during migration is dependent on several factors including resource availability at stopover locations, physical fitness and weather conditions (Gauthreaux 1971, Moore and Kerlinger 1987, Ewert and Hamas 1995, Mehlman et al. 2005). As such, stopover locations are generally categorized by quality, as site characteristics may influence use and occupancy by migrants. It is important to also note that high migrant density has the potential to be a function of the lack of additional suitable habitat (Donovan et al. 2002).

Stopover locations vary greatly between available resources and juxtaposition or arrangement among the landscape, meaning that some areas immediately adjacent to the shoreline may not contain necessary food or cover to fulfil a migrants needs for survival. When combining these factors with a migrants physical condition, there is large variability in whether a stopover location will support a successful migration. Stopover quality indices have been broken down along a spectrum of high habitat quality or "Full Service Hotels" offering plentiful resources to low quality and low resource availability or "Fire Escapes" necessary for emergency stopover (Mehlman et al. 2005).

At a fine spatial scale, migrants may choose to settle in a stopover location (Moore 2005) which provides sufficient cover for predator avoidance and food availability, and at a larger regional scale migrants may choose to stopover in an area of forested cover in close proximity to the shoreline. Food abundance, cover and proximity to a geographic barrier play a crucial role in stopover site appeal to migratory birds (Robbins 1989, Ewert and Hamas 1996, Ewert et al. 2012.); however, information is lacking on the habitat composition at multiple spatial scales for known stopover sites and how it may influence migrant selection. Vegetation composition affects insectivorous and frugivorous species distribution (which differs spatially and temporally), energetic condition (Gauthreaux and Belser 2000), and competition. Unfortunately, a lack of information on habitat attributes that may drive species presence and use at stopover locations places limitations on prioritizing focal areas for conservation (Sherry and Holmes 1995, Newton 2004, Bonter et al. 2008). Improved data on the compositional structure of various habitats utilized throughout annual migration routes will aid in the development of comprehensive conservation strategies for Great Lakes migrants.

During diurnal periods, migrants spend their time foraging at stopover locations to replenish fat stores and resting from an exhaustive journey. During nocturnal periods, migrant birds navigate along their migratory route utilizing favorable weather conditions and protection from predators under cover of darkness. During these nocturnal events, landscape features, such as the proximity to water and forest cover may influence the locations to which concentration occurs (Bonter et al. 2008).

Great Lakes coastal regions provide a wide variety of stopover habitats for migratory birds (Bonter et al. 2008, Diehl et al. 2003, Ewart 2005). Large concentrations of migrants have been documented departing coastal stopover sites during spring migration within the Great Lakes basin using weather surveillance radar (WSR) imagery (Diehl et al. 2003, Bonter et al. 2008, Buler & Dawson 2014). This radar technology is one increasingly useful tool which allows researchers to follow migratory bird movements throughout the Great Lakes and determine the scale at which these exodus events occur. The aforementioned work has been largely important in identifying areas where birds concentrate within the Great Lakes region. This information is also indicative of the region supporting a major migratory corridor, and stopover locations that exist within this corridor (Diehl et al. 2003, Bonter 2008). Of specific interest to this study is determining how migratory birds utilize the Lake Michigan region, specifically between the Leelanau Peninsula and the southern Upper Peninsula of Michigan.

Larger monitoring applications may make landscape scale studies more feasible. Acoustic monitoring techniques are advancing to the point where biologists are able to survey populations during significant time periods such as migration (Blumstein et al. 2011) and provides reliable species identification for rapid biodiversity assessment of local species groups (Hammer and Barrett 2001, Mennill et al. 2006). Using an array of acoustic monitoring devices, one can survey wildlife populations at multiple locations remotely, long term and without disturbance to an area (Blumstein 2011, Cochran 1959, Depraetere et al. 2012, Haselmayer & Quinn 2000). Furthermore, the use of monitoring devices has been successful in providing quantitative information on bird species in a given area (Graber and Cochran 1959, Evans & Mellinger 1999, Evans & Rosenberg 2000, Seefelt 2013). These recordings allow researchers to derive reliable estimates of species occurrence and potentially estimate abundance (Blumstein et al. 2011). Researchers have also used acoustic monitoring to detect the presence of rare or endangered species, as microphone arrays can be placed in remote areas not easily surveyed using standard technology (Fitzpatrick et al. 2005). This avian survey technique allows large scale, long term data collection from multiple locations and habitats (Depraetere et al. 2012) during different periods of the annual cycle and will provide valuable insight into the interactions that species have with their surrounding environment (Blumstein et al. 2011).

As habitat degradation and fragmentation continues throughout the Great Lakes Region, the amount and connectedness of quality suitable stopover habitat decreases, thus confounding threats to long distance migrants. Continued adaptive management techniques applied to landscape scale conservation measures will be necessary to maintain connectivity and suitability between breeding and wintering grounds for migrant birds.

The objectives of this study were to use remote acoustic monitoring surveys to identify and quantify bird use patterns in coastal and island habitats of northern Lake Michigan. Specifically, the objectives include (1) using diurnal recordings to determine the importance of structural habitat characteristics that may influence the occupancy of neotropical and nearactic migrants at stopover locations; and (2) using nocturnal recordings to identify how larger landscape features could influence passage of neotropical and nearctic migrants at night in northern Lake Michigan.

CHAPTER II

METHODS

Study Area

The study area includes the islands of Beaver, Hog and High of the Beaver Island Archipelago (Charlevoix County) as well as nearshore coastal areas along the Upper Peninsula (Mackinac County) and Lower Peninsula (Leelanau, Charlevoix and Emmet Counties) (Table 1, Figure 1). Beaver Island is the only inhabited island of the three included in this study. The coastal areas along Lake Michigan include State land within Leelanau State Park (Leelanau Co.), Wilderness State Park (Emmet Co.), and Lake Superior State Forest. Each of the study sites was accessible by road, trail or boat and was chosen to document bird movements throughout northern Lake Michigan. Each of the sites were located on a shoreline composed of sand or rock with a forested edge predominantly composed of mixed conifer species dominated by northern white cedar (*Thuja occidentalis*).

Table 1. Acoustic Monitor Device Locations (2012-2013) on Islands and in Coastal Mainland Locations in Northern Lake Michigan

Site	Key	Location
1	LEE	Leelanau State Park Campground
2	CHB	Cathead Bay - Leelanau State Park
3	BSB	Big Stone Bay - Wilderness State Park
4	WP	Waugashance Pt - Wilderness State Park
5	MCP	McCauley Pt- Beaver Island
6	CHP	Cheyenne Pt - Beaver Island
7	CMUBS	CMUBS - Beaver Island
8	CB	Cable Bay - Beaver Island
9	HIS	High Island - South
10	HIN	High Island - North
11	HOGN	Hog Island - North
12	HOGS	Hog Island - South
13	SP	Scott Point - Southern Upper Peninsula
14	CP	Cozy Point- Southern Upper Peninsula

Note: Abbreviations are provided as these are used in statistical analysis.

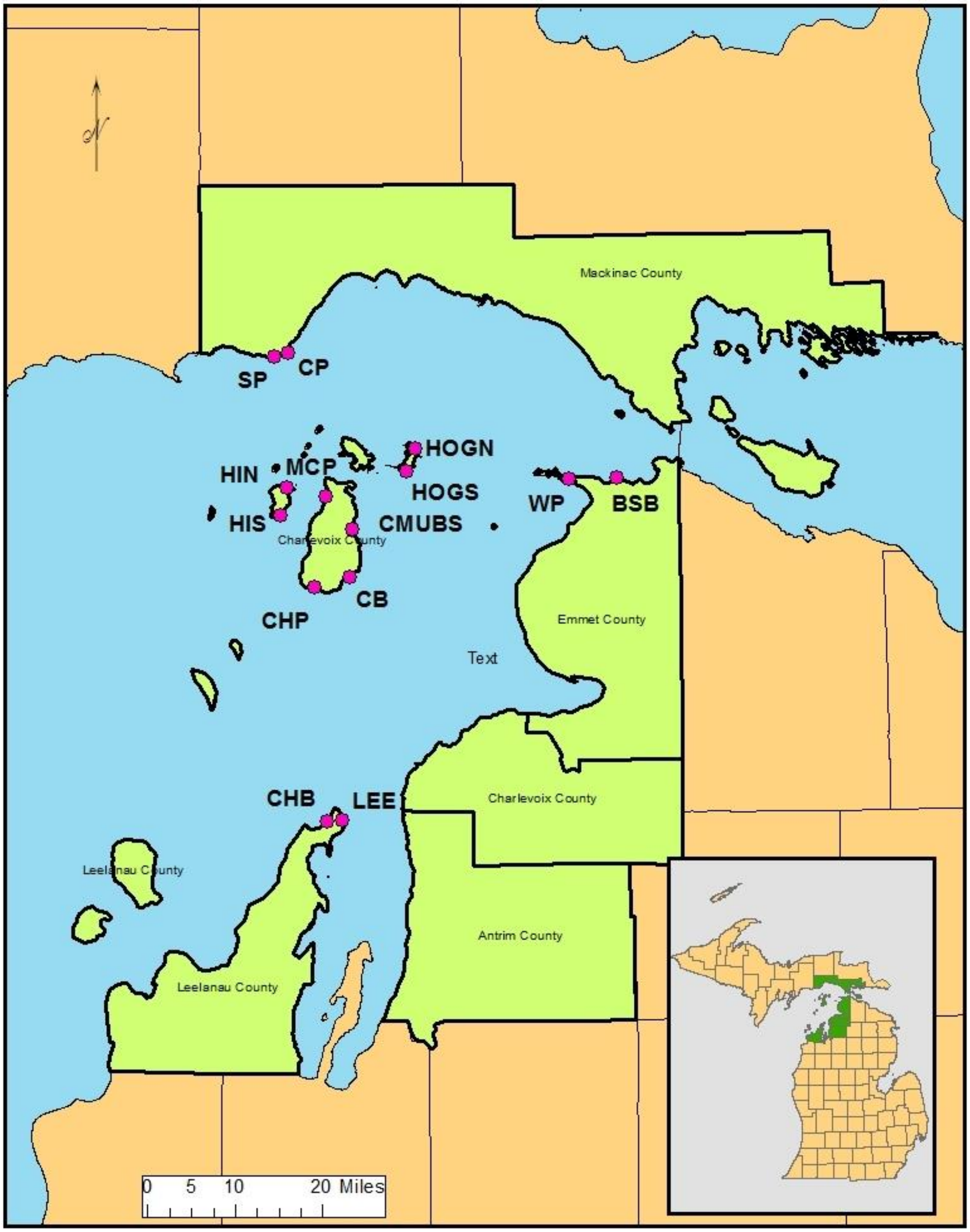


Figure 1. Acoustic Monitoring Locations within Northern Lake Michigan 2012-2013
Note: Abbreviations correspond to those provided in Table 1.

Utilizing Acoustic Monitoring to Inventory Avian Community Diversity

An array of fourteen acoustic monitors was deployed (Table 1, Figure 1), allowing a large geographic area to be monitored during both spring and fall migration. During spring and fall migration 2012-2013, remote acoustic monitoring devices were deployed to record the song and calls of migrants utilizing the study area (Table 2). The SM2+ acoustic recording devices (SM2+ Terrestrial Package, Wildlife Acoustics, Inc. 2005-2012) were used with two weather resistant microphones at each study location in order to document bird presence at stopover locations, as well as the passage of migrants within the migratory corridor. One microphone, the SMX-II, was placed on a tree at the forest/shoreline edge and recorded the dawn chorus for one hour each day beginning 15 minutes before local sunrise. Diurnal data was only recorded during spring migration, as previous recording data indicated weak dawn chorus during the fall. The other microphone, the SMX-NFC (Night Flight Call Package, Wildlife Acoustics, Inc. 2005-2012), designed specifically to record night flight (nocturnal) calls while dampening other noise, was mounted on a 10ft piece of conduit placed over a rebar rod. This microphone recorded acoustic sounds for 15 minutes out of every hour from dusk until dawn. The recording device design delivers smooth frequency retort up to 11 kHz with a beam angle of 125 degrees, however the range of recording potential is unknown and largely dependent on the breadth of call (Wildlife Acoustics, Inc. 2004-2011). GPS coordinates of the survey location (Table 1) were programmed into each device in order to follow day length changes throughout the study period.

Table 2. Begin and End Dates of Acoustic Monitoring Effort for Spring and Fall 2012-2013

	Spring 2012		Fall 2012		Spring 2013		Fall 2013	
Leelanau SP	26-Apr	1-Jun	15-Aug	25-Sep	7-May	31-May	15-Aug	28-Sep
Cathead Bay - Leelanau SP	26-Apr	1-Jun	15-Aug	22-Sep	7-May	31-May	*	*
Big Stone Bay - Wilderness SP	27-Apr	1-Jun	15-Aug	30-Sep	20-Apr	31-May	15-Aug	28-Sep
Waugashance - Wilderness SP	27-Apr	1-Jun	15-Aug	30-Sep	20-Apr	31-May	15-Aug	28-Sep
McCauley Pt - Beaver Is.	17-May	1-Jun	15-Aug	1-Oct	20-Apr	31-May	15-Aug	28-Sep
Cheyenne Pt - Beaver Is	21-Apr	1-Jun	15-Aug	1-Oct	20-Apr	31-May	15-Aug	28-Sep
CMUBS - Beaver Is.	21-Apr	1-Jun	15-Aug	1-Oct	7-May	31-May	15-Aug	28-Sep
Cable Bay - Beaver Is.	21-Apr	1-Jun	15-Aug	1-Oct	7-May	31-May	15-Aug	28-Sep
High Island - South	10-May	1-Jun	15-Aug	15-Sep	22-Apr	31-May	*	28-Sep
High Island - North	8-May	1-Jun	*	*	22-Apr	31-May	*	*
Hog Island - North	7-May	1-Jun	15-Aug	15-Sep	26-Apr	31-May	15-Aug	28-Sep
Hog Island - South	7-May	17-May	15-Aug	2-Sep	26-Apr	31-May	*	28-Sep
Scott Point - UP	27-Apr	1-Jun	15-Aug	30-Sep	26-Apr	31-May	15-Aug	28-Sep
Cozy Point - UP	27-Apr	1-Jun	15-Aug	30-Sep	26-Apr	31-May	15-Aug	28-Sep

Note: *Weather conditions, accessibility and equipment issues prevented data collection.

Acoustic Data Analysis

Acoustic data were analyzed using RavenPro (Bioacoustics Research Program. 2011). This software was developed for users to have the ability to visualize sound spectrograms and analyze wildlife sounds through a user friendly platform. In this case, we were able to listen to individual bird vocalizations recorded from each monitor and visualize the digital signature spectrogram of each song in order to identify the correct species. Acoustic data transcription was placed into a database containing date, time, and species detected. Diurnal data consisted of presence only data, whereas nocturnal night flight data consisted of species counts in which calls of increasing or decreasing strength were considered one individual. Nocturnal counts were conservative estimates of migrant passage. Neotropical migratory birds have been classified by The Neotropical Migratory Bird Conservation Program (Partners in Flight) as those which breed in North America and winter in the tropics and are referred to as "List A" species. Short distance migrants which breed and overwinter within North America are referred to as "List B" species. Species detections were categorized by site into "List A, List B, and Other" species where "Other" referred to species not included on List A or List B. Mean species detection rates for each site and season within 2012 and 2013 were also calculated.

Inventory of the Vegetative Community

To determine structural habitat composition at each monitor location, vegetation was sampled at three plots, each ten meters in diameter following the protocol of James and Shugart (1970) (Table 4). One plot was located at the monitor location and the other two plots were selected at a random distance following the forest edge within 400 meters from the survey point using a random number generator. All variables were measured in each forest plot with the center of each plot located 5m from the forest edge. Percent canopy cover (CAN) was measured using a convex densitometer. To quantify the understory stem density, trees less than 5 inches at diameter breast height (DBH) within the 10 meter radius of the survey point were counted (T1), as well as the number of trees 0.5 meters to 1 meter in height (T3). To quantify the midstory, trees over 5 inches at DBH were counted (T2). The percentage of ground cover within the the forest (GCF) and outside the forest edge (GCB), was estimated along with the percentage of leaf litter within the forest edge interior (LEAF) and the percent of sand/rock/barren (SAND). The amount of coarse woody debris (CWD), classified as downed dead or decaying woody structures with a diameter larger than 5 cm, was individually counted within the plot radius. Snags (SNAG) were identified as standing dead trees and were also counted individually within the plot radius. Average stand height was measured with clinometers by taking three readings from the base of the bole to the top of the crown.

For nocturnal data, the distance from each study site (m) to a landscape feature class of interest was calculated using GIS ArcMap 10.4.1 (ESRI 2016). Landscape features based on attributes which were prioritized within a habitat suitability model described by Ewert et al. (2012) were extracted from the 2011 National Land Cover Database (Homer et al. 2015) within a 25 km buffer from each study site (Table 3). Features were then combined for model simplification. Distance tables were generated by calculating the Euclidian distance from the study site to the nearest feature class. Land cover features included agriculture, forest, wetland, open water, herbaceous, and scrub-shrub. Anthropogenic features included roads, airports, areas of low urban density, and areas of high urban density.

Table 3. Vegetation Variables Measured and Later Compared to Acoustic Data to Determine which may be Important to Migrants

Vegetation Structure		Landscape Features	
Variable	Abbreviation	Variable	Abbreviation
trees >5 in. DBH	T1	distance to shore	Water
trees <5 in. DBH	T2	distance to wetland	Wetland
trees 0.5 m-1m height	T3	distance to herbaceous landcover	Herb
number of snags	SNAG	distance to shrub-scrub landcover	Scrub
number of CWD >5cm	CWD	distance to forest landcover	Forested
% ground cover in the forest edge	GCF	distance to agriculture landcover	Ag
% ground cover outside of edge	GCB	distance to road	Roads
% leaf litter within forest edge	LEAF	distance to airport	Airport/
% sand/rock/barren	SAND	distance to low urban density	Lo_Urban
distance to wetland	DW	distance to high urban density	Hi_Urban
distance to shore	DS		

Note: Small scale structural variables were used to predict stopover location presence with diurnal data, Landscape scale variables were used to predict the use of a migratory route with nocturnal data.

Principle Components Analysis-Vegetation Characteristic

Principle Components Analysis (PCA) with structural vegetation data was utilized to identify and explore linear patterns of correlated vegetation characteristics between coastal and island study sites using software packages R (R Core Team 2013) and Vegan (Oksanen et al. 2016). This analysis was also utilized to explore patterns among study sites and the proximity to anthropogenic features and landcover types. PCA output produces eigenvalues, which represent the percentage of the total data variance captured by each of the PCA components. A Scree diagram plots the eigenvalue against its associated component number and is useful in determining the number of principle components one wishes to retain for additional analysis. In addition, the eigenvector table (where is it) created by running a PCA provides coefficients for a linear combination of the original variables. Varimax rotations or orthogonal rotations (which maximizes the sum of the variances) were then applied to the loadings for further interpretation and simplification of the dataset. The values explained by the first three eigenvectors was the same.

Non-Metric Multidimensional Scaling-Stopover Use

Migrant bird assemblages (List A, B, and Other) at each site were examined using non-metric multidimensional analysis (NMDS) with software R (R Core Team 2013) and package Vegan (Oksanen 2016) using Bray-Curtis dissimilarity indices to quantify dissimilarity between stopover sites. This type of analysis fits our stopover data as normality assumptions cannot be met. Ordination seeks a multi-dimensional solution in space where it randomly shuffles between sites and species, and halts permutations once a stable ranked order of sites has been found. In this case, ordination does not make assumptions (i.e. linear relationships) about the data (Holland 2008), rather assists in determining whether data has structure. The data set between sites and bird species observed was thought to be a good fit for NMDS analysis as ecological systems are spatially structured, and distances between locations may help to achieve fair results.

General Linear Regression-Diurnal Use of Stopover Locations

Output from the PCA and NMDS were then input into a linear regression model in the R package MuMIN (Oksanen 2016) to determine whether structural characteristics at a fine scale were correlated with the observed migrants utilizing stopover locations. In this case we assume that the response variables (NMDS) are normally distributed based on a linear combination of the predictor variables (PCA).

Multiple Linear Regressions-Nocturnal Migratory Route

Software R package MuMIN (Oksanen 2016) was used to examine whether a linear relationship existed between larger landscape features within 5 km of the study locations and migratory bird abundance In this case, we wanted to determine whether landcover and anthropogenic features influence the route that migrants use during nocturnal flight, as opposed to local landscape features and site specific structure that influence diurnal migration. A multiple linear regression was run and Akaike Information Criterion (AIC) was used to determine variables which best describe mean bird species abundance.

Principle Component Analysis and Landcover Features

Principle component analysis allowed us to explore patterns between study sites in relation to proximity to landcover types and anthropogenic features. Principle Components Analysis (PCA) with landcover classification data was compiled using GIS to identify and explore linear patterns of correlated landcover characteristics and anthropogenic features between study sites using software R (R Core Team 2013) and package Vegan (Oksanen et al. 2016). The principle component analysis displayed the landcover characteristics along a trend represented by the first principle component (PC1). Varimax rotations or orthogonal rotations (which maximizes the sum of the variances) were then applied to the loadings for further interpretation and simplification of the dataset.

CHAPTER III

RESULTS

A total of 119 species were detected during the 2012 and 2013 field seasons, including 50 List A species, 27 List B species and 42 Other species (Table 4). The migrant species (List A and List B) are the focus of this study. There was substantial diversity in the species detected by the acoustic monitors for List A, B and Other species groups (Table 4).

Table 4. A Comprehensive List of Species Detected by the Acoustic Monitors during Diurnal and Night Flight through Spring and Fall Migration, 2012-2013, Organized by Migratory Group

List A Species	List B Species	Other Species
American redstart	American goldfinch	American bittern
Bank swallow	American robin	American crow
Baltimore oriole	Belted kingfisher	American woodcock
Black and white warbler	Brown-headed cowbird	Bald eagle
Black-billed cuckoo	Brown creeper	Black bellied plover
Bay-breasted warbler	Cedar waxwing	Black-capped chickadee
Blue-gray gnatcatcher	Eastern meadowlark	Black-crowned night heron
Blue-headed vireo	Eastern phoebe	Barred owl
Blackburnian warbler	Eastern towhee	Blue Jay
Black poll warbler	Fox sparrow	Brown thrasher
Black-throated blue warbler	Hermit thrush	Caspian tern
Black-throated green warbler	Horned lark	Common grackle
Canada warbler	Killdeer	Common loon
Clay-colored sparrow	Northern flicker	Common raven
Chipping sparrow	Pine siskin	Common snipe
Chimney swift	Purple finch	Common tern
Cape May warbler	Ruby-crowned kinglet	Downy woodpecker
Common nighthawk	Red-winged blackbird	Eastern screech owl
Conneticut warbler	Savannah sparrow	European starling
Common yellowthroat	Slate colored junco	Field sparrow
Chestnut sided warbler	Song sparrow	Great blue heron
Eastern wood peewee	Tree swallow	Golden-crowned kinglet
Great crested flycatcher	Vesper sparrow	Great horned owl
Gray-cheecked thrush	White-crowned sparrow	Greater yellowlegs
Gray catbird	White-throated sparrow	Hairy woodpecker

Table 4. A Comprehensive List of Species Detected by the Acoustic Monitors during Diurnal and Night Flight through Spring and Fall Migration, 2012-2013, Organized by Migratory Group (continued)

List A Species	List B Species	Other Species
Grasshopper sparrow	Yellow-bellied sapsucker	Lapland longspur
Least flycatcher	Yellow-rumped warbler	Least sandpiper
Lincoln's sparrow		Lesser yellowlegs
Magnolia warbler		Mourning dove
Merlin		Northern cardinal
Mourning warbler		Pine warbler
Nashville warbler		Pileated woodpecker
Northern parula		Red-breasted nuthatch
Northern waterthrush		Rusty blackbird
Orange crowned warbler		Sandhill crane
Ovenbird		Snow bunting
Rose-breasted grosbeak		Spotted snadpiper
Scarlet tanager		Swamp sparrow
Swainson's thrush		Tufted titmouse
Tennessee warbler		Whimbrel
Veery		Winter wren
Warbling vireo		White-winged crossbill
Willow flycatcher		
Wilson's warbler		
Wood thrush		
Yellow billed cuckoo		
Yellow-bellied flycatcher		
Yellow warbler		
Yellow palm warbler		
Yellow-throated vireo		

Overall, 1,937 List B species were detected during spring migration and 1,524 List A species were detected (Figures 2a and 2b), respectively. During spring migration, the highest number of species were detected on the Leelanau Peninsula, and the lowest number of species were detected on McCauley Point (MCP) of Beaver Island and Hog Island North (HIN). An increased number of species cumulatively passed through the migratory corridor in spring of 2012 (3,471) than spring of 2013 (2, 868).

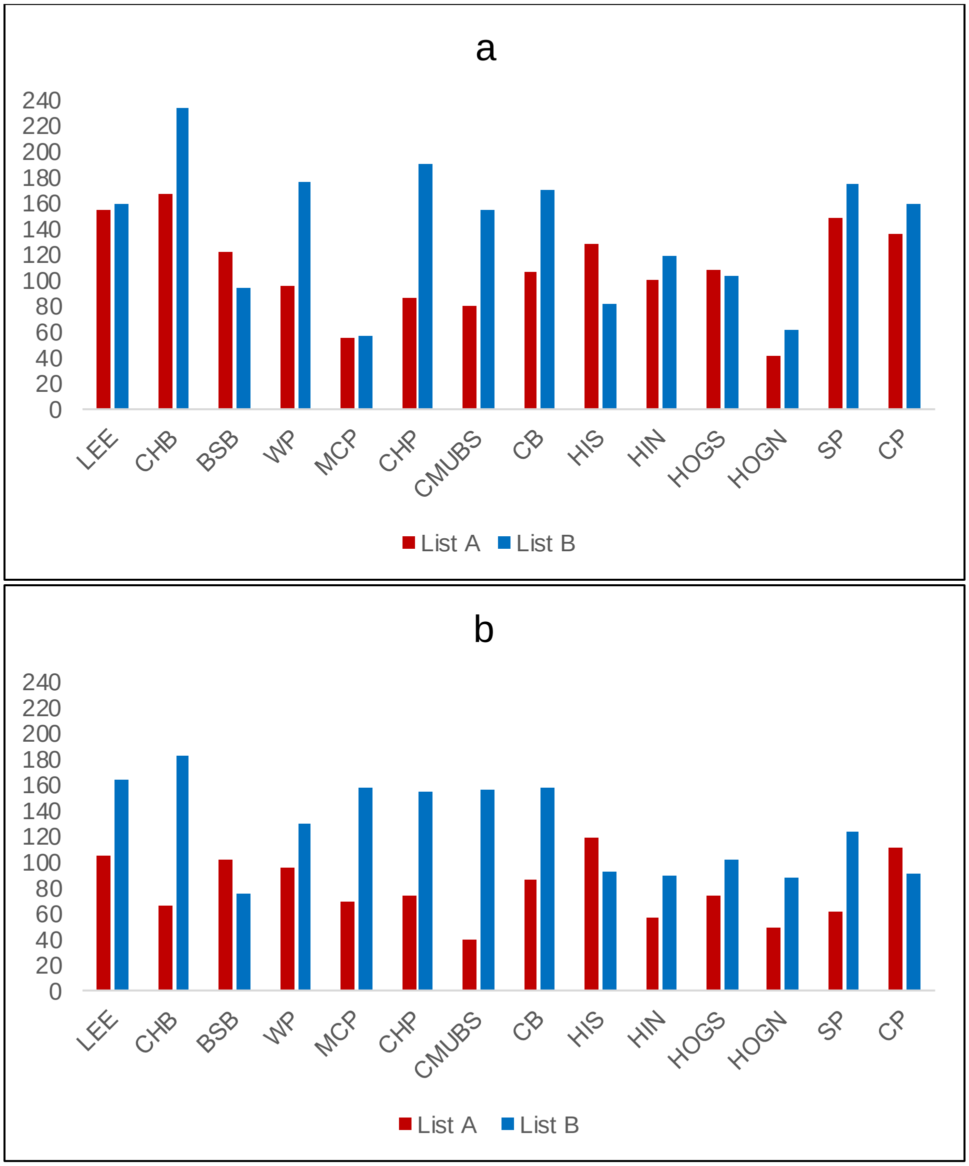
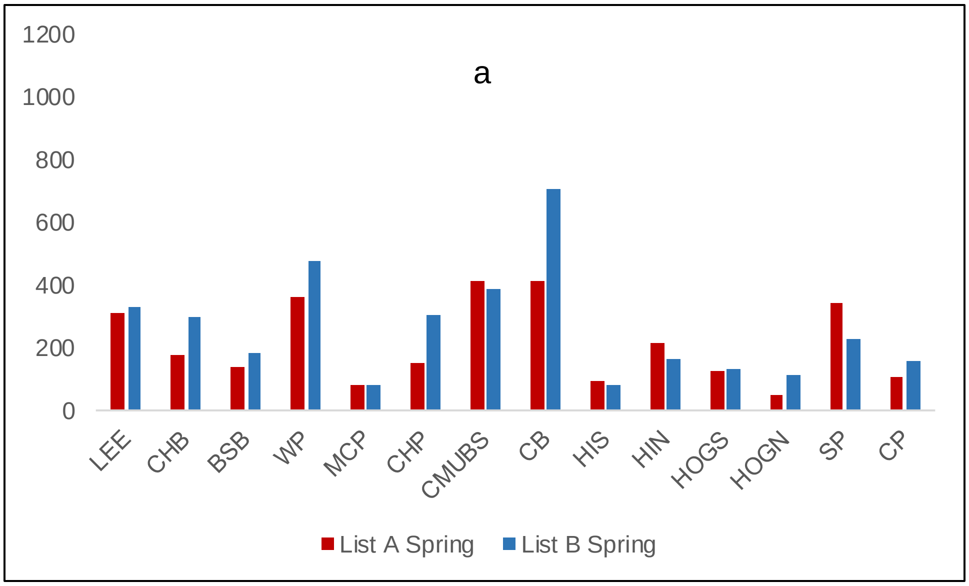


Figure 2. The Total Number of Species Detected by Acoustic Monitors during Diurnal Periods at each Study Location during Spring Migration 2012 (a) and 2013 (b)

A total of 2,979 List A birds and 3,640 List B birds were detected during night flight in spring 2012 (Figures 3a and 3b). A total of 4,282 List A birds and 3,732 List B birds were detected during night flight in fall 2013 (Figures 4a and 4b).



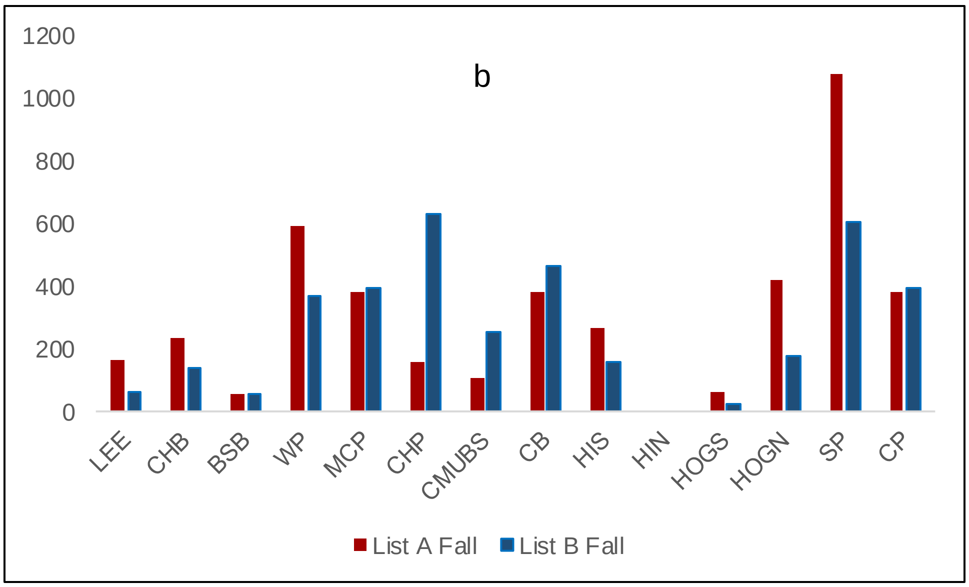


Figure 3. The Total Number of Birds Detected during Night Flight at each Study Location using Acoustic Monitors during Spring Migration (a) and Fall Migration (b), 2012

Note: Weather conditions, accessibility and equipment issues prevented data collection for CHB, HIS, HIN, and HOGN in fall 2013.

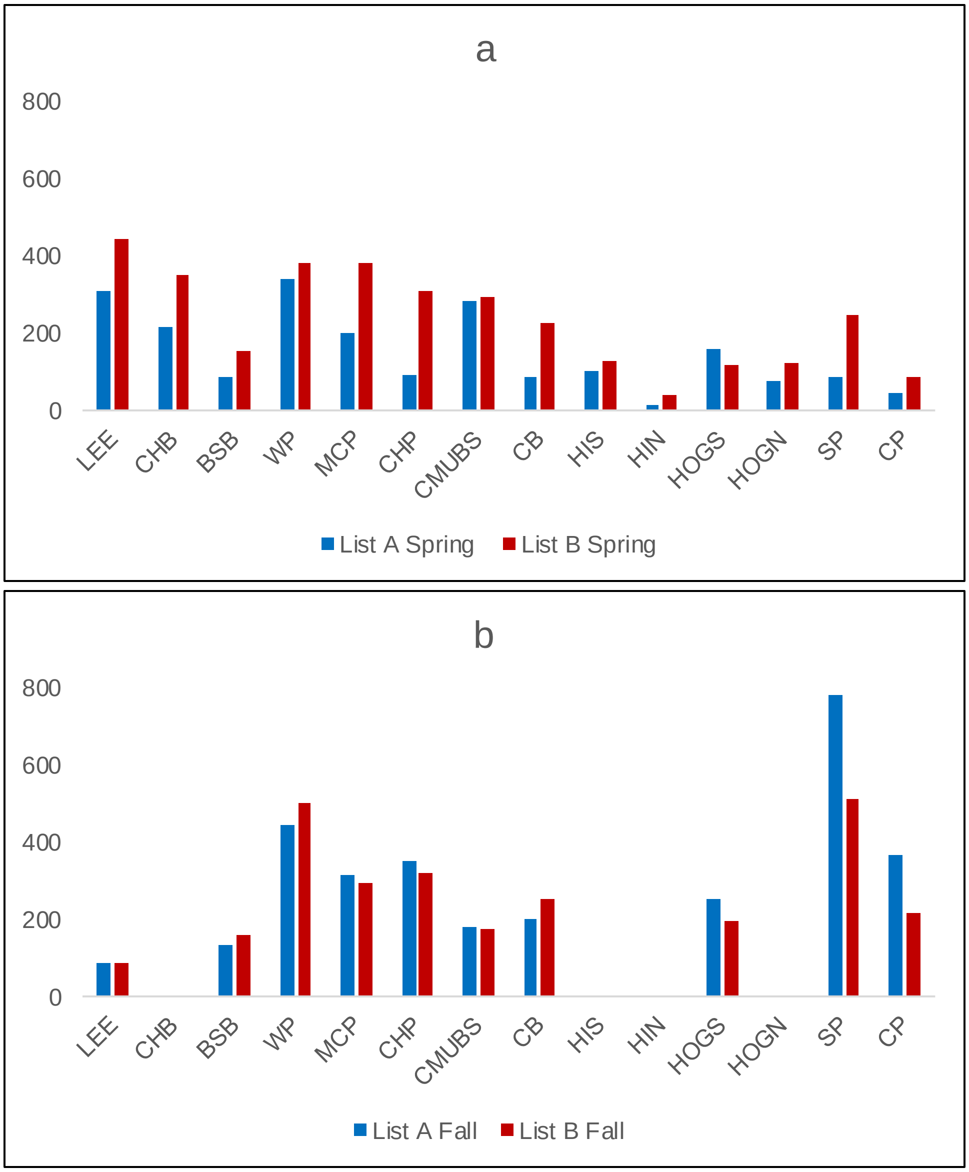


Figure 4. The Total Number of Birds Detected during Night Flight at each Study Location using Acoustic Monitors during Spring Migration (a) and Fall Migration (b), 2013

Principle Components Analysis-Vegetation Structure

Principle components analysis (PCA) results allowed us to interpret associations that may exist between study site and vegetation structure. A bi-plot produced by the PCA analysis (Figure 5) indicates that Principle Component 1 appears to be pulled horizontally to the left by components related to the forest edge such as percent canopy cover (CAN) leaf litter within the forest (LEAF) density of trees 0.5m-1m in height (T3), and snag density (SNAG). Due to the vertical nature of the vectors for percent sand (SAND) and distance to shore (DS) there is not influence on Component 1 or 2. At the bottom of the plot, percent sand or barren cover (SAND) is associated with density of coarse woody debris (CWD) however, these variables are placed near study site 6 which was located on a rocky spit. Component 2 toward the right side of the plot appears to be pulled by variables related to ground cover such as percent ground cover on the beach (GCB) and percent ground cover on the forest edge (GCF) where sites with a stronger shoreline component and less of a forested component are located. The blue ellipsoids were created to draw attention to structural associations between sites and are not statistically significant. Outliers may appear structurally diverse from these groupings. Additionally, we see that associations between sites were not a product of their geographical placement, and that structural similarities exist among nearshore areas and islands in the northern Lake Michigan basin.

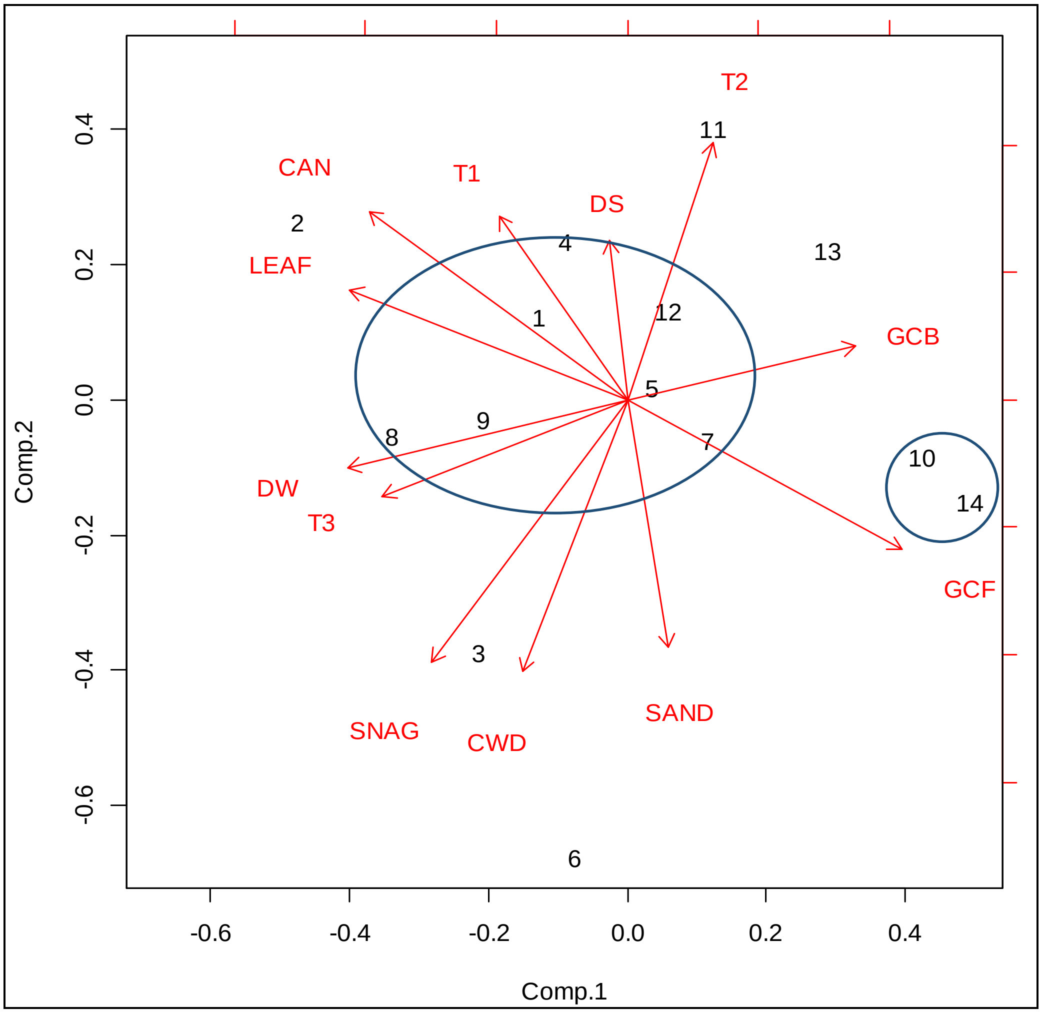


Figure 5. Biplot of the Scaled First Two Principle Components with Correlations of Sites within Blue Ellipsoids (1: Leelanau, 4: Waugashcance Pt., 5: McCauley Pt., 7: CMU Bio Station, 8: Cable Bay, 9: High Island S., 10: High N., 12: Hog N.,14 :Cozy Pt.)

A loading plot produced by PCA analysis provides information on the amount of variance between components (Table 5). The loadings (correlations) between distance to wetland (DW), percent leaf litter (LEAF), and density of trees 0.5-1m in height (T3) correlate strongest with principle component 1, where the number of snags and coarse woody debris correlate strongest with component 2. The percent ground cover within the forested edge (GCF) was grouped with site 10, High Island North, and site 14, Cozy Point. The grouping of percent canopy cover (CAN) and percent leaf litter within the forest interior (LEAF) was grouped with site 2 (Cathead Bay). Cathead Bay indicated the highest number of List A and List B species detected during diurnal periods for 2012, and the highest number of List B species detected during diurnal periods in 2013. The number of trees less than 5 inches DBH (T2) was grouped with site 11 (Hog Island South), which had a low number of List A and B species detections during diurnal periods for 2012 and 2013 when compared to other sites. We can further interpret from these results that 50% of the variance is explained by the first two components (Table 6), and components 1-6 explain 89.5 % of the variation in the dataset. This allowed us to move forward with further analysis with the first two principle components.

Table 5. Loadings Plot Results for Principle Component Analysis Indicating the Influence each Variable has on the First and Second Principle Component

Structural Variables	Comp.1	Comp.2
Trees > 5 in DBH (T1)	-0.185	-0.285
Trees < 5 in DBH (T2)	0.123	-0.399
Trees .5-1 m height (T3)	-0.352	0.15
# snags (SNAG)	-0.281	0.407
# coarse woody debris > 5cm (CWD)	-0.15	0.421
% ground cover within forest edge (GCF)	0.394	0.231
% ground cover on beach (GCB)	0.327	-
% leaf litter (LEAF)	-0.399	-0.171
% sand/rock/barren (SAND)	-	0.385
% canopy cover (CAN)	-0.371	-0.291
distance to wetland (m) (DW)	-0.43	0.106
distance to shoreline (m) (DS)	-	-0.247

Table 6. The Proportion of Variance Explained by each Principle Component (Comp) in the Principle Component Analysis

	Comp.1	Comp.2	Comp.3	Comp.4	Comp.5	Comp.6
Prop Var	0.26266	0.23792	0.14064	0.11494	0.08381	0.05508
Cum Pop Var	0.26266	0.50058	0.64122	0.75616	0.83997	0.89505
Std Dev	1.77537	1.68968	1.29912	1.17442	1.00288	0.81298

Note:50.058 percent of the variance is explained by Component 1 and Component 2.

Non-Metric Multidimensional Scaling-Vegetation Structure

A solution to the NMDS was reached with 3 dimensions. This ordination stabilized at a stress of 0.0157 (Figure 6). The correlation based on stress (S), where $R^2 = 1-S^2$, R-squared= 0.99. Output scores for NDMS1 and NMDS2 are indicated in Table 8. When analyzing the plot produced by the NMDS (Figure 6), species groups may clearly be seen between List A and List B species. Sites grouped closer to each other associate with species assemblages, and those that are farther apart have differing species composition. Interestingly, we have very strong grouping between species groups. It is important to note that this analysis did not produce robust noticeable patterns within these groups in relation to site, structure and the of bird species-this was purely another form of exploratory analysis to determine whether relationships existed between species and sites. By deduction, List A species appear to show a relationship with Big Stone Bay, Cozy Point, and High Island South. In the PCA bi-plot, Big Stone Bay may slightly be associated with the number of snags and coarse woody debris, where Cozy Point and High Island South were driven by ground cover within the forest interior. List B species appear to show a relationship with Waugashance Point, slightly associated with the distance to shore and substory canopy trees less than 5 inches in diameter. List B species also showed a relationship with Cheyenne Point, which was not correlated to other monitor locations and appeared as a structural outlier. Leelanau, McCauley Point, and CMU Biological station, which all share similar structural composition, also indicated an association with List B species. The “Other” species group indicated a relationship with Cathead Bay and the North end of Hog Island, both which appeared structurally dissimilar from the PCA analysis whereas Cathead Bay was associated with canopy cover and leaf litter, Hog Island North showed an association with trees a DBH of over 5 inches. Overall, ellipsoids were placed on the plot by hand without statistical significance but to draw attention to overall relationships. Blue ellipsoids represent List A, List B and Other species groups. Within species groups, associations existed with island (green) and nearshore (orange) study sites.

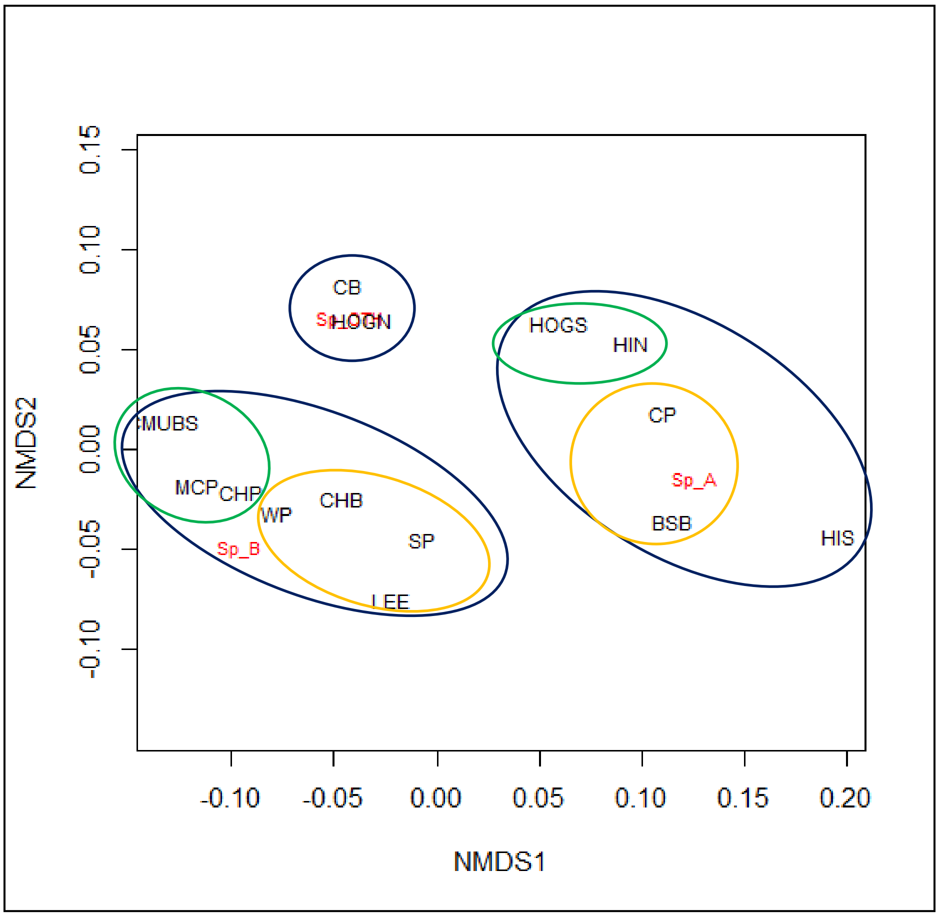


Figure 6. Non-Metric Multi-Dimensional Scaling Ordination Plot Indicating List A and List B Species Associations with Stopover Structure, where NMDS1 Represents the Horizontal Axis and NMDS 2 Represents the Vertical Axis, Stress = 0.0157, 3-Dimension Solution was Reached

General Linear Regression-Vegetation Structure

The model with the best goodness of fit was NDMS1~PC1, where NMDS1 showed a strong relationship to PC1. With these results we were able to infer that there is a strong positive correlation between habitat structure and bird species presence (Figure 7). This analysis produced an R-squared value of 0.6806, indicating that 68% of the NMDS variation is explained by the linear model and a p-value of .0002 (Table 7). In other words, this goodness of fit test indicates that vegetation structure has a positive relationship with diurnal bird species presence.

Table 7. Multiple Linear Regression Results Based on NDMS and PCA Analysis, which Produced an R-Squared Value of 0.6806, Indicating that 68.06 % of the NMDS Variation is Explained by the Linear Model

	Regression Statistics-NMDS and PCA			
NMDS1~PC1	R^2	*F*	*df (regression, residual)*	*p-value*
List A Spring	0.68	25.57	(1,12)	0.0002

Interesting patterns emerge when we join the information from PCA, NMDS, and linear regression results. The information contained within the PCA analysis on vegetation structure in addition to noticeable patterns from the NMDS analysis on diurnal bird species data were superimposed onto the linear regression residual plot (Figure 8). The x-axis (PC1) indicates a shift from canopy cover (CAN) to ground cover within the forest edge interior (GCF), similar associations are present in the PCA analysis.

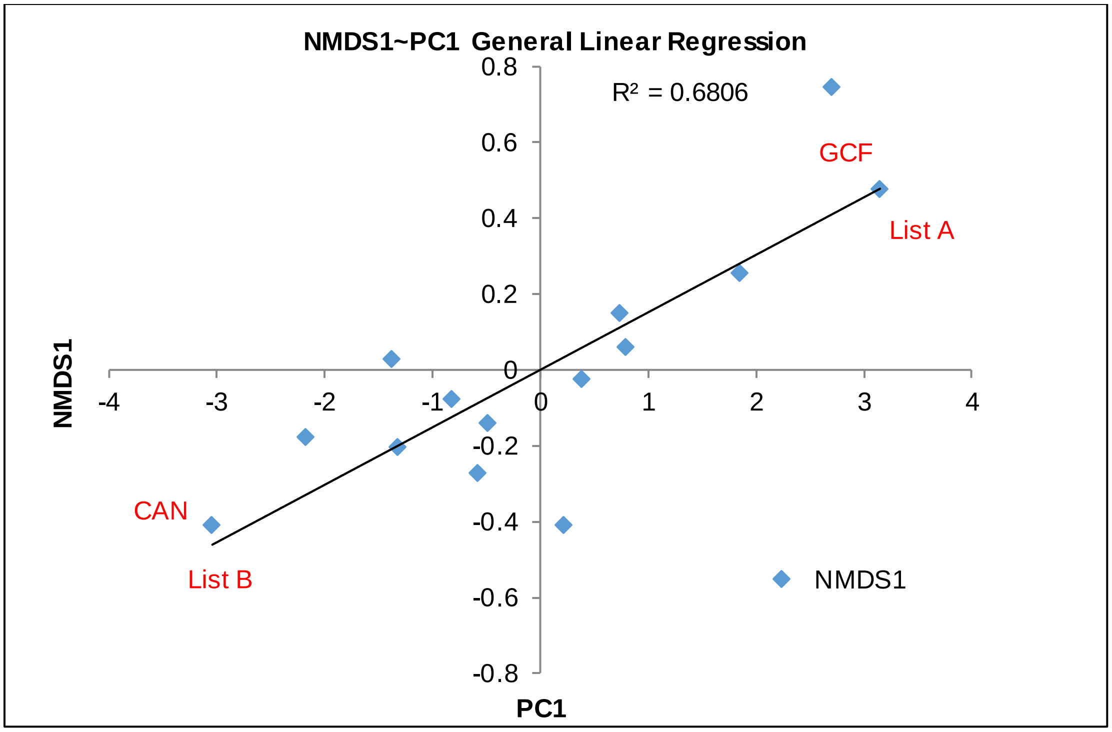


Figure 7. General Linear Regression Model where NMDS~PC1, Observed NMDS1 Values from NMDS Analysis are Plotted against Predicted PC1 Values from PCA Analysis, p-value = .0002

Note: NMDS and PCA indicators superimposed onto the residual plot from the general linear regression, the linear model NMDS1~PC1 has an R-squared of 0.68. Note associations between canopy cover and List B species, as well as ground cover within forested edge and List A species.

The linear regression analysis indicated a positive relationship between List A migrant presence at stopover locations and legacy structures such as snags, as well as coarse woody debris. A relationship between List B migrants and forest canopy cover as well as increased mid story structure at stopover locations was also revealed. This indicates that List A and B migrants appear to utilize different structural components of stopover locations.

Multiple Linear Regression and Principle Components Analysis-Landscape Features

Top model selection results for multiple linear regression indicate landcover types which may best explain variations in the mean number of birds utilizing the migratory corridor at night (Table 8). Based on these results, the proximity of landcover types does not appear to indicate a strong explanation for nocturnal use of a migratory route for migrant birds-however the proximity of vegetative cover adjacent to the shoreline does. AIC (corrected) was used for smaller sample size. In examining top model selection further, we see that our AICc results differ drastically when forested and wetland components are removed from the model for List A migrants. It appears that these variables may have a larger influence on List A species over List B species. Forested cover was included in the top model for List A species, and not for List B species. However, based on these results, the proximity of landcover types measured to not appear to indicate a strong explanation for nocturnal use of a migratory route for migrant birds. Additionally, model selection results for multiple linear regression indicate the effect of anthropogenic features on the landscape which may best explain the effect of these features on nocturnal use of a migratory corridor (Table 9). The top model selection for List A and List B migrants during both seasons was the full model, which included areas of low and high urban density, airports and roads. During both spring and fall, top model selection included each of the anthropogenic features for List A and List B species. This may elude to a stronger influence from anthropogenic features among the landscape than landcover types when following a migratory path during night flight.

Table 8. Model Selection for the Effect of Landcover Type on the Mean Number of Birds Detected while Migrating at Night within Migratory Corridor 2012-2013

		Intercept	AICc	Delta	Weight	R^2 adj	p-value
List A Spring	List A~Water + Ag + Herb + Scrub + Forested	5.28	584.20	0.00	0.99	0.336	0.139
	List A~Water + Ag + Herb + Scrub +Forested+Wetland	5.80	592.60	8.32	0.02		
	List A~Water + Ag + Herb + Scrub	5.87	646.10	61.86	0.00		
Term		*Coef*					
	Constant	354					
	Water	-1.582					
	Ag	0.0294					
	Herb	-0.202					
	Scrub	-0.0579					
	Forested	0.199					
List A Fall		*Intercept*	*AICc*	*Delta*	*Weight*	*R^2 adj*	*p-value*
	List A~Water + Ag + Herb + Scrub + Forested+Wetland	7.21	3333.60	0.00	0.73	0.196	0.294
	List A~Water + Ag + Herb + Scrub + Wetland	7.22	3333.50	1.97	0.27		
	List A~Water + Ag + Herb +Wetland	7.16	3345.10	11.49	0.00		
Term		*Coef*					
	Constant	1288					
	Water	-2.49					
	Ag	-0.0807					
	Herb	-0.245					
	Scrub	-0.022					
	Forested	0.188					
	Wetland	1.133					
List B Spring		*Intercept*	*AICc*	*Delta*	*Weight*	*R^2 adj.*	*p-value*
	List B~Water + Ag + Scrub + Wetland	6.72	544.70	0.00	0.92	0.628	0.010
	List B~Water + Ag + Herb + Scrub + Wetland	6.72	551.00	6.29	0.04		
	List B~Water + Ag + Herb + Scrub + Wetland	6.72	551.20	6.50	0.04		
Term		*Coef*					
	Constant	734					
	Water	-2.984					
	Ag	0.0198					
	Scrub	-0.1039					
	Wetland	-0.344					

Table 8. Model Selection for the Effect of Landcover Type on the Mean Number of Birds Detected while Migrating at Night within Migratory Corridor 2012-2013 (continued)

		Intercept	*AICc*	*Delta*	*Weight*	R^2 adj.	*p-value*
List B Fall	List B~ Water + Ag + Herb + Scrub + Wetland	7.40	1919.90	0.00	0.61	0.379	0.112
	List B~ Water + Ag + Herb + Scrub + Forested+Wetland	7.37	1920.80	0.90	0.39		
	List B~ Water + Ag + Scrub + Forested+Wetland	7.43	1933.90	0.00	0.00		
Term		*Coef*					
	Constant	1117					
	Water	-3.05					
	Ag	-0.0524					
	Scrub	-0.0652					
	Wetland	-0.044					
	Herb	-0.0536					

Note: The top three ranked models from each set were found using AICc.

Table 9. Model Selection for the Effect of Anthropogenic Features on the Mean Number of Birds Detected while Migrating at Night within Migratory Corridor 2012-2013

		Intercept	*AICc*	*Delta*	*Weight*	R^2 adj	*p-value*
List A Spring	List A~ Lo Urban + Hi Urban + Airport + Roads	5.85	658.90	0.00	1.00	0.351	0.095
	List A~ Hi Urban + Airport + Roads	5.95	766.30	107.40	0.00		
	List A~ Lo Urban + Hi Urban + Roads	6.02	993.40	334.47	0.00		
Term		*Coef*					
	Constant	356.1					
	Lo_Urban	-0.0363					
	Hi_Urban	-0.0692					
	Roads	0.0711					
	Airport	0.0286					
List A Fall		*Intercept*	*AICc*	*Delta*	*Weight*	R^2 adj.	*p-value*
	List A~ Lo Urban + Hi Urban + Airport + Roads	7.57	3496.20	0.00	0.91	0.141	0.272
	List A~ Lo Urban + Airport + Roads	7.54	3500.70	4.58	0.09		
	List A~ Lo Urban + Hi Urban + Airport	7.61	3700.70	204.55	0.00		

Table 9. Model Selection for the Effect of Anthropogenic Features on the Mean Number of Birds Detected while Migrating at Night within Migratory Corridor 2012-2013 (continued)

Term		*Coef*					
	Constant						1426
	Lo_Urban						0.146
	Hi_Urban						0.021
	Roads						-0.0948
	Airport						-0.0641
List B Spring		*Intercept*	*AICc*	*Delta*	*Weight*	R^2 adj.	*p-value*
	List B~ Lo Urban + Hi Urban + Roads + Airport	6.42	1005.60	0.00	1.00	0.238	0.176
	List B~ Lo Urban + Hi Urban + Roads	6.48	1099.30	96.65	0.00		
	List B~ Hi Urban + Airport + Roads	6.49	1105.00	99.39	0.00		
Term		*Coef*					
	Constant						575
	Lo_Urban						-0.0457
	Hi_Urban						-0.0639
	Roads						0.0781
	Airport						0.0179
List B Fall		*Intercept*	*AICc*	*Delta*	*Weight*	R^2 adj	*p-value*
	List B~ Lo Urban + Hi Urban + Roads + Airport	7.07	1887.30	0.00	1.00	0.322	0.113
	List B~ Lo Urban + Roads + Airport	7.03	1900.70	13.48	0.00		
	List B~ Lo Urban + Hi Urban + Airport	7.11	2053.00	165.74	0.00		
Term		*Coef*					
	Constant						878
	Lo_Urban						0.0929
	Hi_Urban						0.0044
	Roads						-0.0605
	Airport						-0.0345

Note: The top three ranked models from each set were found using AICc.

Principle component analysis allowed us to explore patterns between study site proximity to major landcover types and anthropogenic features within 5 km. A bi-plot produced by the PCA analysis (Figure 8) indicated that Principle Component 1 appears to be pulled horizontally by anthropogenic disturbance and natural vegetation. Principle Component 2 is pulled vertically by anthropogenic disturbance and natural vegetation. The scattered nature of the plot indicates that sites are within varying proximity to cover types. The loadings (correlations) between areas of high urban density and airports negatively correlate with principle component 1, where wetlands positively correlate with component 1. Forested and herbaceous cover correlated strongest with component 2. Site 3 (Big Stone Bay) was grouped with road density and low urban density, and the total number of List A and List B birds detected during night flight at this site was significantly low compared to other sites. Site 12 (Hog Island N.) is grouped with herbaceous and forested landcover, which had the lowest number of List A birds detected during spring night flight in 2012, and no detections in 2013 for spring or fall due to equipment failure. Sites 7 (CMU Biological Station) 8 (Cable Bay) and 11 (Hog Island S.) were grouped with proximity to water, each of these sites is located on an island within northern Lake Michigan and patterns indicated a much higher number of List A and List B birds detected in the spring than in the fall for 2012 and 2013. Additionally, site 13 (Scott Point) was grouped with wetland proximity and indicated the highest number of List A birds detected during fall night flight for both 2012 and 2013. We can further interpret from these results that 57.5% of the variance is explained by the first two components (Table 11), and components 1-4 explain 83 % of the variation in the dataset.

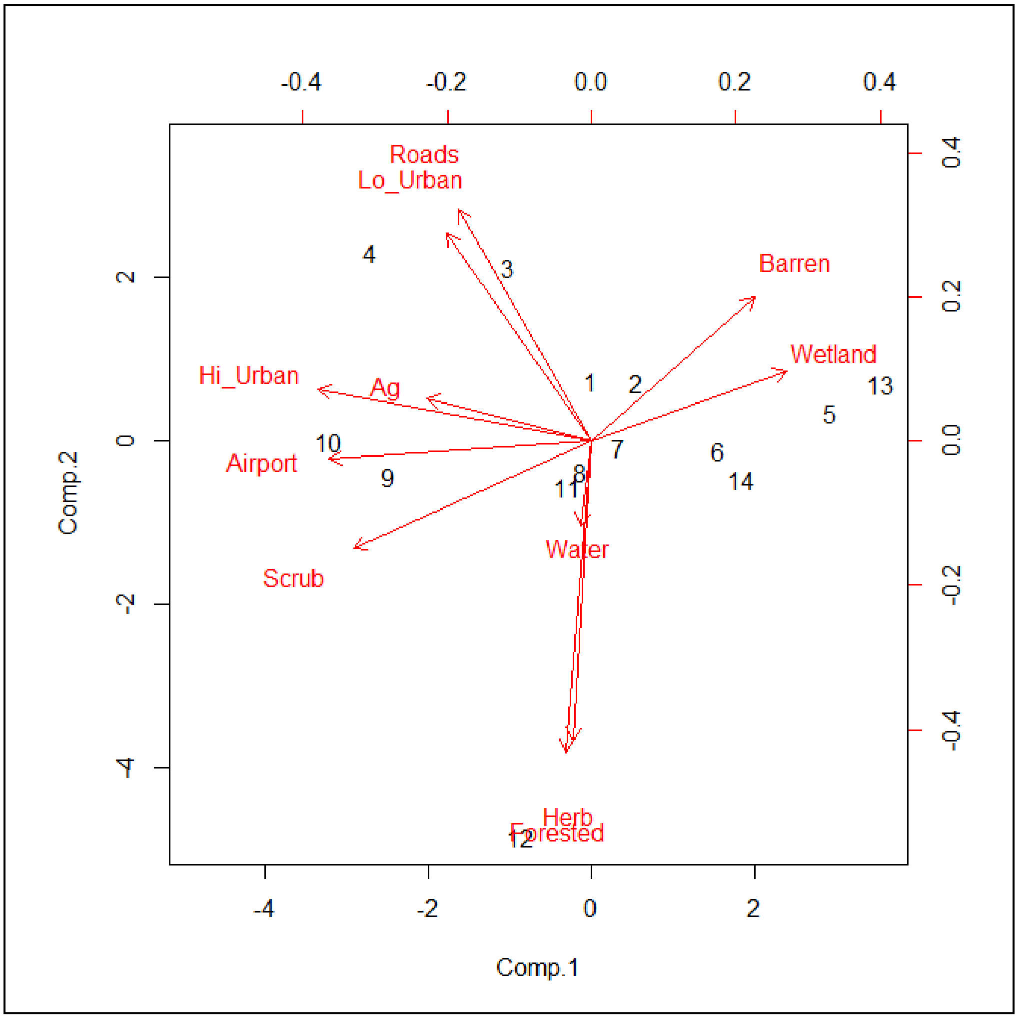


Figure 8. Biplot of the Scaled First Two Principle Components
Note: Component one appears to be Split between areas of anthropogenic disturbance and natural vegetation (left to right). Component two Also appears to be split between anthropogenic disturbance and natural vegetation (top to bottom).

Table 10. Loadings Plot Results of Principle Component Analysis Indicating the Influence Each Variable has on the First and Second Principle Component

Variable	Comp.1	Comp.2
Water		-0.147
Lo_Urban	-0.251	0.361
Hi_Urban	-0.475	-
Barren	0.283	0.249
Ag	-0.286	-
Herb		-0.519
Scrub	-0.412	-0.187
Airport	-0.456	-

Table 10. Loadings Plot Results of Principle Component Analysis Indicating the Influence Each Variable has on the First and Second Principle Component (continued)

Variable	Comp.1	Comp.2
Roads	-0.232	0.4
Forested		-0.54
Wetland	0.338	0.122

Table 11. The Proportion of Variance Explained by Each Principle Component (Comp) in the Principle Component Analysis

	Comp.1	Comp.2	Comp.3	Comp.4
Std Dev	1.942401	1.597762	1.243247	1.153297
Prop Var	0.342993	0.232077	0.140515	0.120918
Cum Prop Var	0.342993	**0.57507**	0.715585	0.836502

Note: 0.57507 or 57.507 percent of the variance is explained by the first Component 1 combined with Component 2.

CHAPTER IV

DISCUSSION

Acoustic monitors detected a wide diversity of neotropical and Nearctic migrant species utilizing stopover locations adjacent to Lake Michigan during spring migration, further supporting the critical importance of these areas for migrant birds. Migrants utilized islands and coastal migration routes consistently during both spring and fall migration. Study sites were structurally diverse, yet similarities existed between mainland and island sites. List A species detections during diurnal periods appeared to be correlated to sites with legacy structures, such as snags and coarse woody debris as well as the proportion of ground cover within the forest interior, whereas List B species detections appear to be associated with small diameter sub canopy trees and canopy cover, or areas with a high stem density and significant mid-story structure. Differences between List A and List B may be further investigated in terms of forest age class where one appears to have a propensity to legacy structures found in mature forests and the other toward shade tolerant forest composition with increased structural diversity indicative of young forests- here we may conclude that species groups are utilizing areas of differing ecological complexity.

Overall, detections were greater during spring migration for both years. Weather plays an important role in an increased number of birds migrating in the spring, as birds are more likely to migrate during overcast skies than during periods of rain or fog (Seefelt 2013) which are widespread during spring in the Great Lakes region. Further, higher detection rates occurred on mainland locations compared to island locations. These results are opposite of McCann et al. 1993, who found higher concentrations on island locations when compared to mainland locations. Our results may be due to the geographical variation that we see in habitat use by species, even in areas of similar habitat complexity (Brawn 2001). Further, spring conditions provide a suite of harsh conditions for a migrant (Blake and Hoppes 1986) including variability in available food and cover as well as treacherous weather conditions (Ewart and Hamas 1996). This might lead to later foliage development on islands of the Great Lakes compared to mainland locations, and available foliage may be a cue for a malnourished migrant seeking resources such as cover and forage opportunities. There is still complex decision making acting as a driving force behind which habitats migrants choose to utilize (Hutto 1985). Temporal differences in detections also occurred in the spring, where a greater number of species were detected during diurnal periods in spring of 2012 than spring 2013. This may be due to a number of extrinsic factors, including weather patterns exhibited between years and would require further investigation. Spatial patterns emerged during spring night flight, where List A species detections increased on mainland locations. List B species did not show noticeable spatial variation detections were similar at island and mainland locations. These patterns were not as prevalent during fall migration. Increased detections on mainland locations may be related to the physical condition of the migrant (Kerlinger and Moore 1987), it has also been suggested that coastlines act as a guide for nocturnal migrants along a path.

We now have a small snapshot of the structural composition of these coastal stopover locations and available resource juxtaposition among the landscape. The structural composition of coastal stopover locations appears to provide information about bird diurnal species assemblages utilizing these areas during seasonal migration events, and some suggest that stopover locations are selected during daylight hours (Moore et al. 1995). Intuitively, these structural components influence critical foraging opportunities for forest songbirds during stopover (Hutto 1985, Moore and Kerlinger 1987, Ewert et al. 2005) and it has been suggested that the use of stopover locations has been based upon complex evaluations (Hutto 1985). Each of the study locations were quite diverse and structurally complex, and our data indicates that each site supported a wide diversity of migrants. Diurnal models indicated that vegetation structure had a positive relationship with bird species presence and this is continually supported in the literature (Hutto 1985, Bonter et al. 2009, Buler et al. 2011). Analysis of the diurnal data allowed us to conclude that associations exist between stopover habitat structure and bird species presence, and that List A and List B migrants appear to utilize different structural characteristics at stopover locations. Again, this is likely be due to species specific response to habitat structure. The analysis of List A species continually indicated a strong relationship between percent ground cover within the forest edge. This association may be related to forage selection of neotropical migrants based on structure (Thompson et al. 1992). List A migrants also showed a strong association to snags and coarse woody debris. Snags or other legacy structures have long been associated with bird species abundance and diversity due to the plethora of foraging opportunities they provide. List B migrants appear to have been associated with vertical structure, midstory structure may be indicative of foraging preference in areas with higher stem density and age class diversity as well as areas with dense canopy cover. Migrants have shown strong associations with mature edge dominated habitat as well as early successional forests during fall stopover (Rodewald and Brittingham 2004). The information we present here may indicate that migrants are selecting stopover locations based on these structural characteristics.

Associations between sites were not a product of their geographical placement, in other words structural similarities exist among nearshore areas and islands in the northern Lake Michigan basin. The PCA biplot indicated that although sites were very diverse based on the characteristics that we measured; they also shared strong similarities in vertical structure between the understory, midstory, and canopy cover. Interestingly, High Island in the Beaver Archipelago indicated associations with Cozy Point in the southern Upper Peninsula based on ground cover characteristics and not structure. These findings further elude to the presence of significant suitable stopover habitat available along this migratory route among island and coastal locations.

Subtle associations between the number of species detected during night flight and the distance to a landcover type or anthropogenic feature were present, but larger landscape variables were not a significant predictor of birds migrating at night in this study. Sites grouped closer to wetlands had a higher number of List A and B species detected in fall than spring for both years. This is likely due to forage opportunities that wetlands provide to fall migrants. The proximity and juxtaposition of various landcover types did not appear to have a significant influence on the route utilized by migrants during night flight events. Each landcover type adjacent to the shoreline that we analyzed was an important factor in each of the models, and proximity to cover type did not seem to influence use of a migratory route. This leads us to believe that specific landcover characteristics are not an important visual cue when moving along a migratory route, and that adjacency to a large geographical barrier and proximal forest cover are clearly more influential (Gauthreaux 1971, Bonter et al. 2008) no matter the season. Forest cover and wetland proximity may be utilized as a visual cue as birds move through the region at night and appear to be important to both List A and List B species groups. Watson et al. 2016 recently found that areas with low anthropogenic disturbance, such as street lights, disoriented nocturnal migrants and resulted in an increased amount of night flight calls. Considering the extended distance from each of our study sites to areas of low to high urban density and the lack of anthropogenic lights along the shoreline, we did not observe such a pattern. With this study, the majority of the coastline that we examined contains intact forested habitat, leading us to believe that forest cover may not be a predominant cue for a migratory pathway-our linear models also support this. However, it has been suggested that in areas succumbing to intense deforestation, a migratory route may not maintain its efficacy as suitable stopover habitats would not exist (Tankersley and Orvis 2003). Further investigation into migratory pathways suggest that the placement of suitable habitat along a migratory route is imperative in understanding why the route remains intact. We know that innate cues, genetic dispositions, weather patterns and geographic barriers all act as cues for migrants along well established routes. Regional studies may be developed to continue to explore these relationships. In this instance, exploring landscapes which exhibit a large amount of variation (Deppe and Rotenberry 2008) may indicate differing patterns, as land cover features across our study area were fairly congruent and may have prevented us from determining which features are important to nocturnal migrants at this scale. In Great Lakes region, developing a habitat suitability model (potentially expanding upon Ewart et al. 2012) and overlaying flight orientation models (Tankersley and Orvis 2003) to identify optimal migration routes may allow us to further identify landscape scale variables that influence these migration events.

Management Recommendations

Improved data on the compositional structure of various habitats utilized throughout annual migration routes will aid in the development of comprehensive conservation strategies for Great Lakes migrants. Conserving important coastal and island stopover locations for migrant birds should evolve into maintaining intact forest cover that we continually see along the northern Lake Michigan shoreline. Preserving legacy structures such as snags and coarse woody debris among dense vertical structure of varying age classes and diameters would involve more active management but is recommended. Areas with limited management capability should continue to maintain contiguous ownership of coastal forested areas to reduce potential fragmentation. Continued adaptive management techniques applied to landscape scale conservation measures will be necessary to maintain connectivity and suitability between breeding and wintering grounds for migrant birds, as well as to support declining populations-specifically those of special concern. Habitat fragmentation and development will further threaten the existence of critical stopover habitat in this region linking the breeding and wintering grounds, which could potentially result in a collapse of the migration route itself.

In this study, we provide quantifiable information for structural attributes which contribute to diurnal species presence and use at stopover locations, as well as documenting the migratory route connecting these stopover locations. However, our study offers only a snapshot of potential suitable habitat for migrants in this region. Additional work is necessary to better understand stopover habitat use and existing migration routes. For example, the combination of acoustics which provides detailed information on the composition of migrant flocks with weather satellite radar which offers detailed information of flock density as well as specific migrant arrival and exodus. Additionally, with the marginal influence from anthropogenic disturbance that we saw in our results, it leads us to question whether these disturbances actually influence the migratory route being utilized. Additional spatial analysis is needed, and likely with varying landcover resolution. It is our hope that this information will remove broad limitations on the prioritization of focal areas for conservation.

Conclusions

There is a broad diversity of migrants utilizing the northern Lake Michigan region and island and mainland locations in northern Lake MI offer suitable stopover habitat of varying structural complexity. Analysis of vegetation structure can lead to inference regarding diurnal migratory bird use of temporal stopover locations, specifically those within close proximity of water. Further, the structural composition of coastal stopover locations provides insight into diurnal species assemblages utilizing these areas during seasonal migration events. The composition of each site supported a diverse array of migrants, and continuity of structural characteristics along the northern Lake Michigan shoreline was evident through visual analysis of the landscape alone. Overall, robust differences in structure between mainland coastal areas and islands within the Beaver Archipelago were not prevalent; island and mainland locations provided suitable stopover habitat of varying structural complexity. Our results suggest that structure does influence species presence at stopover locations (differs by List A and B)-however there may be large differences within groups as to how these species utilize structure and this warrants further exploration. List A migrants continually indicated a strong relationship between percent ground cover within the forest edge, which is important when considering juxtaposition to the shoreline. List B migrants appear to associate with vertical structure, midstory structure may be indicative of foraging preference in areas with high stem density and age class diversity as well as areas with dense canopy cover also in relation to juxtaposition to the shoreline. Nevertheless, adjacency to a geographical barrier appears to be a driving factor in species use of stopover locations.

Significant patterns in our models associated with proximity to larger landscape features were not as apparent, which may allow us to conclude that intact suitable stopover habitat (intact forest cover) adjacent to the shoreline must play a role in the pathway that migrants are utilizing.

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