Bat Migration Along the Lake Michigan and Lake Huron Coastlines: A Pilot Study To Inform Wind Turbine Siting

PROJECT NUMBER 10-309-06

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Cover photograph by Joelle Gehring.

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INTRODUCTION

Wind power is an environmentally friendly way of producing electricity that should lessen the overall problem of global warming and our reliance on fossil fuels. In Michigan, the rate of wind turbine construction is expected to soar due to the abundance of areas with high potential for wind development along the Great Lakes. While wind energy is often considered "green" energy, there are environmental impacts associated with both the structures and the transmission lines.

Of great concern is the impact of turbines on bats, as these structures are known to cause mortality due to both collision and decompression (barotraumas). The central mast of modern wind turbines can be 70–100 m or more in height and rotor blades are typically as long as jet airplane wings. Long rotor blades result in very high speeds at the rotor tip (ca. 55–80 m/sec) and a large area of potential contact with flying vertebrates in the rotor-swept area. Consequently, collisions by birds and bats with these tall structures and/or fast-moving blades often cause mortality (Arnett et al., 2008; Kunz et al., 2007a, 2007b). Furthermore, as many as half the bats that are killed show no injuries related to actual collisions (Baerwald et al., 2008) but instead are being killed by barotrauma. The quickly moving rotors leave behind a low-pressure vortex and as the bats fly through this zone or are sucked into it, they suffer severe lung damage, especially pulmonary hemorrhage. Essentially, the blood vessels in their lungs burst because of the difference in pressure between the air and the blood in their capillaries. Birds, which have a different type of respiratory anatomy, do not seem as affected as bats by these momentary low pressures.

The number of bats killed can be quite large. For example, up to 1,980 bats died over a 6-week period in late summer 2004 at a single wind farm in West Virginia (Arnett, 2005), which may have been due to the farm's location on a ridge close to hibernacula. Based on mortality rates observed at functioning wind farms, as well as the projected increase in number of wind developments, biologists estimate that the number of deaths in the year 2020 for the Mid-Atlantic region alone is 33,000–110,000 bats (Kunz et al., 2007b). About half the approximately 45 species of bat in the United States and Canada already are considered endangered or

threatened at the national or local level (Ellison et al., 2003), and any further threats to bats, in general, are a cause of concern to wildlife biologists.

Bat species in the eastern half of the US are under tremendous threat due to the increased presence of wind turbines and the affects of white-nose syndrome. Nine species of bats live in Michigan, including the five species that are most commonly killed at wind turbines. The nine Michigan species are Eastern Red bat (*Lasiurus borealis*), Hoary bat (*Lasiurus cinereus*), Silver-haired bat (*Lasionycteris noctivagans*), Eastern Pipistrelle (*Perimyotis subflavus*), Big Brown bat (*Eptesicus fuscus*), Little Brown bat (*Myotis lucifugus*), Indiana bat (*M. sodalis*), Northern Long-eared bat (*M. septentrionalis*), and Evening bat (*Nycticeius humeralis*). One of these species, the Indiana bat, is the only resident mammal of Michigan that is on the federal list of endangered species. The evening bat is currently being classified as threatened in Michigan, and the eastern pipistrelle is listed as a species of "special concern" by the Michigan Department of Natural Resources. Furthermore, the state's Wildlife Action Plan labels these three species, as well as the eastern red bat, hoary bat, silver-haired bat, and northern bat, as species of "greatest conservation need" (MDNR 2006).

In this multi-year study, we are researched the question of whether bats follow linear migration routes adjacent to the Great Lakes coastline in high priority wind development areas. A secondary assessment of bird migration was included. Answering this question is important to the wind-power industry because it may affect placement of individual turbines and perhaps entire wind farms. Areas of high persistent winds frequently occur along coastlines and our study will help determine whether wind farms placed in such areas will have a greater impact on bats than wind developments that are placed elsewhere. By learning the migratory habits of bats and birds, specifically whether they are using the coastline, inland pathways, or offshore routes, wind energy developers can significantly reduce negative impacts to bats by siting wind turbines in areas with a low concentration of migrants. The Ontario Ministry of Natural Resources, our collaborator in Canada, is addressing the question of east/west migration in Lakes Huron, Ontario, and Erie under separate funding. The results of both studies will provide valuable information on bat migration in the Great Lakes, and will lead to future research on a region

wide scale. This information will also be useful to local planning agencies as they develop guidelines for wind turbine siting.

The objectives of this study were to monitor and record the presence and flight behaviors of bats and nocturnal migrant birds in a north south direction and in association with the Lake Michigan and Lake Huron shorelines to assess bat migration and the collision risk that the installation of wind turbines could pose to those organisms.

Special consideration was given to four specific aspects of airborne wildlife behavior; 1) the timing of risk (seasonal and within-night hours), 2) the response in flight behavior to topography-habitat features within the study area, 3) the influence of the lakeshore on bat and bird night migrant populations, and 4) weather influences on flight behavior.

METHODOLOGY AND STUDY AREA

To determine the use of the coastline as migratory routes, we sampled from a total of 10 sites along the Lake Michigan and Lake Huron shoreline (Fig. 1) including five coastal and five inland (located approximately 4.8 km (3 mi) inland). The sites were located near Cheboygon, Glen Arbor, Manistee, Ludington, and Sebewaing. An effort was made to select specific locations that were similar in habitat type.
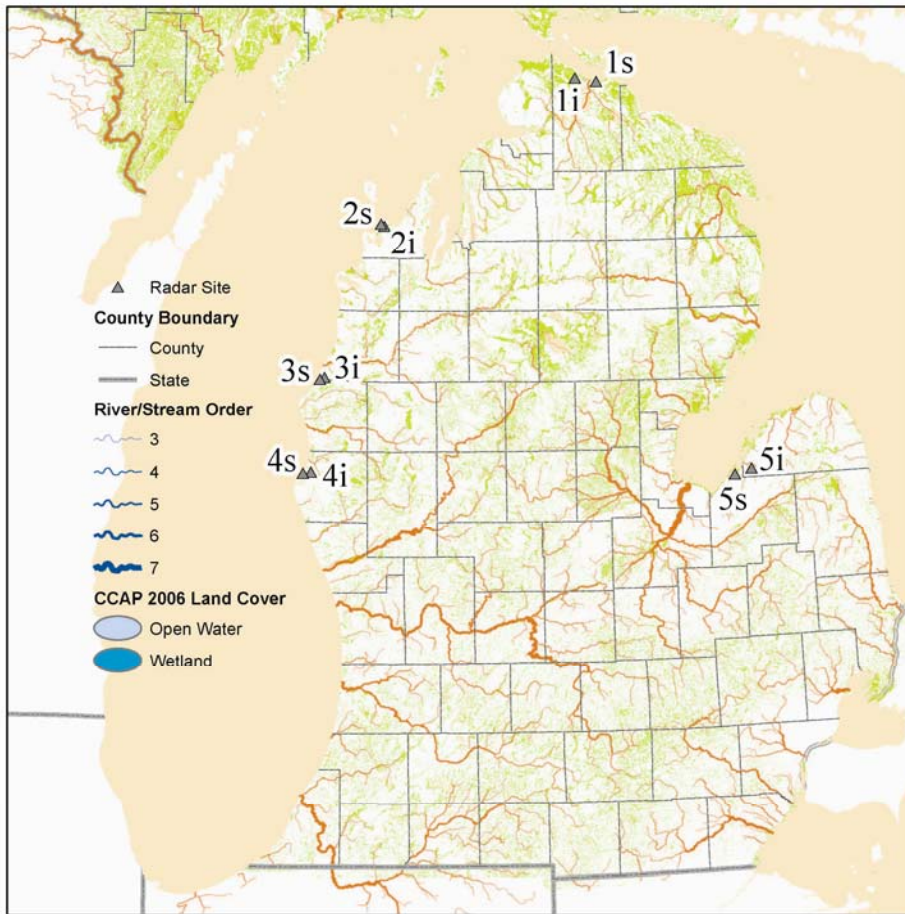
Fig. 1. Location of study sites along the Lake Michigan and Lake Huron coastlines.

Each site was sampled for 4 nights during the migratory period (between July 30 and September 30). Radar was used to monitor airborne movement within a 2-km radius (a surveillance area four km in diameter) and up to 870 m in altitude (via Echo Track, Appendix A). Acoustics waveform analysis was employed to recognize and locate species. Acoustic sampling was

conducted for two distinct frequency ranges. Audible frequencies (sounds audible to the human ear; between 2-10 kHz) were used to monitor bird calls and ultra-frequencies (20-140 kHz) are used to monitor bat calls. The nightly sampling pattern involved collection of four samples in the first hour of sampling (dusk), two per hour through the night, and then a similar series of four final samples in the last hour of sampling (dawn) for four days per site. All samples were fourteen minutes in duration. The equipment was rotated among sites daily. Specialized analysis programs were used to identify recorded flight-paths in three dimensions (both location and altitude) and to associate the recognized species with them. All acoustic sampling included species identification. For one night at each sampling plot, the digital record of all flight paths in the radar swept area and all bird and bat calls in the detection zones of their respective microphones during the sampling periods was preserved for future analysis or inquiry.

The variables to be measured were selected to compare the coastal and inland plots over different spatiotemporal scales and include total numbers of flights, height, speed, flight direction, and response to environmental attributes. Acoustic and ultra-frequency sampling were conducted at all plots on all sampling nights. Flight path analysis was conducted on all radar data collected at all sites. Each 14-minute ultrafrequency sample recorded was searched for the presence of bat and bird signals. Activity was measured and expressed as the number of seconds of calling relative to the total number of seconds sampled. Each section that was determined to have bat calls was then re-analyzed for the particular waveforms of selected species. All waveforms were identified using spectrogram analysis for minimum frequency, duration and shape. Echo Track was contracted to loan equipment and instrumentation, train MNFI employees how to use the instrumentation, and analyze the data and write the included report (Appendix A).

RESULTS AND DISCUSSION

Our objectives included a determination of: the effect of the distance from lakeshore on bat and bird flight activity, the proportion of migrants flying through that are at risk to collisions with wind turbine blades (Rotor Swept Area, RSA), and the species complex. We found that the densities of bats and birds flying through the area were higher at the inland sites when compared to the shoreline sites. This trend was consistent during all nights and all times of the night, and was most evident at the northern sites than at the southern research sites (Appendix A).

Few bats (15-18%) were detected to be flying in the RSA of the typical turbines (Appendix A). Echo Track determined that the highest proportion of bats flying in the RSA were at the shore plots in the north. The southern sites were predicted to have the fewest turbine fatalities as fewer bats flew within the RSA.

The most common species detected was the Big brown / Silver-haired bat complex (calls too similar to differentiate). The long distance migrant bats were most common at the southern sites (i.e., Silver-haired, Hoary, and Red bats, which are common wind turbine fatalities). Although we attempted to standardize the habitat types at all of the sites, higher bat species diversity was detected at the sites with more forest cover. Wetlands were also related to higher species diversity and agricultural land was related to low species diversity.

The timing of migration is important to understand when interpreting data and when planning potential turbine mitigation efforts. We determined the fall 2010 migration timing for both birds and bats (Appendix A). Echo Track determined the peak of bat migration to occur in the first hour post-dusk. Birds were slightly later with the second hour after dusk as the peak at inland sites and the fourth hour after dusk at the shoreline sites (Appendix A).

These data suggest that while Lake Michigan and Lake Huron shorelines are important habitats for many species they may not be migration travel corridors for birds and bats. However, the flight heights of bats near the shorelines are closer to the RSA of contemporary turbines than at inland sites, thereby making shoreline sites more risky for bat collisions with turbines. Forested sites tend to support a higher diversity and density of migratory bats than do agricultural areas. This supports the efforts to develop wind farms in agricultural areas of the state instead of forested areas. By examining the migration timing detailed by Echo Track in Appendix A, wind farm developers can estimate when migration is at its peak levels (nightly and seasonally) and temporally focus their mitigation efforts, such as increasing turbine cut-in speeds (Arnett et al. 2009).

By obtaining information on the use of the Lake Michigan and Lake Huron shorelines by migrating birds and bats, we have begun to inform the siting of wind turbines by providing spatial and temporal migratory data that will allow wind developers to minimize impacts to bat species (thus protecting biodiversity and a federally endangered species) and provide clean energy.

ACKNOWLEDGEMENTS

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Bat Migration Along the Lake Michigan and Lake Huron Coasts

A pilot study to inform wind turbine siting

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1   INTRODUCTION

1.1   **Background**

Little is known about the migration of bats and specifically, if they use the shore of Lake Michigan and Lake Huron. Whether they use the lake shore has implications for the siting of wind turbines. Wind development is predicted to grow along these lakes (AWEA, CanWEA).

Bats are particularly vulnerable to wind development. Given the severe population declines in Eastern North America due to white-nose syndrome, the cumulative impact of wind development is believed to be unsustainable. There are nine species of bats in Michigan, one which is federally endangered and one listed as special concern in the state.

Second to bats, night migrant birds also collide with wind turbines. Occasionally they too fly at night and fly within turbine blade height in low visibility conditions. Given the similar ecology of bats and night migrant birds, we hypothesized that bats would use the same migration routes. This project was designed to compare bat and night migrant bird abundance and flight behaviour at shore and inland sites. We expected concentrations to occur at preferred habitat/topography. We expected preferred habitat did NOT include water; AND we expected this was a linear relationship where increased distance from shore is correlated with increased abundance for all species.

1.2   **Terms**

The following terms are defined for clarity. In sampling, a **site** is a geographic location, a **plot** is a sampling area within the site, and a plot is either **evaluation** (proposed to have wind turbines) or **control** (no turbines proposed). Evaluation and control plots are 2 km-radius circles sampled by EchoTrack. A **replicate** is a repeated sample of a plot. A **sample** is an approximately 11-hour time period, depending on the length of night, from sunset to sunrise and includes both radar and acoustic recordings.

A summary of the observations from these samples have been tabulated and delivered in this final report. These tabulations have included the number of bats and birds per time period (i.e, hour, date, and season) and plot, the species at risk if observed, and the flight behaviour, defined as flight speed, direction, height, speed, and type (bird, bat or unknown). Those data have been **interpreted** using statistical analysis and the author's experience to assess the potential significance of the **collision risk** relative to the total population moving through the site. The collision risk is estimated as the relative flight activity within the proposed sweep area of the blades.

2   APPROACH

2.1   **Objective**

The objective of this study is to determine if bats follow linear migration routes adjacent to the Michigan coastline; a priority area for wind development. A second objective is to see if the migration route for bats is true for night migrant birds.

By learning the migratory habits of bats and birds, specifically whether they are using the coastline, inland pathways, or offshore routes, wind energy developers can significantly reduce negative impacts to bats by siting wind turbines in non-migratory areas.

This is part of a larger study with Ontario Ministry of Natural Resources, where the migration is west-east in Lakes Huron, Ontario and Erie. The results of both studies will provide valuable information on bat migration in the Great Lakes region.

Special consideration is given to four specific aspects of airborne wildlife behaviour:

1. The timing of maximum abundance (seasonal and within-night hours)
2. The response in flight behaviour to topography-habitat features within the project area
3. The influence of the lake shore on bat and bird night migrant populations
4. Weather influences on flight behaviour.

The data are collected rigorously and with a repeatable design such that patterns observed in this study could serve as a basis of comparison of predicted risk of wind turbine development to observed mortality and change in flight behaviour post-installation. .

2.2 **Methods**

2.2.1 **Site selection**

To monitor bat migration along the Lake Michigan coast, five sites were selected at increasing distance to the south; Sleeping Bear Dunes National Lakeshore to Ludington on Lake Michigan and Cheboygan to Bay City on Lake Huron (Fig. 1). Each of the five sites had two plots; a coast and an inland radar-acoustic plot. The sites were selected to be representative of the regional topography and habitat. The paired plots were expected to have the same bat (and night migrant bird) population if there was no effect of the shore and therefore the paired plots should be more similar to each other than they are to other sites.
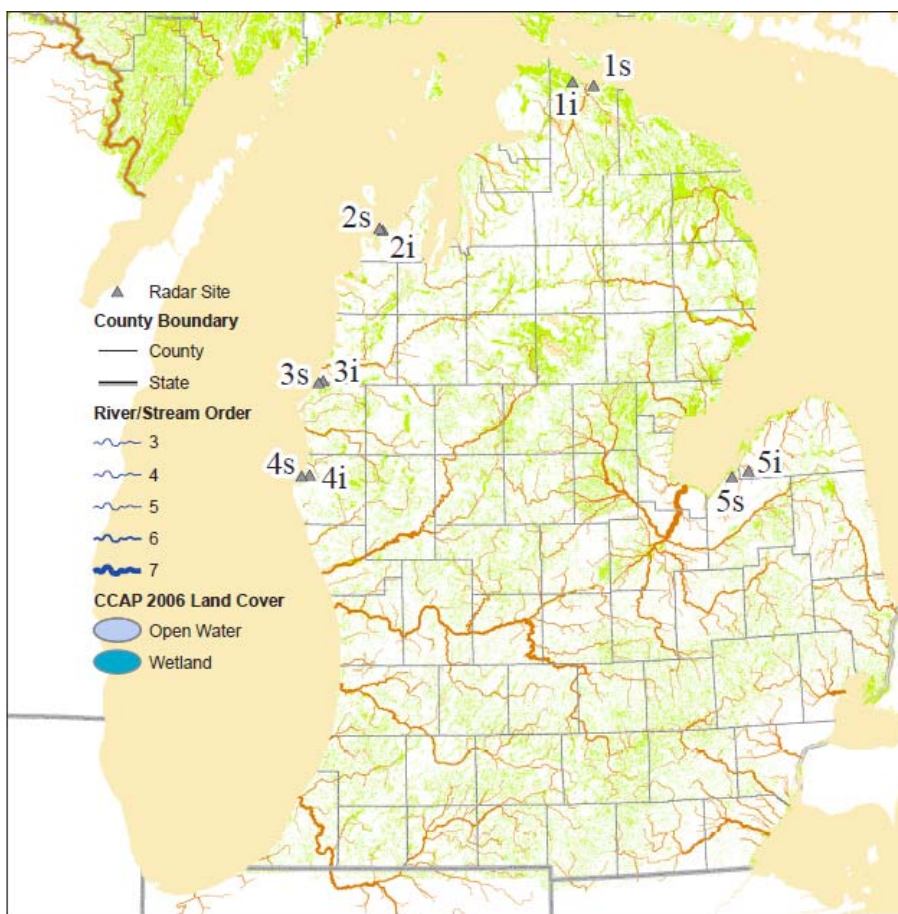
Fig. 1. Distribution of the radar-acoustic sampling plots. Ten plots were located at increasing distance south along the Lake Michigan and Lake Huron coasts, with plots paired to have a shore and inland plot at the five sites (e.g. 1I, 1S). Orientation of the shore at the radar plot was N-S for 3S, 4S and 5S but W-E for 1S and 2S.

We expected sites further north to have an earlier migration such that species would arrive in the data earlier further north and peaks in abundance would occur in a wave over the season; a slight delay or offset in date with distance south. Therefore we expect within site plots to have first dates of arrival (in the data) more similar than first dates between sites.

Plots were selected to be similar in habitat so differences in the spatial distribution of migration could be attributed to distance from shore. For each site, a shore and inland plot was selected; e.g. 2S and 2I respectively. The plot pairs selected had similar habitat composition (e.g. cultivated crops at 5S and 5I, forest at 3S and 3I; wetland at 1S and 1I; Fig. 2). For all plots, inland or shore, the predominant habitat was forest and cultivated crops, then wetlands. 'Shore' was obviously only present at shore plots. Cultivated crops were most prevalent at southern plots (4I, 4S, 5I and 5S). Wetland was a larger component of the northern plots (1I, 1S).
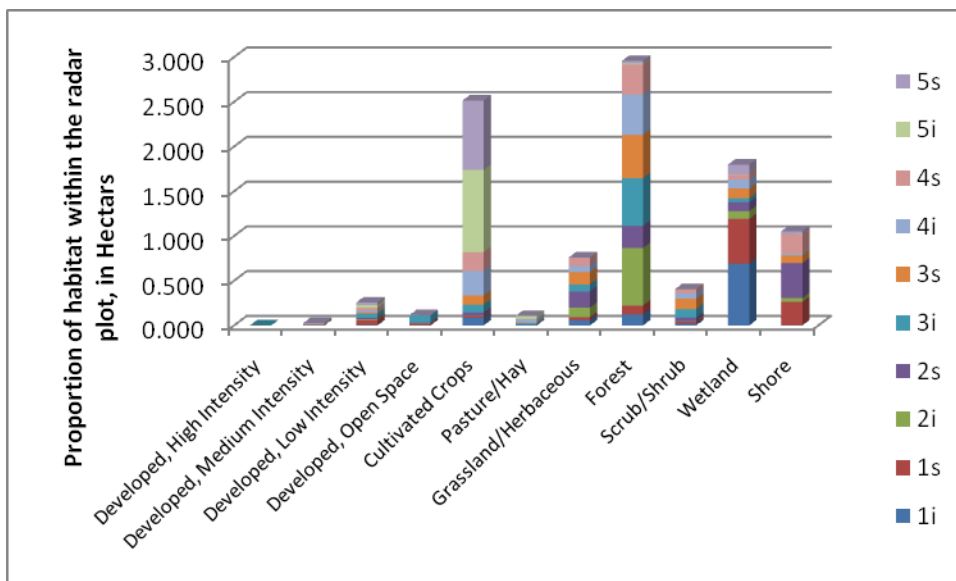
Fig 2. Relative habitat composition of inland versus shore plots. Sites are paired inland (I) and shore (S); for example, Site 5 has Plots 5S (shore) and 5I (inland).

If migrant bats and/or birds use a plot for stopover, the habitat at that plot was expected to affect the species recorded. Based on the habitat composition, we would expect:

- forest bats like the Eastern red bat (*Lasiurus borealis*), to be most active at plot 2I, then 3I, 3S and 4I. Other forest species include the Northern long-eared bat, *Myotis septentrionalis*, which gleans from foliage in open canopy forest and the Silver-haired bat, *Lasionycteris noctivagans*, which is not separable by spectrogram from the non-forest Big brown bat, *Eptesicus fuscus*.

- wetlands at plots 1S and 1I, to attract the largest diversity and potentially highest activity early and late in the night when bats need to drink to initiate their flight and before sleeping for the day. Species that feed near streams and open water include the Silver-haired bat, Hoary bat, *Lasiurus cinereus*, and Eastern pipistrelle, *Perimyotis subflavus*.

- scrub habitat at plots 3S and 3I to attract open foragers like the Big brown bat and Hoary bat.

- disturbance or cultivated habitat at 5S and 5I to be least attractive to migrants, but attract the wide-ranging species like the Little brown bat, *Myotis lucifugus*

Three of the plots lie on protected areas; 1S is in the Cheboygan State Park, and 2S and 2I are part of Sleeping Bear Dunes National Lakeshore. Site 5S is on State land but is not a State park.

2.2.2 **Replication**

Each site was sampled four times over the expected range of dates for fall migration of bats; 30 July to 30 September 2010 (Appendix I, Table 1). Site 4I was sampled five times to include the later part of the fall migration. Combing all 10 plots, there were 41 nights of radar-acoustic monitoring along the Lake Michigan and Lake Huron coasts.

We expected seasonal variation in species composition. To control for this, sampling was rotated nightly (with one exception) using a stratified design. Shore and inland plots were sampled close in time to minimize the confounding effect of season on diversity and abundance of migrants; potentially masking the effect of distance from shore. However, the sampling order for sites

(north to south pairs of plots) was varied as much as the travel time between plots would allow, so one site was not consistently monitored before another (Appendix I, Table 1).

We expected nightly variation in flight activity. Within a night, flight activity and behaviour were monitored over a standardized air volume for a standard 14 minutes. Activity was expected to vary most in the first and last hour of the night so sampling included each quarter hour for the first and last hour of the night, and then the first half hour every hour for the rest of the night. Most nights were 11 hours long, allowing for 26 14-minute samples per night.

2.2.3 **Sampling Protocol**

For every 14-minute sample, all radar-determined flight paths were recorded with time, location, height, speed, direction and then categorized as bird, bat or other. The same criteria were used at all plots and for all nights. Radar is used to monitor airborne movement within a 2 km radius (a surveillance area four kilometres in diameter) and up to 870 m in altitude.

Simultaneous to the radar sampling, acoustic sampling was conducted for two distinct frequency ranges (sounds audible to the human ear; between 2-10 kHz; and ultra-frequency sounds (20-140 kHz) emitted by bats but not audible by humans) are used to monitor. Acoustic sampling was alternated between bats and birds such that the first and last 14-minute sample of the night was birds. Each 14-minute sample in between was alternated between birds and bats; 13 of the 26 14-minute samples in a night were bat acoustic recordings.

Specialized analysis programs were used to identify recorded flight-paths in three dimensions (both location and altitude) and to associate the recognized species with them.

The acoustic array was set 75 m into a field, perpendicular from the trailer-mounted radar and the bird and bat microphones set on tripods in an array of four microphones each (Fig. 3).

Fig. 3. Within plot sampling protocol. The radar is trailer mounted and the bird and bat microphones are set on tripods in an array that is 75 m in a field perpendicular to the trailer.

All acoustic sampling includes species identification. EchoTrack microphones are custom designed to be omni-directional to associate echolocation calls with an individual and to record over a volume of air that extends into the blade sweep area of a modern wind turbine; a blade extent of 40 to 120 m above ground.

The environmental attributes included in the sampling design are those expected to concentrate bats and birds within the sweep volume of the proposed turbines and thereby, increase the risk of

a collision and/or disturbance: timing of migration (the interaction of distance south and day of season), topographic feature (shore versus inland) and within site habitat (water, trees).

To further determine the effect of shore on activity of migrants, a line was drawn along the shore within the radar scan volume of each shore plot, and the total number of migrants crossing the line compared within the plot to the number of flights at increasing distance over land or water from that line (Fig. 4; example plot 1S). The activity along the shore line is also compared to activity along an equivalent line (length and orientation) at the paired interior plot. If migrants concentrate along the shore, we expect a significant difference in activity along the shore than activity at increasing distances from the shore (either over water or inland) and a significant difference in activity along an equivalent line at the paired inland plot.

Fig. 4. Example configuration for Site 1S. The radar detects individual flights, with height, to a radius of 2 km (yellow circle). Bat and bird microphones are set in an array (orange circles) to monitor species-specific activity within a subset of the radar volume of detection (100 m from each bat microphone and 600 m from each bird microphone). A line is drawn along the shore within the radar volume of detection for analysis of activity and behaviour along the shore versus an equal length line, drawn at the same orientation, within the paired inland plot.

2.2.4 Analysis

2.2.4.1 Flight activity

For every 14-minute sample, the number of flight paths are counted and expressed as a number per minute per sampling volume (6.7 km^3). The data are presented for bats and night migrant birds. Migrants that are not clearly a bat or a bird were classified as 'other' migrants but were not included in the analysis because they are 1% or less of the total number of flights.

The temporal pattern of activity is then compared in two ways:

- Over the season, and
- Over the night, based on the time from sunset.

Flight activity data are also compared relative to the shore and habitat composition of each plot.

2.2.4.2 Acoustic activity

Each 14-minute acoustic sample recorded was searched for the presence of bat signals. Found signals were identified to species and the number of calls expressed as the number per total number of seconds sampled. All waveforms were identified using spectrogram analysis for minimum frequency, duration and shape. The species investigated included all eight species expected to be present in the area; the Big brown bat, Little brown bat, Northern long-eared bat, Eastern small-footed bat, Silver-haired bat, Hoary bat, Eastern Red bat, and Eastern pipistrelle.

2.2.4.3 Hypothesis testing

Consistent with the study objectives, statistical tests were performed to investigate:

- Importance of shore versus inland: Paired T-test (5 sites; shore versus inland) to compare average activity over the season and species diversity

- The presence of a detectable wave of bat migration north to south: using ANOVA for site (i.e., distance south) with total activity and species diversity (bats, Shannon index)

- The importance of shore orientation, as we found along Lake Ontario and Lake Erie: using Paired T-test of abundance at a predominantly north-south shore (3S, 4S) versus east-west shore (1S, 2S, 5S)

- Seasonal change in species composition and activity: ANOVA for abundance by season

- Time of night effect on species composition and activity, looking for an offset in time past sunset, by species and regression of activity by time after sunset.

2.2.4.4 Relevance to wind development

With respect to the potential risk of wind development along Lake Michigan, statistical tests were performed to investigate:

- What proportion of the bats migrating through, fly at blade height and whether the proportion is higher at shore than inland sites as well as sites with wetlands versus those cultivated: using paired T-test for the proportion at blade height for shore versus inland sites, and paired t-test for proportion at blade height at wetland (1I, 1S) versus cultivated (4I, 4S, 5I and 5S) plots.

- Are there features requiring setback, namely shore and if so, what distance? Is there a concentration along shore within the shore plot? If so, what is the relationship between activity and distance from shore (regression of 8 distances from 0 to 2000 m) and over water versus over land

- Is the orientation of the shoreline important for abundance and distance over water: using Chi-square test N-S sites versus W-E sites for ratio of flights over water

- Are the results consistent for bats and birds and if so, are there generalities that can be used as guidelines for wind development

- Are there confounding factors that increase or decrease potential risk such as weather influences on flight behaviour: using ANOVA for the effect on flight height or proportion of flights at blade height and ANOVA for the effect on flight height or proportion of flights at blade height

- Bird species at risk: Incidental visual observations were conducted for bird species at risk.

3 RESULTS

3.1 Do bats follow the Michigan coastline

If bats follow the Michigan coastline in migration, we expect a higher abundance at shore plots than plots paired in latitude, but situated inland. Contrary to expected, flight activity was higher on average (all nights and times of night) for both bats and birds, at inland plots. This was particularly true where shore plots were located on a north-south orientation rather than a west-east orientation (Appendix V, Table 2).

Looking at the distribution of bats and birds within the 2000 m radius monitoring volume of four shore plots, activity was greatest along the shore and over the water at sites to the south (Sites 3 and 4) but activity is concentrated more inland at the sites to the north (Sites 1 and 2) (Fig. 5).
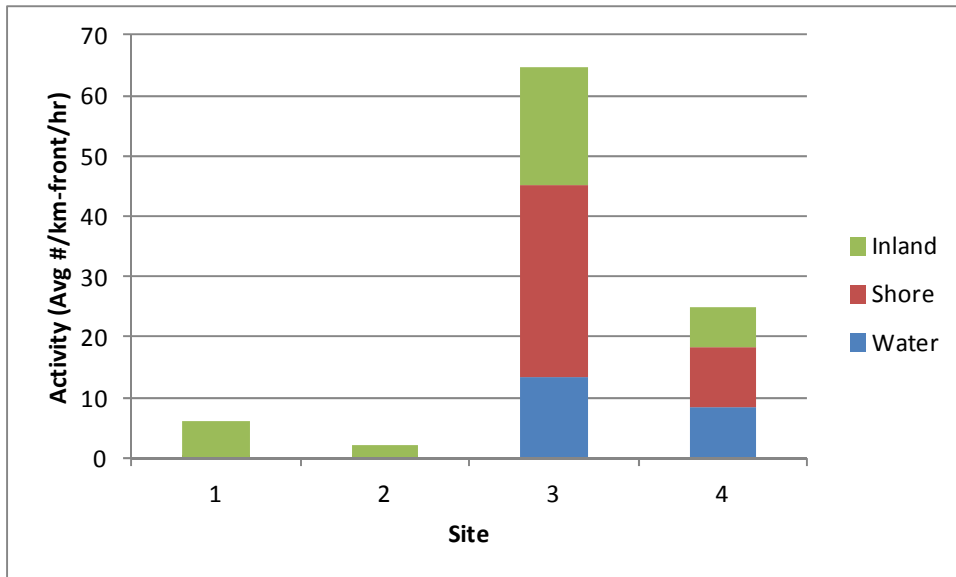
Fig. 5. Selection of habitat at shore plots by migrants (bats and night migrant birds combined). The activity is expressed as the number of flight paths crossing a kilometre-long vertical plane over water, shore and inland habitat within the radar plot.

If migration was linear along the Lake Michigan and Lake Huron shores, we expect a pattern in arrival where paired coast and inland sites (e.g. 1I and 1S) are closer in the date of higher abundance and date of first arrival of a species, than between sites (e.g. 1I and 2I). Sites further north should have an earlier migration such that species would arrive in the data earlier further north and peaks in abundance would occur in a wave over the season; a slight delay or offset in date with distance south. Therefore, we expect within site plots to have first dates of arrival (in the data) more similar that first dates between sites.

There was an effect of period on bat abundance where abundance declined over the migration study (Appendix V, Table 3; ANOVA, bat abundance on period, F-test $(3,33)$ $p < 0.05$).

It was expected as bats left their summer habitats for overwintering sites, their abundance would peak earlier, at north sites than south sites. To test for this, migration "traffic" was compared at plots north to south (site 1 to site 5), early to late in the season (period 1 to 4). Abundance was weighted by the maximum for each plot and then mapped over the season (Fig. 6). A greater proportion of the fall migration was occurred earlier (period 1) for site 2 and 3 (Fig. 6). However,

a greater portion of Site 1 migration occurred in the last period than in Site 5 further south, which isn't consistent with the offset in time predicted for a linear migration pattern.
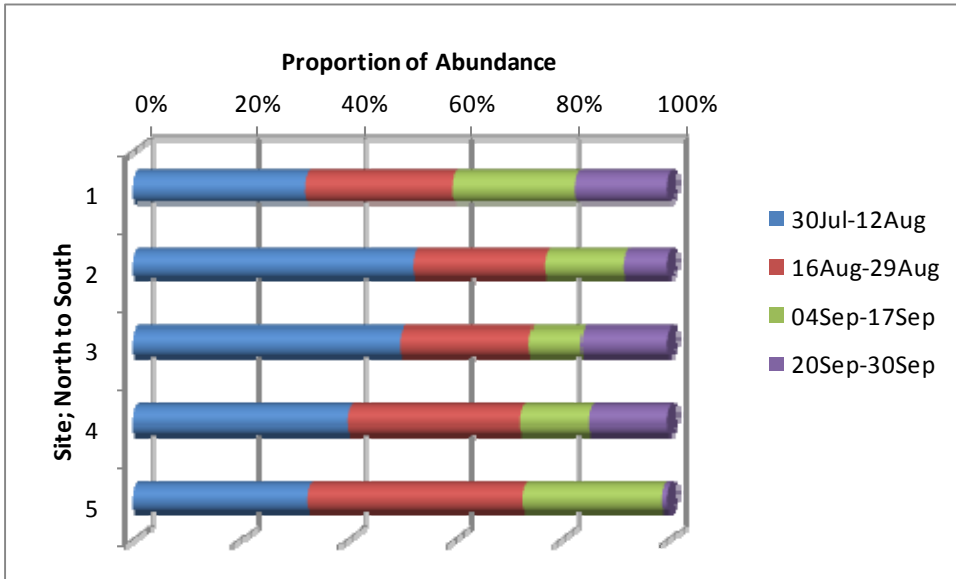
Fig. 6. Pattern of bat migration south along Lake Michigan and Lake Huron in fall 2010. The y axis shows sites at increasing distance south from 1 to 5. The x axis shows the relative proportion of total abundance at each site, increasing in date in 4 periods from 30 July to 30 September.

3.2 Is the migration route for bats true for night migrant birds

The timing of peak abundance is statistically correlated (p < 0.005) for birds and bats (Appendix V, Table 3b).

3.3 Airborne wildlife behaviour

Several aspects of migration behaviour were noted; timing of maximum abundance (seasonal and over the night) and response to topography and habitat features.

3.3.1 Seasonal changes in abundance

Bat abundance, over the fall migration season, measured as the number of flights per radar scan volume (6.7 km^3) per hour of monitoring, decreased from 30 July to 30 September, and the trend was significant for shore sites (Fig. 7; F(shore)$_{3,1}$ = 43.8, p = 0.02; Appendix V). The trend was averaged over four time periods for all plots, then shore and inland plots. The corresponding trend for birds was not significant (regression, p > 0.05; Appendix V).
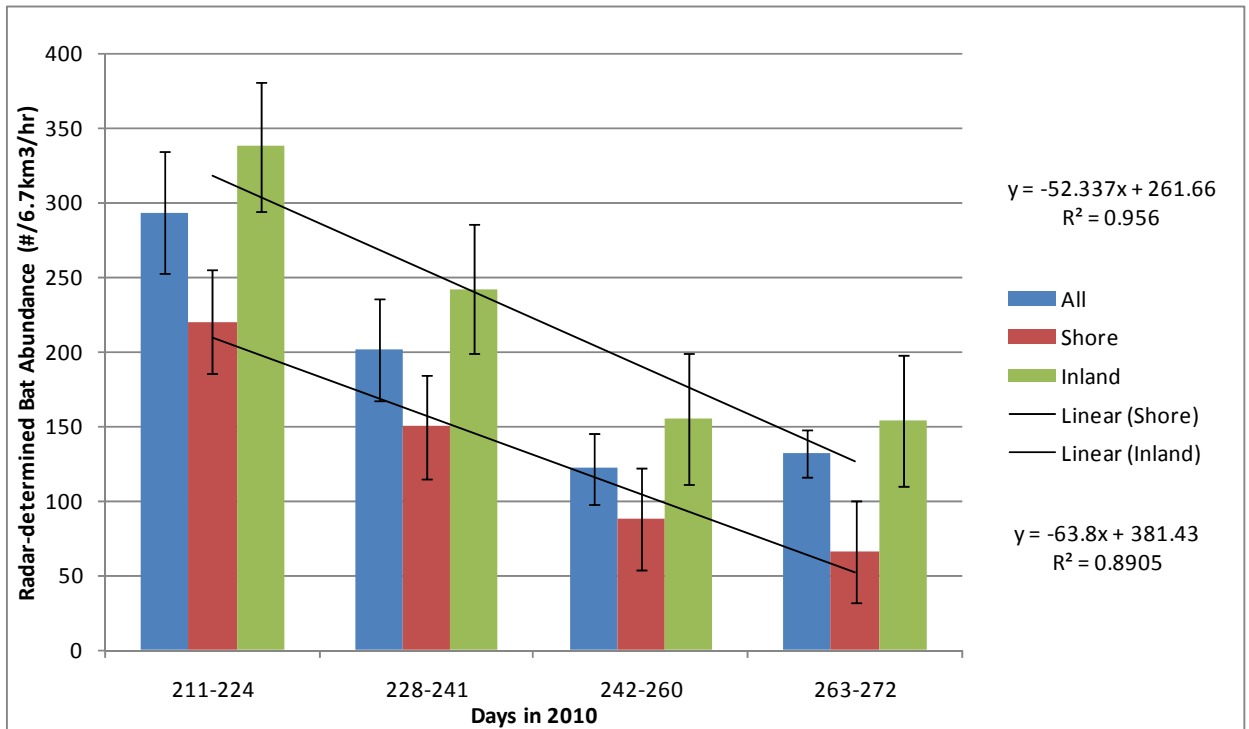
Fig. 7. Pattern of bat migration in fall 2010 (30 July to 30 September) at shore and inland plots. Bat abundance, determined by radar, decreased over the season.

3.3.2 **Change in abundance by time of night**

At both shore and inland sites, radar-determined bat abundance peaked in the first hour after sunset with a smaller peak, slightly offset in time between shore and inland plots, in the last hour of night (Fig. 8). Bird abundance peaked later; the second hour for inland sites and fourth hour for shore sites (Fig. 9).
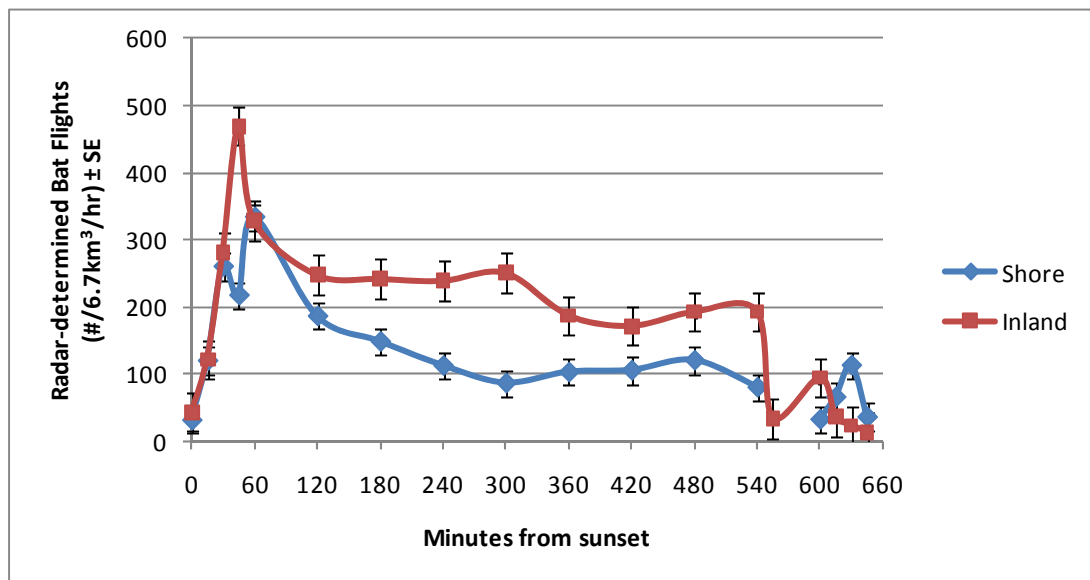
Fig. 8 . Radar-determined bat abundance over the night for all nights combined at shore and inland sites. Radar data are expressed per radar scan volume (6.7 km3) per hour ± SE.
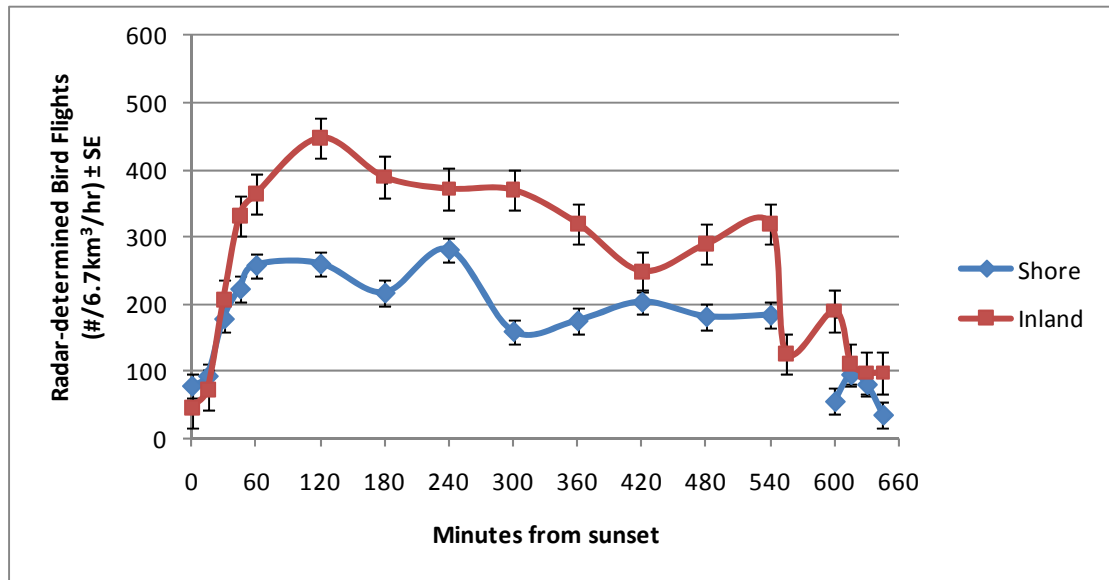
Fig. 9. Radar-determined bird abundance over the night for all nights combined at shore and inland sites. Radar data are expressed per radar scan volume (6.7 km3) per hour ± SE.

3.3.3 **Spatial distribution of migration**

Bat and bird abundance was statistically greater at inland plots than shore plots (T-test, p = 0.005; Appendix V, Table 2); the mean difference (inland minus shore) is 91 for bats and 158 for birds. The only exception where activity was higher along the shore (i.e., a negative difference) occurred within 30 minutes of sunset for birds and the last hour of the night for bats (Fig. 10).
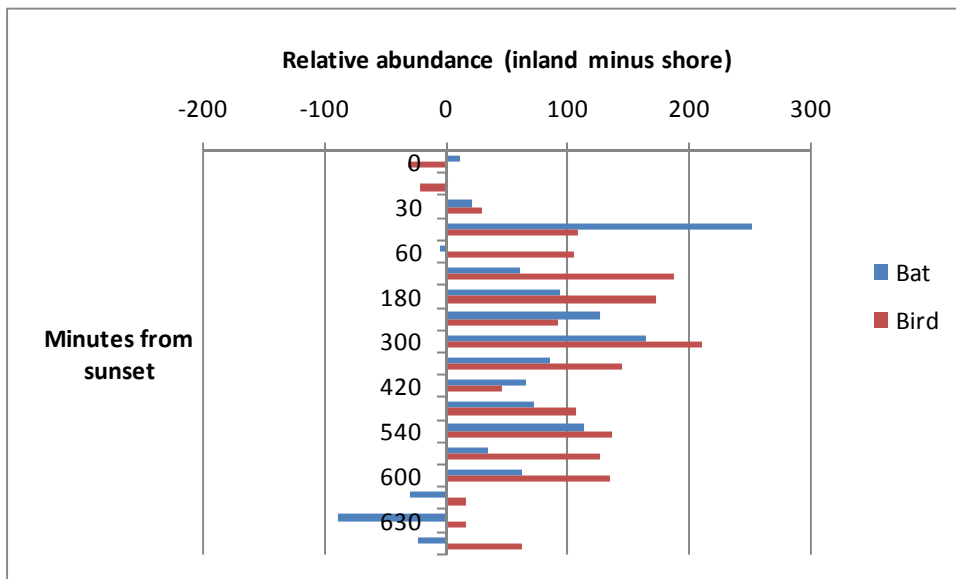
Fig. 10 . Relative bat and bird abundance inland versus along the shore, by time of night (minutes from sunset) for all plots combined. Positive numbers indicate a greater abundance inland.

To determine potential spatial factors in the observed abundance of bats and birds, the habitat composition of inland versus shore plots was compared by site. For the majority of sites (at least four of five), inland plots had more forest and less shore habitat (i.e., a positive y in Fig. 11). Disturbance-related habitats were a larger component of inland sites (cultivated crops and pasture

at inland plots versus grassland and scrub at shore plots). Wetlands - important stopover habitat for birds and bats - were present at both inland and shore plots, from north to south; site 1 to 5.
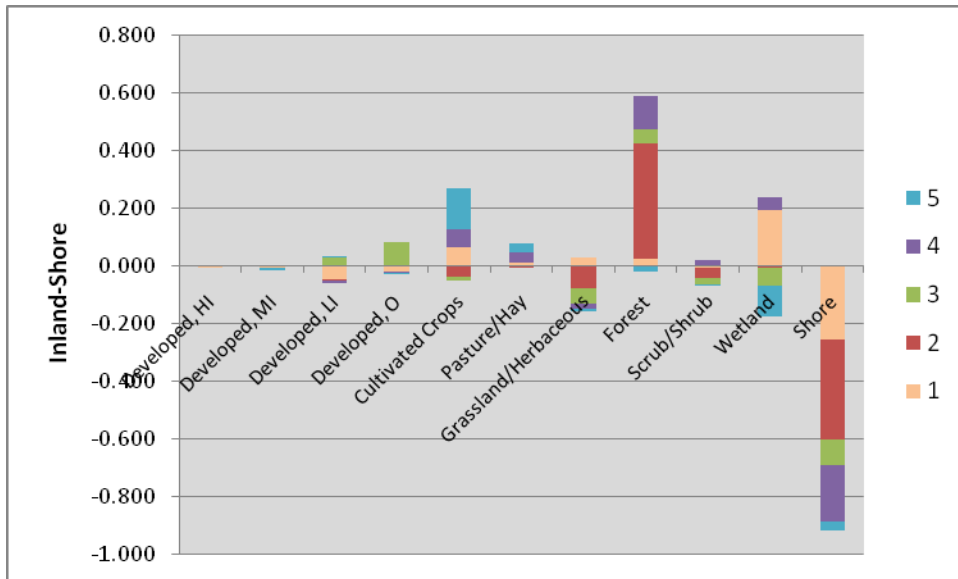
Fig. 11. Relative habitat composition of inland versus shore plots for all five sites (1,2,3,4, and 5). A positive number indicates a larger representation of a particular habitat type at inland sites.

3.3.4 **Species complex and diversity**

Consistent with the radar-determined activity, bat acoustic activity was greater at inland plots than the paired shore plots (Fig.12). The data were averaged over all nights and times of night for each plot and species. Sixty-six percent of the acoustic sampling periods had no bat calls (221/367 samples). Total abundance was expressed as the number of bat passes per species; averaged per minute of sampling.

The most common species is the Big brown / Silver-haired bat complex. Long distance migrant bats (Silver-haired, hoary and red bat) were most common in the southern sites (Appendix III, Table 1).

Diversity was greatest at the inland plot of Site 3 (Appendix III, Table 1). In order of diversity, the sites were 3I, 2I > 4S, 1S, 3S, 2S, > 1I > 4I >> 5S and 5I. Bat diversity cannot be explained by habitat diversity within the plot (Appendix III, Table 3; R-square = 0.27, p > 0.05). Though, the plots highest in forest cover (2I and 3I) were highest in bat diversity and the plots lowest in forest cover (5I, 5S) were lowest in bat diversity.
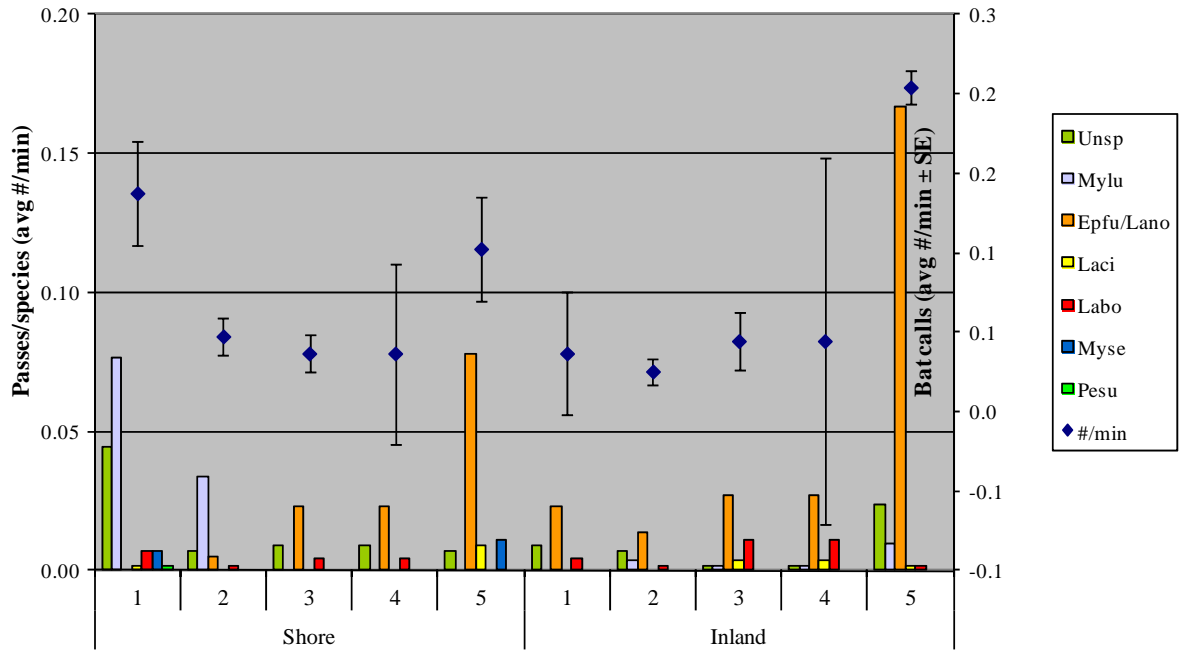
Fig. 12. Total bat acoustic activity and activity by species at shore and inland plots. Data are expressed per minute of recording and then averaged over all nights and times of night.

3.3.5 **Predicted collision risk**

The proportion of bats flying at a typical wind turbine blade height of 40 to 120 m above ground is highest at shore plots in the north. The predicted risk of collision by bats is lowest for both shore and inland plots at the southern most site (Site 5). The collision risk is significantly affected by site; more at shore sites than inland sites (ANOVA, $p < 0.0001$ versus $p < 0.05$ respectively).

The predicted collision risk, declines over the fall migration (period 1 to period 4) but not significantly.

4 DISCUSSION

4.1 Do bats follow the Michigan coastline

By learning the migratory habits of bats and birds, specifically whether they are using the coastline, inland pathways, or offshore routes, wind energy developers can significantly reduce negative impacts to these migratory wildlife by siting wind turbines in non-migratory areas.

Based on these results, bats do not migrate along the shores of Lake Michigan or Lake Huron. Rather, bat flight activity is greater at inland sites, particularly for sites where the predominant orientation of the closest shore of Lake Michigan is north-south in orientation versus west-east orientation. This is also true for night migrating birds.

The higher abundance at north-south orientation sites agrees with results found in 2009 with bat and bird migration along Lake Ontario and Lake Erie (Millikin, 2010). However, the tendency to move inland at a north-south orientated shore is not consistent with the 2009 results. On Lake Ontario and Lake Erie where night migrants ventured further over the water at north-south shorelines than west-east shorelines, these shorelines were peninsulas extending into the lake, in the direction of migration.

In the case of Lake Michigan, the north-south shorelines where increased migratory activity was observed, are part of a continued shore that extends slightly west, against the SE direction of fall migration. Flying inland would provide a more direct migration route.

Lake Michigan and Lake Huron (Sites 1 and 5) have their long axis oriented north south versus the other Great Lakes (Erie, Ontario and Superior) which have their long axis oriented east west. During migration, the Great Lakes are a potential obstacle to tree bats, especially lakes that are oriented east-west, with wide expanses of water that bats must either fly across or around. There is considerable anecdotal evidence (Peterson, 1966; Saunders, 1930) and numerous unpublished observations by bird banders that tree bats migrate as do birds, over narrow points in Lake Erie (e.g., Point Pelee and Long Point) and Lake Superior (e.g., Whitefish Point).

Although the Great Lakes that are oriented east-west may be barriers to migration, the lakes that are oriented north-south may be beneficial, if bats use the coastlines as navigational guides. Kurta et al. (2007) documented the immigration of the eastern pipistrelle into Lower Michigan within the last 30 years and noted that all current records of these bats are associated with the coastline, from Berrien County in the south to Manistee County in the north.

The migration appears to be consistent in timing across sites with little indication of a southward wave expected for linear migration along Lake Michigan. Bat migration through Michigan seems more related to site-specific habitat than it is to landscape features (like the shoreline). Sites further north have more forest cover than cultivated crops which predominate in the south sites.

Based on a priori habitat descriptions, stopover habitat for forest bats is best at plots 2I, 3I, 3S and 4I. More forest-related bats, including the Eastern red bat, Silver-haired and Northern long-eared bat, were recorded at these plots with forest cover and fewer were recorded at the cultivated plots 5I and 5S.

The wetlands at plots 1S and 1I did attract the most species (not the highest diversity index) including the only record of the Eastern pipistrelle. The scrub habitat at plots 3S and 3I did indeed attract open foragers like the Big brown bat and Hoary bat. And as predicted, the cultivated habitat at 5S and 5I was least attractive to migrants.

Of the nine species of bat that live in Michigan; five are commonly killed at wind turbines. The nine Michigan species are the Eastern red bat, Hoary bat, Silver-haired bat, Eastern pipistrelle, Big brown bat, Little brown bat, Indiana bat (*M. sodalis*), Northern long-eared bat, and Evening bat (*Nycticeius humeralis*). The Indiana bat is the only resident mammal of Michigan that is on the federal list of endangered species (U.S. Fish and Wildlife Service, 2007). However, the Evening bat is currently classified as threatened in Michigan, and the Eastern pipistrelle is listed as a species of "special concern" by the Michigan Department of Natural Bat and Avian Migration Along the Lake Michigan Coastline (2008a, 2008b). All but the Indiana bat and Evening bat were recorded in this study. Some calls identified as *M. lucifugus* could be *M. sodalis*. The range of the Indiana bat is apparently restricted to southern Michigan but may extend into the study area.

Three of the plots lie on protected areas; 1S is in the Cheboygan State Park, and 2S and 2I are part of Sleeping Bear Dunes National Lakeshore. Site 5S is on State land but is not a State park. Protected area status was not a determinant for abundance or diversity of bats. The species most prevalent at plots within protected was the Little brown bat, which is a wide-ranging species not particularly reliant on habitat protection. Though, with White-nosed syndrome, there is a heightened concern for all Myotis populations.

4.2   **Implications for wind development**

To study the potential impact of wind development, the risk of an impact is defined as a concentration of flights of bats within the height of typical modern turbines (40 to 120 m above ground. Only 15-18% of bats fly at heights of blades typical to current wind turbine design.

In previous studies of the flying height of bats in Michigan, bats were recorded more at 1.5 and 22 m than 44 m above ground (Arnett et al. 2006) and Hoary bats were most often (65%) found at 55m (not 2 or 35 m) and Red bats at either 35 or 55 m (C. Rockey, in review). This suggests that the Red bats and Hoary bat are at greater risk of collision or barotraumas given their proximity to the turbine blades.

5   CONCLUSIONS

Fall migration of bats is not along the coast of Lake Michigan like it is in Lake Ontario and Lake Erie. Bats move more inland than along the shore or over water, likely because the Lake Michigan shore, where the plots were situated, leads away from the main direction of fall migration.

A small proportion of bats (15-18%) fly at heights of blades typical to current wind turbine design. Therefore, the collision risk for bats is not predicted to be large.

Bat species diversity and abundance was most closely related to forest cover and inversely related to a cover of cultivated crops. To further minimize the impact of wind development on bats, a priority should be given to wind development on agricultural lands.

Bats and night migrant birds have many similarities in their night migration. However, their habitat preferences are different.

6 LITERATURE CITED

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7 APPENDICES

7.1 Appendix 1. Sampling design

Table 1. Sampling effort over the season. Ten plots were selected at increasing distances north to south (1 to 5), paired at by distance from (shore or inland), and sampled a minimum of four times over the extent of the fall migration of 2010. A total of 41 nights had radar-acoustic monitoring along the Lake Michigan coast, for a total of 469.49 sampling hours.

Relative Distance South	Shore / Inland	Replicates					Total Hours/plot
		1	2	3	4	5	
1	Shore	9-Sep	10-Sep	20-Sep	21-Sep		46.22
	Inland	3-Aug	16-Aug	6-Sep	22-Sep		44.05
2	Shore	7-Aug	18-Aug	5-Sep	30-Sep		46.07
	Inland	30-Jul	19-Aug	4-Sep	29-Sep		45.13
3	Shore	31-Jul	26-Aug	12-Sep	27-Sep		46.29
	Inland	9-Aug	27-Aug	11-Sep	28-Sep		45.56
4	Shore	1-Aug	28-Aug	13-Sep	26-Sep		45.03
	Inland	10-Aug	29-Aug	14-Sep	15-Sep	25-Sep	57.93
5	Shore	12-Aug	24-Aug	16-Sep	23-Sep		46.33
	Inland	11-Aug	25-Aug	17-Sep	24-Sep		46.88
Total	10 plots	41 nights					469.49 hours

Table 2. Distribution of habitat by plot. All ten plots were selected at increasing distances north to south (1 to 5), paired at by distance from (shore or inland), and sampled a minimum of four times over the extent of the fall migration of 2010. A total of 41 nights had radar-acoustic monitoring along the Lake Michigan coast, for a total of 469.49 sampling hours.

PLOT	1i	1s	2i	2s	3i	3s	4i	4s	5i	5s
Developed, High Intensity	0	6300	0	0	3600	0	0	0	0	0
Developed, Medium Intensity	1800	77400	3600	7200	23400	5400	900	13500	30600	153000
Developed, Low Intensity	91800	678600	130500	183600	560700	193500	264600	359100	385200	377100
Developed, Open Space	8100	245700	45000	78300	1029600	9900	4500	22500	900	2700
Cultivated Crops	1044000	247500	35100	484200	1101600	1298700	3438000	2655900	11570400	9743400
Pasture/Hay	119700	3600	0	10800	149400	127800	492300	31500	387900	15300
Grassland/Herbaceous	764100	397800	1326600	2282400	999000	1719900	889200	1098000	0	76500
Deciduous Forest	1069200	722700	5004900	2143800	3817800	3784500	4530600	3358800	103500	330300
Evergreen Forest	236700	297000	55800	514800	1181700	1459800	792000	536400	1800	18000
Mixed Forest	251100	214200	468900	423000	541800	837900	378000	323100	9900	19800
Scrub/Shrub	254700	133200	369000	318600	504900	688500	284400	737100	11700	61200
Palustrine Forested Wetland	5259600	4249800	275400	657000	256500	1075500	628200	369900	13500	101700
Palustrine Scrub/Shrub Wetland	2823300	1085400	201600	340200	108000	162900	265500	129600	17100	684000
Palustrine Emergent Wetland	608400	934200	284400	222300	116100	126900	362700	195300	3600	587700
Unconsolidated Shore	0	187200	5400	3600	0	0	0	0	0	100800
Bare Land	0	752400	900	255600	1800	306900	66600	487800	25200	50400
Open Water	32400	2328300	361800	4639500	0	776700	165600	2243700	900	248400
Palustrine Aquatic Bed	9000	0	8100	0	0	0	0	0	0	0
Total Plot area	12573900	12561300	8577000	12564900	10395900	12574800	12563100	12562200	12562200	12570300

Table 3. Simpson's diversity index for habitat by plot. In decreasing order of diversity; the plots of maximum habitat diversity are 4s, 2 s and 3s; where 4s is the shore plot at site 4.

Total (N)	98.98	93.27	88.91	99.40	85.24	104.48	101.85	95.23	96.52	95.40
	0.49	0.63	0.45	0.75	0.58	0.74	0.72	0.77	0.09	0.33

7.2 Appendix II. Radar-determined abundance

Table 1. Radar-determined abundance of bats by period and plot.

			Site and Plot										Overall average		
			1		2		3		4		5				
	Period	Year-day	1	2	1	2	1	2	1	2	1	2	All plots	Shore	Inland
Average	1	211-224		276		194	472	549	129	575	59	92	293	220	337
Average	2	228-241		281	59	125	283	277	36	514	221	13	201	150	242
Average	3	242-260	246	101	56	19	74	142	62	402	1	110	121	88	155
Average	4	263-272	132	102		43		411		209	0	4	132	66	154
	All periods		207	196	44	96	258	338	72	422	71	52	180		
SE	1	211-224		75		46	70	29	22	60	8	17	41	33	45
SE	2	228-241		31	13	25	64	32	8	51	87	4	34	43	28
SE	3	242-260	22	22	17	4	9	12	28	152	1	31	24	15	44
SE	4	263-272	16	12		7		162		28	0	1	16	8	42

Table 2. Radar-determined abundance of birds by period and plot

			Site and Plot										Overall average		
			1		2		3		4		5				
	Period	Year-day	1	2	1	2	1	2	1	2	1	2	All plots	Shore	Inland
Average	1	211-224		115		136	209	480	75	587		125	247	142	289
Average	2	228-241		150	74	115	181	788	178	617	156	137	266	147	362
Average	3	242-260	423	92	123	128	354	585	112	279	19	178	229	206	252
Average	4	263-272	132	786		63		241		351	1	19	132	67	292
	All periods		323	250	107	110	253	566	124	490	107	113	180		
SE	1	211-224		17		34	36	151	9	86	21	21	44	22	62
SE	2	228-241		29	10	23	23	77	34	65	54	14	37	30	42
SE	3	242-260	73	18	22	19	51	57	18	120	8	21	18	34	47
SE	4	263-272	11	107		16		89		43	1	2	5	6	52

7.3 Appendix III. Bat species complex

Table 1. Simpson's diversity index for bats at sites north to south (1 to 5) and at paired plots within each site (1 = shore, 2 = inland). The plot of highest diversity is the inland plot at site 3 (i.e., 3I) and then the inland plot at site 2 (i.e., 2I).

	Site	Plot	Mylu	Epfu/Lano	Laci	Labo	Myse	Pesu	Myle	Total (N)	Diversity
Number (n)	1	1	45		1	4	4	1		55	0.33
		2	46		2	2	3			53	0.25
	2	1	20	3		1				24	0.30
		2	2	8		1				11	0.47
	3	1		10		2				12	0.30
		2	1	15	2	6				24	0.56
	4	1		35	4		5			44	0.35
		2	5	84	1	1				91	0.15
	5	1		4			3			7	0.00
		2		5						5	0.00
n(n-1)	1	1	1980	0	0	12	12	0	0	2004	
		2	2070	0	2	2	6	0	0	2080	
	2	1	380	6	0	0	0	0	0	386	
		2	2	56	0	0	0	0	0	58	
	3	1	0	90	0	2	0	0	0	92	
		2	0	210	2	30	0	0	0	242	
	4	1	0	1190	12	0	20	0	0	1222	
		2	20	6972	0	0	0	0	0	6992	
	5	1	0	12	0	0	6	0	0	18	
		2	0	20	0	0	0	0	0	20	

7.4   Appendix IV. Orientation of shore

A priori categorization of the shoreline as: 1) north-south orientation (3S, 4S); and 2) west-east orientation (1S, 2S, 5S)
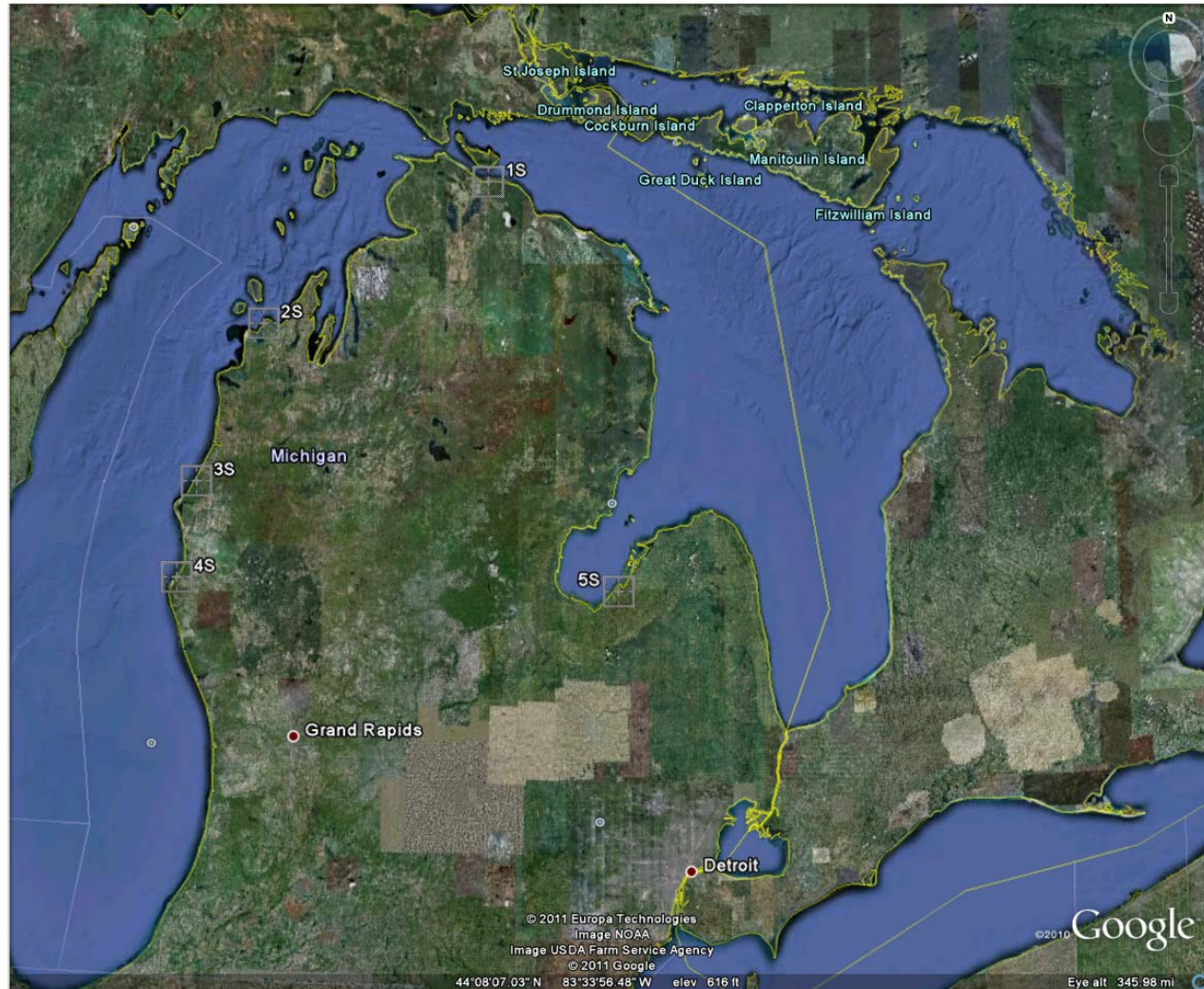
7.5 **Appendix V. Statistical comparison**

Table 1. Relative abundance of bats and birds at shore versus inland plots. The average radar-determined number of flights over all nights and times of night, compared between shore and inland plots, paired by site, for bats and birds separately. Abundance is greater at inland sites, particularly for sites with north-south orientation versus west-east orientation (paired t-test, $p < 0.05$).

Matched Pairs
Difference: Inland-Shore

Inland	243.584	t-Ratio 2.182875
Shore	144.7	DF 9
Mean Difference	98.8837	Prob > |t| 0.0569
Std Error	45.2998	Prob > t 0.0285*
Upper 95%	201.359	Prob < t 0.9715
Lower 95%	-3.5915	
N	10	
Correlation	0.41981	

Across Groups

Orientation	Count	Mean Difference	Mean Mean
N-S	4	251.15	278.08
W-E	6	-2.629	138.19

Test Across Groups

	F Ratio	Prob>F	
Mean Difference	41.0661	0.0002*	Within Pairs Y Axis
Mean Mean	7.7936	0.0235*	Among Pairs X Axis

	Orienta	Avg. # bats		Avg. # birds	
Site	tion	Shore	Inland	Shore	Inland
1	W-E	217	209	306	259
2	W-E	55	89	108	98
3	N-S	207	319	194	495
4	N-S	78	362	131	438
5	W-E	60	52	91	113
Total		133	214	176	291

SE-bat		SE-bird	
Shore	Inland	Shore	Inland
7.0	10.6	9.8	12.5
7.9	8.2	9.7	10.2
9.4	8.4	11.4	10.4
9.8	7.5	14.0	9.0
8.3	8.4	11.9	12.0

Table 2. Effect of period, or time of year, on bat abundance at sites north to south. There is a significant effect of period (ANOVA, bat abundance on period, F-test (3,33) p < 0.05; (a)) and the effect of period is statistically correlated (p < 0.005) for birds and bats (b).

)

Oneway Analysis of #Bats By Period

Missing Rows   3

Oneway Anova

Summary of Fit

Rsquare	0.260186
Adj Rsquare	0.19293
Root Mean Square Error	141.7281
Mean of Response	169.0396
Observations (or Sum Wgts)	37

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Period	3	233123.74	77707.9	3.8686	0.0178*
Error	33	662865.98	20086.8		
C. Total	36	895989.71			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	8	301.883	50.108	199.94	403.83
2	9	196.029	47.243	99.91	292.15
3	10	106.522	44.818	15.34	197.71
4	10	100.992	44.818	9.81	192.18

Std Error uses a pooled estimate of error variance

b)

Matched Pairs

Weight: Site

Difference: Bird-Bat

Bird	0.48496	t-Ratio	3.40914
Bat	0.31217	DF	19
Mean Difference	0.17279	Prob > |t|	0.0029*
Std Error	0.05068	Prob > t	0.0015*
Upper 95%	0.27888	Prob < t	0.9985
Lower 95%	0.06671		
N	20		
Correlation	0.70477		

Across Groups

Period	Count	Mean Difference	Mean Mean
1	5	0.0324	0.5477
2	5	0.2348	0.4876
3	5	0.3016	0.3299
4	5	0.1224	0.229

Test Across Groups

	F Ratio	Prob>F	
Mean Difference	1.4922	0.2545	Within Pairs Y Axis
Mean Mean	1.6304	0.2219	Among Pairs X Axis

Table 3. Regression of bat species diversity by habitat diversity. The relationship is not statistically significant.

Bivariate Fit of Bat Diversity By Habitat Diversity
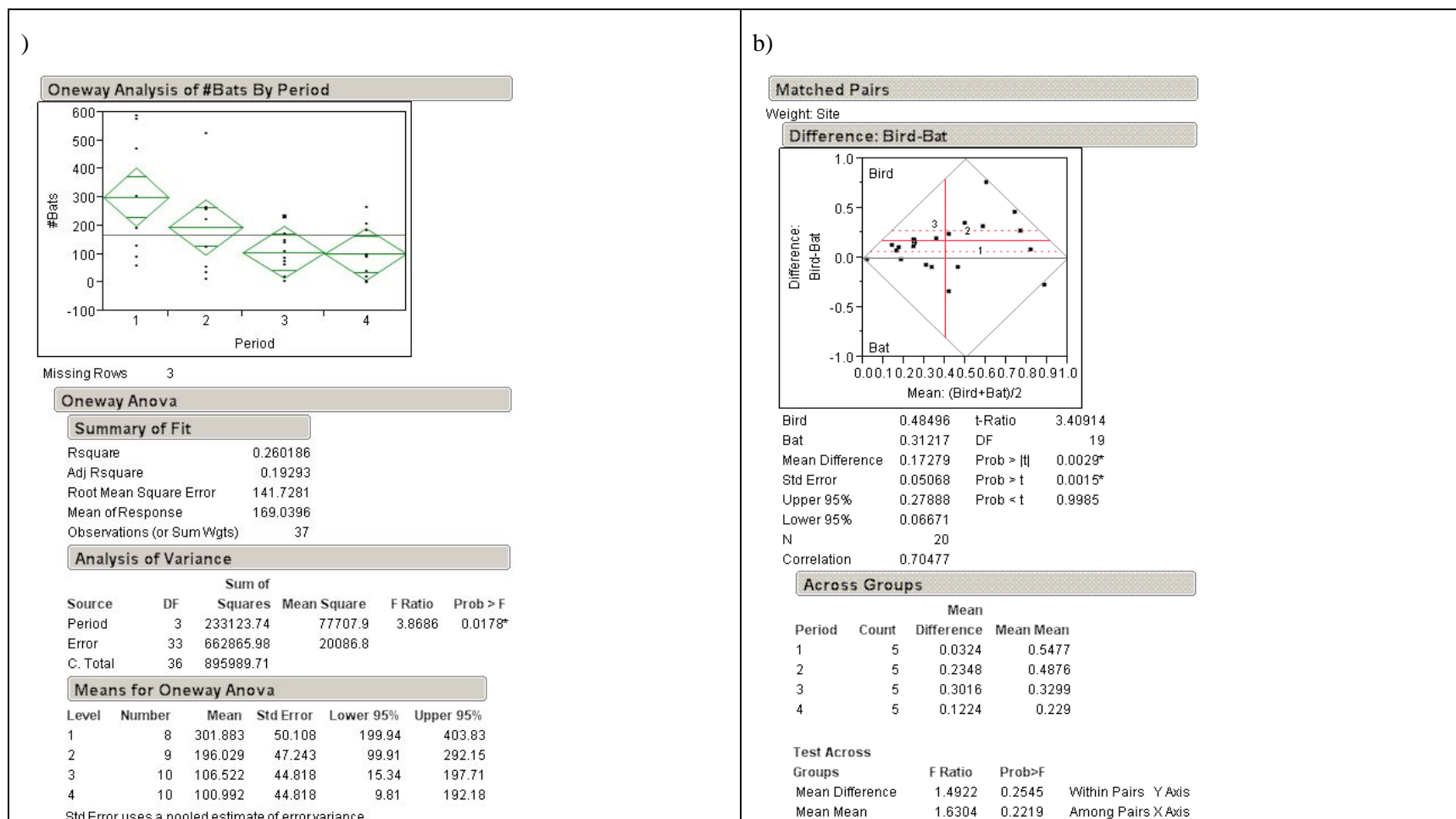
Linear Fit

Bat Diversity= 0.0316998 + 0.4311715*Habitat Diversity

Summary of Fit

RSquare	0.272163
RSquare Adj	0.181184
Root Mean Square Error	0.164239
Mean of Response	0.271
Observations (or Sum Wgts)	10

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.08069375	0.080694	2.9915
Error	8	0.21579625	0.026975	Prob > F
C. Total	9	0.29649000		0.1220

Parameter Estimates

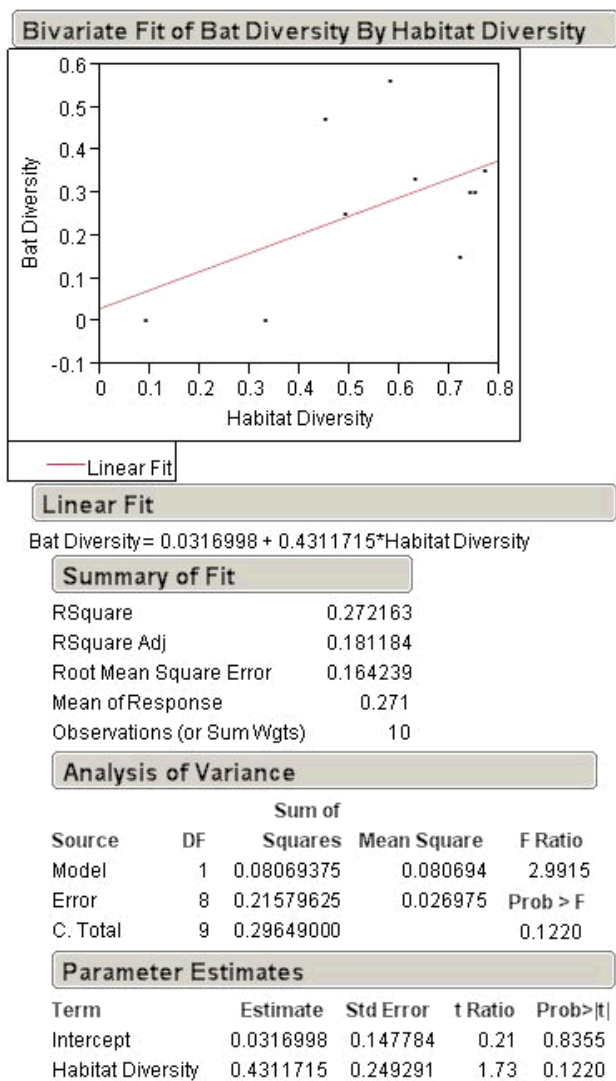| Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0316998	0.147784	0.21	0.8355
Habitat Diversity	0.4311715	0.249291	1.73	0.1220

Table 4. Predicted collision risk for bats at shore and inland plots for sites north to south (Site 1 to Site 5 respectively). There is a significant effect of site (ANOVA, $p < 0.0001$ for shore plots and $p < 0.05$ for inland plots).

Oneway Analysis of Shore By Site
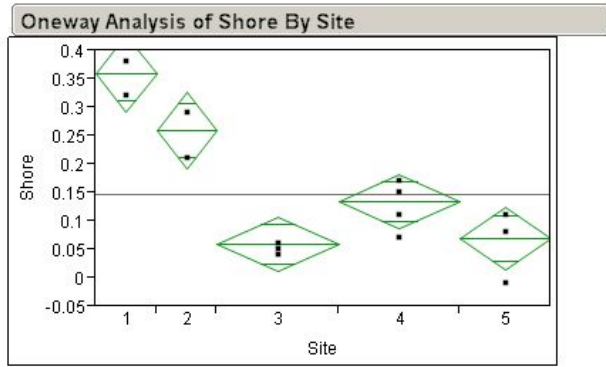
Missing Rows   5

Oneway Anova

Summary of Fit

Rsquare	0.897156
Adj Rsquare	0.856018
Root Mean Square Error	0.043474
Mean of Response	0.148667
Observations (or Sum Wgts)	15

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Site	4	0.16487333	0.041218	21.8086	<.0001*
Error	10	0.01890000	0.001890		
C. Total	14	0.18377333			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	2	0.360000	0.03074	0.29151	0.42849
2	2	0.260000	0.03074	0.19151	0.32849
3	4	0.060000	0.02174	0.01157	0.10843
4	4	0.135000	0.02174	0.08657	0.18343
5	3	0.070000	0.02510	0.01407	0.12593

Std Error uses a pooled estimate of error variance

Oneway Analysis of Inland By Site
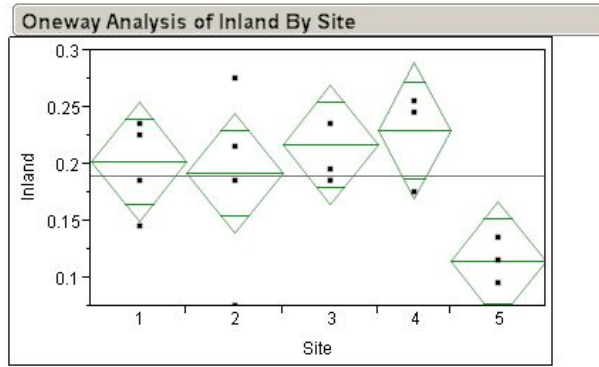
Missing Rows   1

Oneway Anova

Summary of Fit

Rsquare	0.483187
Adj Rsquare	0.335526
Root Mean Square Error	0.048642
Mean of Response	0.189474
Observations (or Sum Wgts)	19

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Site	4	0.03096974	0.007742	3.2723	0.0432*
Error	14	0.03312500	0.002366		
C. Total	18	0.06409474			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	4	0.202500	0.02432	0.15034	0.25466
2	4	0.192500	0.02432	0.14034	0.24466
3	4	0.217500	0.02432	0.16534	0.26966
4	3	0.230000	0.02808	0.16977	0.29023
5	4	0.115000	0.02432	0.06284	0.16716

Std Error uses a pooled estimate of error variance