Avian Night Migration Intensity In Michigan:
Knowledge important to the siting of wind farms and other tall structures

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Cover photo taken by Joelle Gehring

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Executive Summary

Many populations of migratory birds are declining in size and migration challenges have been found as the main source of adult landbird mortality (Sillett and Holmes 2002). These fatalities could be detrimental to populations of birds, especially those that are already in decline or at low levels. The frequency of avian collisions with wind turbines appears to be directly correlated with the densities of birds flying through the wind farm. Therefore, placing wind farms in areas with low avian densities can decrease and minimize their impact. Both resident and migrant birds have been documented to collide with wind turbines. Passerines (e.g., songbirds) were the most frequent avian group to collide with turbines outside of California (Erickson et al. 2001). The mean fatality rate, based on 12 studies (not including California), is 2.3 birds per turbine per year, and 3.1 per megawatt per year of capacity.

Due to the propensity for high, steady winds, the shorelines of the Great Lakes are targeted for a large increase in wind farm development. The Great Lakes' shorelines have also been documented as being of particular importance to migratory songbirds (Diehl et al. 2003, Ewert et al. 2005, Shieldcastle 2004, Bonter et al. 2008). Several studies have documented migrant songbird concentration areas and specifically stopover sites in areas proximal to the Great Lakes (Diehl et al. 2003, Ewert et al. 2005, Shieldcastle 2004, Bonter et al. 2008). While stopover sites are important to delineate, avian collisions are thought to occur during the actual flight portion of migration and therefore we believe that it is important to determine and delineate concentrations of migrants throughout the night, and not just during stopover periods.

Specifically our objectives were to:

1. use radar ornithology (i.e., **NEX**t Generation **RAD**ar (NEXRAD)) to identify areas with concentrations of migrant birds higher than surrounding areas over time.
2. test whether those areas of high concentration were randomly distributed in the landscape or clustered in specific areas.

We used NEXt generation RADar (NEXRAD, WSR-88D) to quantify numbers of birds migrating over Michigan (Diehl et al. 2003, Gauthreaux and Belser 2003). Radar transmits and receives electromagnetic waves to determine the distance, direction, altitude, and speed of both moving and stationary objects. While this type of radar ornithology excels at determining bird migration at large-scales and provides a density of birds (mean number of birds/ km^{-3}) in an area; it does not provide an exact number of birds (Diehl et al. 2003). However, this otherwise excellent technology has been proven to provide large-scale estimates and indices of the intensity of bird migration. To analyze the spatial distribution of reflectivity values, we utilized a grid of points evenly spaced 500 m apart. The points were intersected with the radar polygons and each point was assigned the reflectivity value of the corresponding radar polygon. Due to the combined effects of the earth's curvature, and the angle of the radar antenna, as one moves away from the radar location the distance above the earth's surface represented by each radar polygon increases. To compensate for the changing distance above earth's surface, we created four bands representing the radial distance from radar site. Starting at a distance 10 km from the radar site, each band, except the outermost band, was 30 km in width (10 – 40 km, 40 – 70 km, 70 – 100 km, and > 100 km). Each point in the analysis grid was then assigned to an appropriate distance band. The choice of 30 m distance bands is consistent with the distance used by Diehl et al. (2003) in their use of NEXRAD data.

To determine those areas that on any given day had significantly higher migratory bird concentrations than other areas, we analyzed the distribution of radar reflectivity values in each 30 km ring individually. For each ring, and for each day of data, we calculated the percentage of points with any given reflectivity value. The frequency distribution of the number of points with a given reflectivity value tended to be distributed somewhat normally. We then selected a critical threshold reflectivity value by summing, from the lowest reflectivity value to the highest reflectivity value, the percentage of the total points with each reflectivity value. The critical threshold reflectivity value was determined to be that value where the cumulative percentage reached at least 95% of the total number of points. Those points that exceeded the threshold reflectivity value at least one day were then converted to a raster dataset, with each point the center of a 500-meter pixel. The daily rasters were then summed to produce a single 500-meter pixel raster for each 30-km ring where the pixel value was the number of times during the study period a pixel exceeded the reflectivity value threshold that determined a daily significantly high migration concentration. The composite raster for each radar site was then converted to a polygon dataset, using the raster pixel values to establish polygon boundaries. To determine if the observed patterns were not the result of random chance, we performed an autocorrelation test using the Morans Index test. The Morans Index simultaneously tests feature values and the spatial arrangement of the features to determine if a spatial pattern is clustered, random or dispersed.

Upon analyzing the distribution of radar reflectivity values in 30-km rings via calculating the percentage of points with any given reflectivity value, we found that most areas had low bird densities over time, thereby highlighting those areas with high densities. Using the Morans Index text, the spatial pattern for all four sites was determined to be clustered and the likelihood for the observed patterns being the result of chance was less than one percent. When mapped at a state-level scale one can not only detect the areas with high concentrations of birds for one night of migration but also those areas with several nights of high bird concentrations.

The radar site in Detroit, MI quantified several areas of high bird concentrations in the southeastern portion of the state. These data suggest that the thumb region of Michigan does not support high densities of migrant songbirds during the spring migration. Contrary to the thumb region of Michigan, the areas to the southwest and southeast of the Detroit radar site support higher densities of migrant songbirds. Additional valuable information was identified from the radar site in Grayling, MI. While there are several areas of consistently high concentrations of migrant birds in the central portion of the northern Lower Peninsula, there are also concentration areas along the finger regions of the area (northwestern portion of radar scan). However, the Lake Michigan shoreline, as observed from the Grand Rapids radar site, supported consistent concentrations of migrant birds, identified by the yellow, orange, and red cells aligned with the shoreline. This provides the clearest example of an area where wind developers may consider buffering the Lake Michigan shoreline in an effort to minimize avian collisions. The Marquette, MI radar site is not the most useful source of NEXRAD radar ornithology data. The majority of the radar scan area appears to be blocked by topography or another source of interference. While there are some cells with consistently high concentrations of birds it does not appear that these areas are aligned or associated with the Lake Superior lakeshore.

These data are useful for identifying areas of potential high risk for the development of wind energy resources and closer examination of the data from each radar site provides more site-specific information. This product can be utilized by wind developers, local planning and zoning commissions, and natural resource agencies during the wind farm planning and review assessment stages. Those areas with high concentrations of bird migration would be expected to be involved in more songbird fatalities than those areas with low concentrations of bird migration. As additional data become available we plan to improve our product and update stakeholders.

Introduction

Many populations of migratory birds are declining in size and migration challenges have been found as the main source of adult landbird mortality (Sillett and Holmes 2002). While there are a multitude of issues negatively affecting their populations, Neotropical migratory bird species are impacted by habitat alterations to and loss of their migration stopover sites, as well as direct collisions with tall structures, such as wind turbines. Migrant songbirds appear to become disoriented when night skies are overcast and are then attracted to the lights of tall structures (Larkin 2000). In 2001 it was estimated that more than 2 birds per turbine per year were killed in the United States (Erickson et al. 2001). As taller wind turbines are now constructed in higher densities, the overall risk of avian fatalities has increased. These fatalities could be detrimental to populations of birds, especially those that are already in decline or at low levels. The frequency of avian collisions with wind turbines appears to be directly correlated with the densities of birds flying through the wind farm. Therefore, placing wind farms in areas with low avian densities can decrease and minimize their impact.

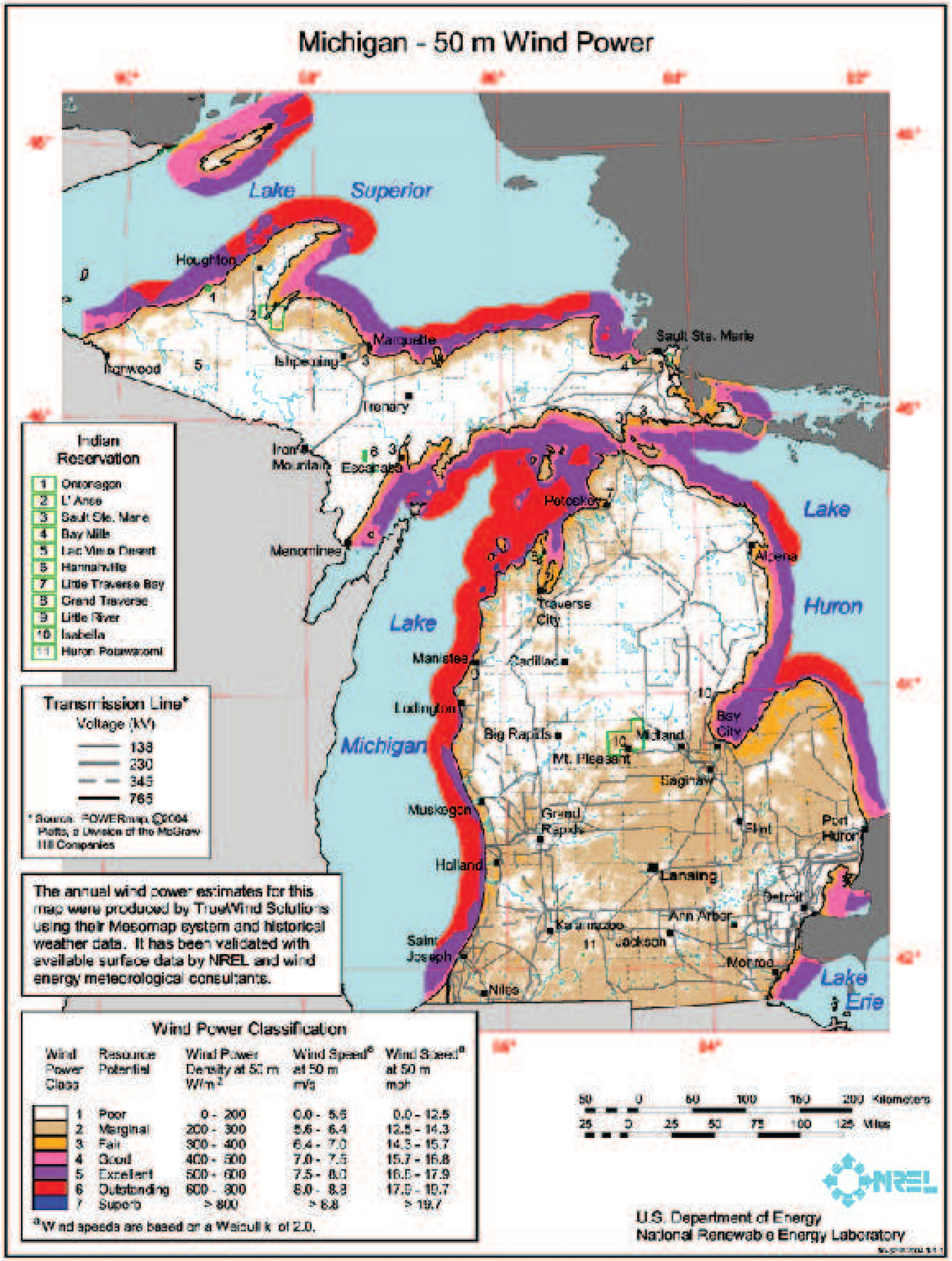
Wildlife collisions with wind turbines

Both resident and migrant birds have been documented to collide with wind turbines. Passerines (e.g., songbirds) were the most frequent avian group to collide with turbines outside of California (Erickson et al. 2001). The mean fatality rate, based on 12 studies (not including California), is 2.3 birds per turbine per year, and 3.1 per megawatt per year of capacity. In 2001, Erickson et al. estimated that 10,000 – 40,000 birds collided with wind turbines in the United States ever year; however, the number of turbines has significantly increased since then. The frequency of avian collisions with wind turbines has a high level of variance and appears to be related to site-specific variables. For example, a study at a wind farm in an agricultural area of Oregon documented 0.63 bird fatalities per turbine (1 per megawatt of capacity), while a wind farm in a mountainous, forested area of Tennessee documented 10 bird fatalities per turbine per year (15 per megawatt of capacity) (NWCC 2004). Variables believed to affect the frequency of avian collisions include the concentration of birds within and traveling through the wind farm area, the vegetation present in and around the wind farm, and topographic landscape features (NWCC 2004). Past research suggests that birds, primarily night migrating songbirds, become disoriented when overcast night skies obscure stellar constallations from view. During these conditions birds appear to be particularly prone to an attraction to the lights of tall structures (Larkin 2000). While the lighting systems of wind turbines were designed in part to consider and minimize this risk, it is possible that birds are still attracted to these lit structures, especially during periods of inclimate weather. Therefore, it is important to minimize the potential for avian fatalities by considering avian migration concentration areas in the wind farm siting process.

Migration in the Great Lakes region

Tax credits, renewable energy mandates, and a strong desire for non-polluting, renewable energy sources have increased the use and development of wind energy resources worldwide. However, due to the propensity for high, steady winds, the shorelines of the Great Lakes are targeted for a large increase in wind farm development (Fig. 1). The Great Lakes' shorelines have been documented as being of particular importance to migratory songbirds (Diehl et al. 2003, Ewert et al. 2005, Shieldcastle 2004, Bonter et al. 2008). Several studies have documented migrant songbird concentration areas and specifically stopover sites in areas proximal to the Great Lakes (Diehl et al. 2003, Ewert et al. 2005, Shieldcastle 2004, Bonter et al. 2008). Bonter et al. (2008) focused on identifying habitat variables in the Great Lakes region associated with high concentrations of dusk migrant bird departures (i.e., exodus from daytime stopover areas). They found that areas with large concentrations of birds were characterized by 1.2 times more forest cover and 9.3 times more water cover than areas with lower migrant concentrations. They also identified large concentrations of birds departing from shoreline areas near some of the Great Lakes. These large concentrations of birds near the shorelines could be explained by some of the research conducted by Diehl et al. (2003). They documented that migrant songbirds commonly migrated over the Great Lakes and upon sunrise redirected their flight toward the nearest shoreline, likely for refueling and stopover (Diehl et al. 2003). This resulted in concentrations of birds in shoreline areas between dawn and dusk. Ewert et al. 2005 and Shieldcastle (2004) also studied the importance of migratory songbird stopover sites along the southwestern shore of Lake Erie. Considering that avian collisions are thought to occur during the actual flight portion of migration we believe that it is important to determine and delineate concentrations of migrants throughout the night, and not just during stopover periods. This unique information is valuable to the wind industry and resource managers.

Great Lakes' shorelines and dune habitats are known to specifically provide migration areas and stopover habitats for the endangered Piping Plover, Kirtland's Warbler, and Prairie Warbler, as well as other rare species like the Cerulean Warbler, Northern Goshawk, and Red-shouldered Hawk. Additional Partners in Flight priority bird species



Indian Reservation

1	Ontonagon
2	L' Anse
3	Sault Ste. Marie
4	Bay Mills
5	Lac Vieux Desert
6	Hannahville
7	Little Traverse Bay
8	Grand Traverse
9	Little River
10	Isabella
11	Huron Potawatomi

Transmission Line*
Voltage (kV)
138
230
345
765

* Source: POWERmap, ©2004 Platts, a Division of the McGraw Hill Companies

The annual wind power estimates for this map were produced by TrueWind Solutions using their Mesomap system and historical weather data. It has been validated with available surface data by NREL and wind energy meteorological consultants.

Wind Power Classification

	Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
⬜	1	Poor	0 - 200	0.0 - 5.6	0.0 - 12.5
🟫	2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
🟧	3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
🟪	4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
🟪	5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
🟥	6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
🟦	7	Superb	> 800	> 8.8	> 19.7

[a] Wind speeds are based on a Weibull k of 2.0.

Figure 1. Michigan shorelines have strong consistent winds conducive to the generation of wind energy. Map courtesy of the Department of Energy – National Renewable Energy Laboratory (http://www.windpoweringamerica.gov/images/windmaps/mi_50m_800.jpg; accessed 2004).

that migrate and stop over in Michigan, likely in shoreline areas, include the Sedge Wren, Yellow Rail, Golden-winged Warbler, Wood Thrush, Veery, Rose-breasted Grosbeak, and Canada Warbler. It is important that we understand where to develop wind turbines in these sensitive areas and throughout the Great Lakes area in order to prevent negative impacts to these and other migratory bird populations utilizing these areas.

The increase in the construction of wind farms heightens the value and urgency of determining this relationship. For example, the United States Fish and Wildlife (USFWS) is interested in gaining specific, scientifically based information on migrant bird concentrations near the Great Lakes' shorelines. They are also interested in learning whether those potential concentrations decrease at a particular threshold distance from the shorelines. While they are currently suggesting a 3-mile buffer of the Great Lakes shorelines they have few data on which to base this recommendation. Similarly, as the potential for offshore wind energy development grows in the Great Lakes, resource managers are increasingly interested in the geography of bird migration over these large water bodies (i.e., migrant concentrations and distance from lakeshores). Information on the relationship between bird densities and the Great Lakes' shorelines is exceptionally important as resource managers and wind developers work together for the sustainable development of renewable energy.

Objectives

In an effort to address the relationship between bird concentration areas and the Great Lakes' shorelines, thereby contributing to resource management decisions, we utilized radar ornithology. Our approach is consistent with the priorities established at a 2006 U.S. Geological Survey workshop: "Applying radar technology to migratory bird and bat conservation and management: strengthening and expanding a collaborative effort" in Albuquerque, New Mexico. Specifically, this workshop determined the need to develop the capability to evaluate migration over time and space to help resource managers better understand the timing, pathways, and stopover characteristics of migrants across landscapes.

Specifically our objectives were to:

1. use radar ornithology (i.e., **NEX**t Generation **RAD**ar (NEXRAD)) to identify areas with concentrations of migrant birds higher than surrounding areas over time.
2. test whether those areas of high concentration were randomly distributed in the landscape or clustered in specific areas.

Several organizations are currently mapping and quantifying the wind resources of Michigan and the Great Lakes Region in concert with the ecologically sensitive areas (e.g., Great Lakes Wind Collaborative, Michigan State University's Land Policy Institute). These efforts provide excellent data to assist with the siting of wind energy development. However, the spatially quantified intensity of bird migration, such as our product, is a needed data layer for these mapping efforts. This information may be especially important in the coastal areas of Michigan. The likely importance of these areas to Neotropical migratory birds combined with the growing demand for wind energy development in coastal areas make this research very important to the sustainable development of renewable energy.

Study Area and Methods

Michigan is situated within four of the five Great Lakes. With more freshwater shoreline than anywhere in the world, Michigan is a unique and important site to study bird migration in relation to the Great Lakes' shorelines. Our research focuses on the areas within the technological reaches of 4 NEXRAD sites in the following Michigan locations: Grand Rapids, Detroit, Gaylord, and Marquette (Fig. 2).

We used NEXt generation RADar (NEXRAD, WSR-88D) to quantify numbers of birds migrating over Michigan (Fig. 3; Diehl et al. 2003, Gauthreaux and Belser 2003). Radar transmits and receives electromagnetic waves to determine the distance, direction, altitude, and speed of both moving and stationary objects. During the late 1980s and early 1990s the National Weather Service installed over 150 Weather Surveillance Radar-1988 Doppler sites throughout the United States, called the Next Generation Weather Radar system. NEXRAD Doppler radar is primarily used for weather forecasting, tracking and analysis.

The NEXRAD radar sites send out radio waves from an antenna. Objects in the air, such as raindrops, hailstones, insects and birds, scatter or reflect some of the radio waves back to the antenna. The computer at the radar site electronically converts the reflected radio waves into images showing the location and intensity of objects. The Doppler component of the radar also measures the frequency change in returning radio waves. Waves reflected by something moving away from the antenna

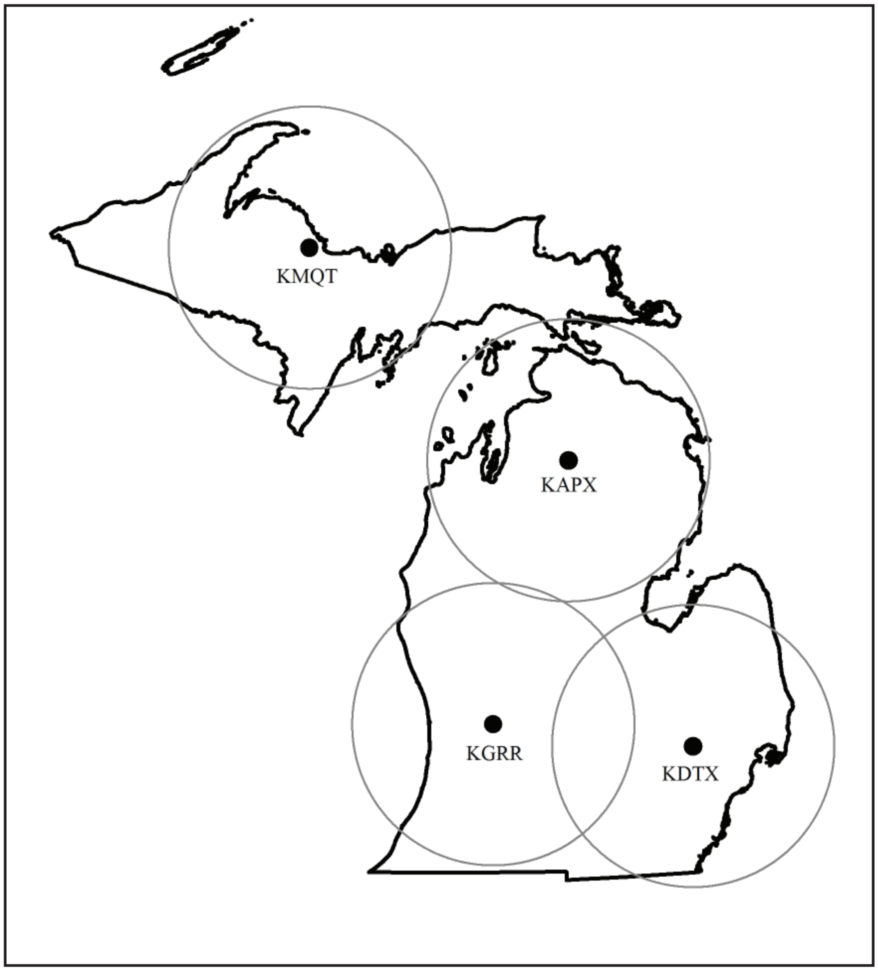


Figure 2. Data from four Michigan NEXt Generation RADar sites (WSR-88D) were used to determine bird migration concentration areas. These data will be used to predict the potential impact of the development of wind energy resources on migratory birds.

change to a lower frequency, while waves from an object moving toward the antenna change to a higher frequency.

NEXRAD sites operate in two modes, Clear Air Mode and Precipitation Mode. In either of these modes, several volume coverage patterns (VCP) are employed. A VCP is one 360° scan of the atmosphere at a particular elevation tilt and in a specified time period. In Clear Air Mode, the most sensitive operation state, the initial elevation is 0.5° and the scan is completed in 10 minutes. The radar beam itself is 1° so it returns information for between 0° and 1° degree above the horizon. Along the beam the returning energy is recorded every kilometer. Because of the curvature of the earth, the altitude of the area the radar "sees" increases with distance.

Because of its superior sensitivity in Precipitation Mode, Clear Air Mode is the optimum radar mode from which to detect birds. In the absence of weather events, the image is generally clear, but during migration season researchers have demonstrated evidence of nocturnal bird movement (Gauthreaux and Belser 2003).

While this type of radar ornithology excels at determining bird migration at large-scales and provides a density of birds (mean number of birds/ km^{-3}) in an area; it does not provide an exact number of birds (Diehl et al. 2003). However, this otherwise excellent technology has been proven to provide large-scale estimates and indices of the intensity of bird migration. These types of data analyses typically focus on bird migration; however, it is likely that the data include birds, bats and likely some insects. It is not possible, at this time, to discern those species groups using NEXRAD (some insect targets are discernable) but by combining ground based surveys with the NEXRAD data, studies have found that the bulk of the signal is birds.

We collaborated with M. Suarez and P. Heglund (USGS) on the process of acquisition and preprocessing of archived NEXRAD data. They have worked extensively with NEXRAD technology in the Great Lakes and are knowledgeable on the details and challenges of this type of research. NEXRAD images were obtained from the National Climatic Data Center (http://www.ncdc.noaa.gov/oa/radar/radarresources.html#welcome) for the four NEXRAD sites in Michigan. We selected the dates April 21-May 31, 2008 as the height of the spring migration. Diehl et al. (2003) identified 23:30 UTC as the time at which migration was at peak intensity, hence we obtained the image collected closest to this time for each day. We pre-selected this temporal sample to target the height of the spring migration season and the peak density of the daily migration. Take-off, landing, and stopover sites have been examined by Bonter et al. (2008), but we were more focused on the flight periods of migration. NEXRAD images with precipitation and high numbers of insects were identified (and subsequently removed from analysis) by examining the pattern of the reflectivity, the speed of the targets (compared to winds aloft data), and the direction of the movement (Gauthreaux et al. 2003, Bonter et al. 2008). Converting NEXRAD data to biologically useful data required several steps. Radar reflectivity is typically measured in units of Z, which describe the intensity of the echo caused by the target(s) in the measured volume of space. Because Z can vary greatly it is represented on a logarithmic scale as dBZ. We converted reflectivity dBZ to a linear measure of bird density (birds/km^3) after Diehl et al. 2003. In addition, the curvature of the earth causes the NEXRAD data to attenuate with greater distance from the radar site (Diehl et al. 2003). This attenuation results in the radar signal projecting above the altitude of the migratory layer of birds; thereby, not quantifying the refraction of the birds. We limited the analyzed data to those within 120-km radius of the radar site.

Analysis

The radar data consists of data values for irregular sized polygons. Each polygon is approximately a half degree wide. The physical distance of a half degree changes as one moves more distant from the radar location. In addition to changing with the distance from the radar site, the length of a polygon depends on the reflectivity values. Typically the length of a radar polygon would be one kilometer. If however, adjoining polygons had the same reflectivity

Figure 3. Data from NEXt Generation RADar (NEXRAD, WSR-88D) was used to quantify bird concentrations during migration with direct application to minimizing avian collisions with wind turbines (photo: J. Gehring).

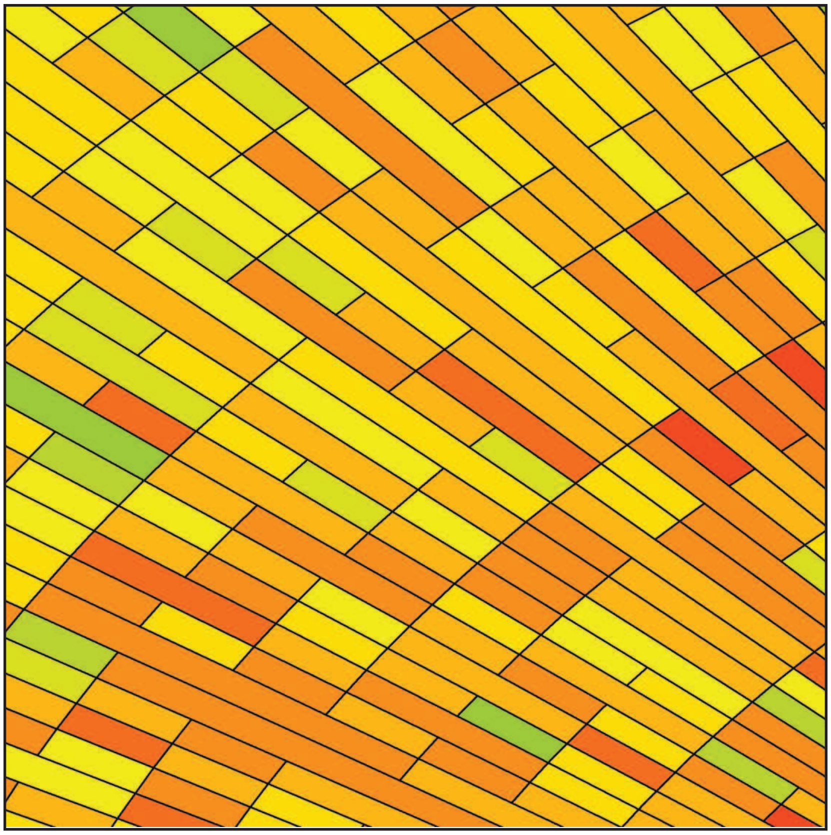


Figure 4. NEXt Generation RADar data consist of irregular sized polygons. The size and length of the polygons depends on the distance from the radar site and the reflectivity values of surrounding cells (i.e., adjoining equal valued polygons are dissolved into a single polygon).

value, the adjoining equal valued polygons would be dissolved into a single polygon (Fig. 4)

To analyze the spatial distribution of reflectivity values, we utilized a grid of points evenly spaced 500 m apart (Fig. 5). The points were intersected with the radar polygons and each point was assigned the reflectivity value of the corresponding radar polygon (Table 1). Due to the combined effects of the earth's curvature, and the angle of the radar antenna, as one moves away from the radar location the distance above the earth's surface represented by each radar polygon increases. To compensate for the changing distance above earth's surface, we created four bands representing the radial distance from radar site. Starting at a distance of 10 km from the radar site, each band, except the outermost band, was 30 km in width (10 – 40 km, 40 – 70 km, 70 – 100 km, and > 100 km). Each point in the analysis grid was then assigned to an appropriate distance band. The choice of 30-m distance bands is consistent with the distance used by Diehl et al. (2003) in their use of NEXRAD data.

To determine those areas that on any given day had significantly higher migratory bird concentrations than other areas, we analyzed the distribution of radar reflectivity values in each 30-km ring individually. For each ring, and for each day of data, we calculated the percentage of points with any given reflectivity value. The frequency distribution of the number of points with a given reflectivity value tended to be distributed somewhat normally (Fig. 6). We then selected a critical threshold reflectivity value by summing, from the lowest reflectivity value to the highest reflectivity value, the percentage of the total points with each reflectivity value. The critical threshold reflectivity value was determined to be that value where the cumulative percentage reached at least 95% of the total number of points. All points with reflectivity values greater than the threshold value were considered to be daily high concentrations of migratory birds. Typically the number of points below the critical threshold value represented more than 95% of the total points. In most cases this represented only one – two percent of the points in any ring exceeded the critical threshold (Table 2).

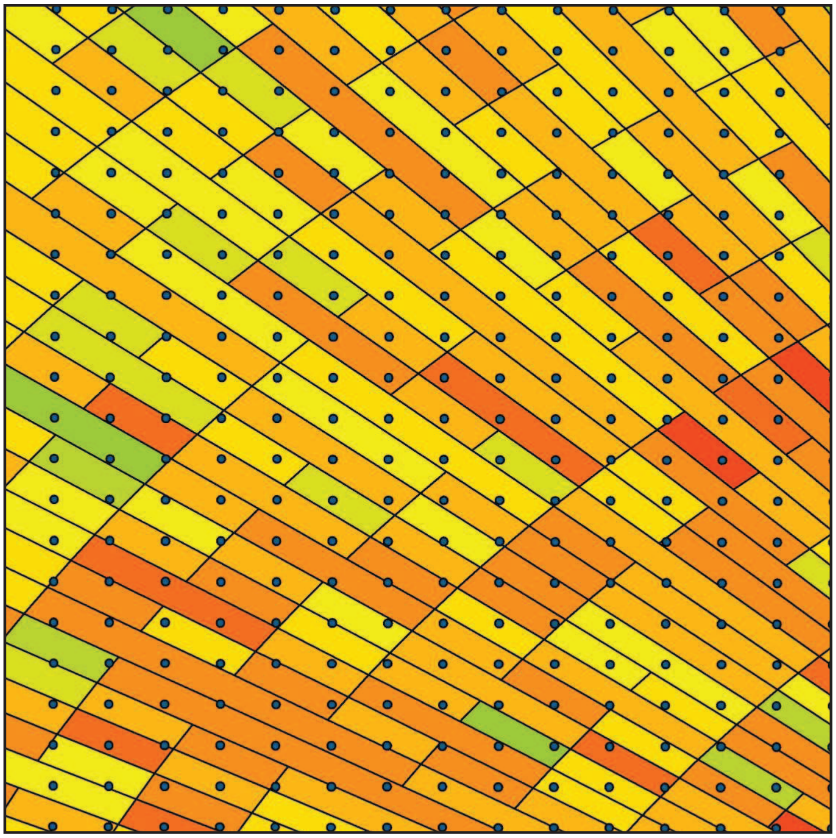


Figure 5. NEXt Generation RADar data consist of irregular sized polygons. To analyze the spatial distribution of reflectivity values, we utilized a grid of points evenly spaced 500 m apart.

Table 1. The points were assigned the reflectivity value of their corresponding radar polygon. There were large numbers of points specific to each radar band width per radar site.

	10 – 40 km	**40 – 70 km**	**70 – 100 km**	**> 100 km**
Detroit	18850	41472	64094	55286
Gaylord	18850	41471	64089	55287
Grand Rapids	18850	41467	64083	55303
Marquette	18852	41471	64082	55284

Those points that exceeded the threshold reflectivity value at least one day were then converted to a raster dataset, with each point the center of a 500-m pixel. The daily rasters were then summed to produce a single 500-m pixel raster for each 30-km ring where the pixel value was the number of times during the study period a pixel exceeded the reflectivity value threshold that determined a daily significantly high migration concentration. Finally the rasters for each site's 30-km rings were combined to produce a composite raster that ranged from 10 km – 120 km from each site. The value of each pixel in the composite raster was the number of times during the migration period that a pixel represented a high concentration of migratory birds by exceeding a daily threshold concentration.

The composite raster for each radar site was then converted to a polygon dataset, using the raster pixel values to establish polygon boundaries. To determine if the observed patterns were not the result of random chance, we performed an autocorrelation test using the Morans Index test included in ESRI ArcGIS 9.3. The Morans Index simultaneously tests feature values and the spatial arrangement of the features to determine if a spatial pattern is clustered, random or dispersed (O'Sullivan and Unwin 2002, Mitchell 2005).

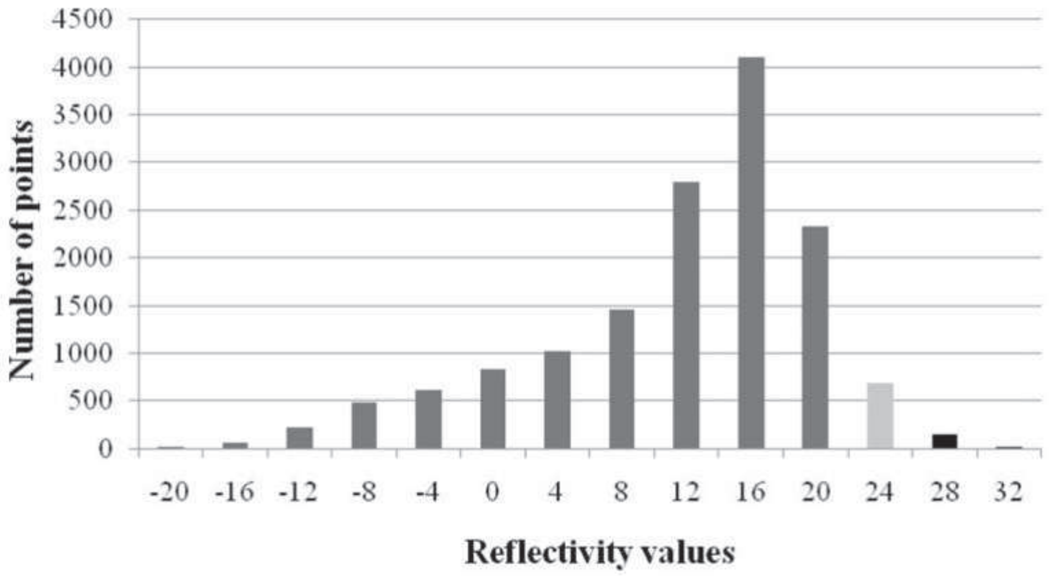


Figure 6. The typical distribution of reflectivity values was approximately normal. The critical threshold value is in light gray. Those values above the critical threshold represent the most significant concentrations of migratory birds. These data are from Marquette (KMQT) on May 28 in the 10 – 40 km band.

Table 2. Typical distribution of reflectivity values was approximately normal. All points with reflectivity values greater than the threshold value were considered to be daily high concentrations of migratory birds (red), accepted values in blue. These data are from Marquette, May 28, 10 – 40 km band.

Reflectivity	**Number of points**	**Percent of total**	**Cumulative percentage**
-20	2	0.000135382	0.000135382
-16	57	0.00385839	0.003993772
-12	218	0.014756651	0.018750423
-8	482	0.03262709	0.051377513
-4	612	0.041426928	0.092804441
0	834	0.056454342	0.149258783
4	1020	0.069044879	0.218303662
8	1458	0.098693563	0.316997225
12	2791	0.188925743	0.505922968
16	4112	0.278345631	0.784268598
20	2327	0.157517092	0.94178569
24	694	0.046977594	0.988763284
28	153	0.010356732	0.999120016
32	13	0.000879984	1

Results and Discussion

After we removed from analysis those days with inclimate weather and likely high levels of insect activity we had a mean of 17.8 nights of useful data for the four radar sites (Table 3). Upon analyzing the distribution of radar reflectivity values in 30-km rings via calculating the percentage of points with any given reflectivity value, we found that most areas had low bird densities over time, thereby highlighting those areas with high densities (Tables 4-7). Typically the number of points below the critical threshold value represented more than 95% of the total points which assisted in the isolation of those areas with high bird concentrations over time. Using the Morans Index text, the spatial pattern for all four sites was determined to be clustered and the likelihood for the observed patterns being the result of chance was less than one percent (Table 8). This lends further support to the validity of the identification of bird migration concentration areas and utility to the application of these analyses to landscape management decisions.

Table 3. Several nights of bird migration data were removed from analysis due to inclimate weather and likely high levels of insect activity. The sites had relatively similar sample sizes of data nights remaining.

	Number of days
Detroit	20
Gaylord	17
Grand Rapids	16
Marquette	18

When mapped at a state-level scale one can not only detect the areas with high concentrations of birds for one night of migration but also those areas with several nights of high bird concentrations (Fig. 7). These data are useful for identifying areas of potential high risk for the development of wind energy resources and closer examination of the data from each radar site provides more site-specific information.

The radar site in Detroit, MI quantified several areas of high bird concentrations in the southeastern portion of the state (Figs. 8 and 9). These data suggest that the thumb region of Michigan (northeast portion of Fig. 8) does not support high densities of migrant songbirds during the spring migration. The first wind farm in Michigan was constructed in this area and additional wind farms have been proposed for development over the next several years. The overlap of acceptable conditions for wind farm development and lower spring migrant bird densities suggests that wind development in this area may result in fewer avian impacts than in other areas with higher avian densities. Contrary to

Table 4. The number of points and the number of days those points were significant migration concentrations in each 30-km band of NEXRAD data for KDTX (Detroit).

	10 - 40 km ring	40 - 70 km ring	70 - 100 km ring	> 100 km ring
Number of days	**Number of points**	**Number of points**	**Number of points**	**Number of points**
0	13776	32773	38764	49001
1	3150	6563	18912	5055
2	1112	1652	4928	912
3	466	393	1200	248
4	202	70	252	53
5	87	20	30	15
6	36	1	8	2
7	15	0	0	0
8	4	0	0	0
9	1	0	0	0
10	1	0	0	0

Table 5. The number of points and the number of days those points were significant migration concentrations in each 30-km band of NEXRAD data for KAPX (Grayling).

	10 - 40 km ring	**40 - 70 km ring**	**70 - 100 km ring**	**> 100 km ring**
Number of days	**Number of points**	**Number of points**	**Number of points**	**Number of points**
0	15335	27844	57960	50410
1	2615	9868	5053	4767
2	615	2336	766	109
3	169	649	203	1
4	45	269	48	0
5	34	154	38	0
6	19	89	1	0
7	4	48	5	0
8	4	49	0	0
9	3	43	0	0
10	7	55	5	0
11	0	21	5	0
12	0	25	5	0
13	0	11	0	0
14	0	6	0	0
15	0	4	0	0

Table 6. The number of points and the number of days those points were significant migration concentrations in each 30-km band of NEXRAD data for KGRR (Grand Rapids).

	10 - 40 km ring	**40 - 70 km ring**	**70 - 100 km ring**	**> 100 km ring**
Number of days	**Number of points**	**Number of points**	**Number of points**	**Number of points**
0	10125	32093	48256	34010
1	5933	6088	11027	11680
2	1934	1869	2925	6474
3	621	864	1094	2451
4	180	345	416	558
5	40	132	241	122
6	14	36	95	8
7	3	23	29	0
8	0	9	0	0
9	0	8	0	0

Table 7. The number of points and the number of days those points were significant migration concentrations in each 30-km band of NEXRAD data for KMQT (Marquette).

	10 - 40 km ring	**40 - 70 km ring**	**70 - 100 km ring**	**> 100 km ring**
Number of days	**Number of points**	**Number of points**	**Number of points**	**Number of points**
0	15599	38051	56899	53419
1	1993	2522	5986	1659
2	636	553	723	174
3	312	195	271	32
4	155	64	132	0
5	87	27	45	0
6	32	29	16	0
7	26	18	10	0
8	6	8	0	0
9	5	0	0	0
10	1	4	0	0

Table 8. The results of autocorrelation tests using Moran Index test determined that the areas of high bird concentrations were clustered in the landscape and not random.

	Moran's Index	**Expected Index**	**Variance**	**Z Score**	**Significance**
Detroit	0.084233	-0.000121	0.000000	271.791089	< 0.01
Gaylord	0.086995	-0.000287	0.000000	132.039487	< 0.01
Grand Rapids	0.061889	-0.000171	0.000000	155.544237	< 0.01
Marquette	0.136613	-0.000420	0.000000	112.088819	< 0.01

the thumb region of Michigan, the areas to the southwest and southeast of the radar site support higher densities of migrant songbirds. The southeastern portion of Figure 9 shows high concentrations of birds along the lacustrine and riverine corridors of Lake Erie, Lake St. Clair, and the Detroit River. Unlike the thumb region of Michigan, this is consistent with the belief that the Great Lakes' shorelines and other major water bodies concentrate migrating songbirds (Diehl et al. 2003, Ewert et al. 2005, Shieldcastle 2004, Bonter et al. 2008).

Additional valuable information was identified from the radar site in Grayling, MI (Fig. 10). While there are several areas of consistently high concentrations of migrant birds in the central portion of the northern Lower Peninsula, there are also concentration areas along the finger regions of the area (northwestern portion of radar scan). These data suggest that not only are the lakeshore areas important for migrant bird stopover sites, in particular peninsular areas, but they may also be important for birds in the flight and navigation process of migration. Several wind energy project have been proposed for this region of the Lake Michigan shoreline, as well as some of the islands shown in Figure 10.

The radar site in Grand Rapids, MI quantified many fairly dispersed bird migration concentration areas within the sweep of the radar unit (Fig. 11). However, the Lake Michigan shoreline supported consistent concentrations of migrant birds, identified by the yellow, orange, and red cells aligned with the shoreline. This provides the clearest example of an area where wind developers may consider buffering the Lake Michigan shoreline in an effort to minimize avian collisions. The areas of this radar scan that overlap with the Detroit radar also support the conclusion that the central portion of southern Michigan has high concentrations of bird migration (Fig. 12). Thus far, the central portions of Michigan have not been the focal point of many proposed wind farms.

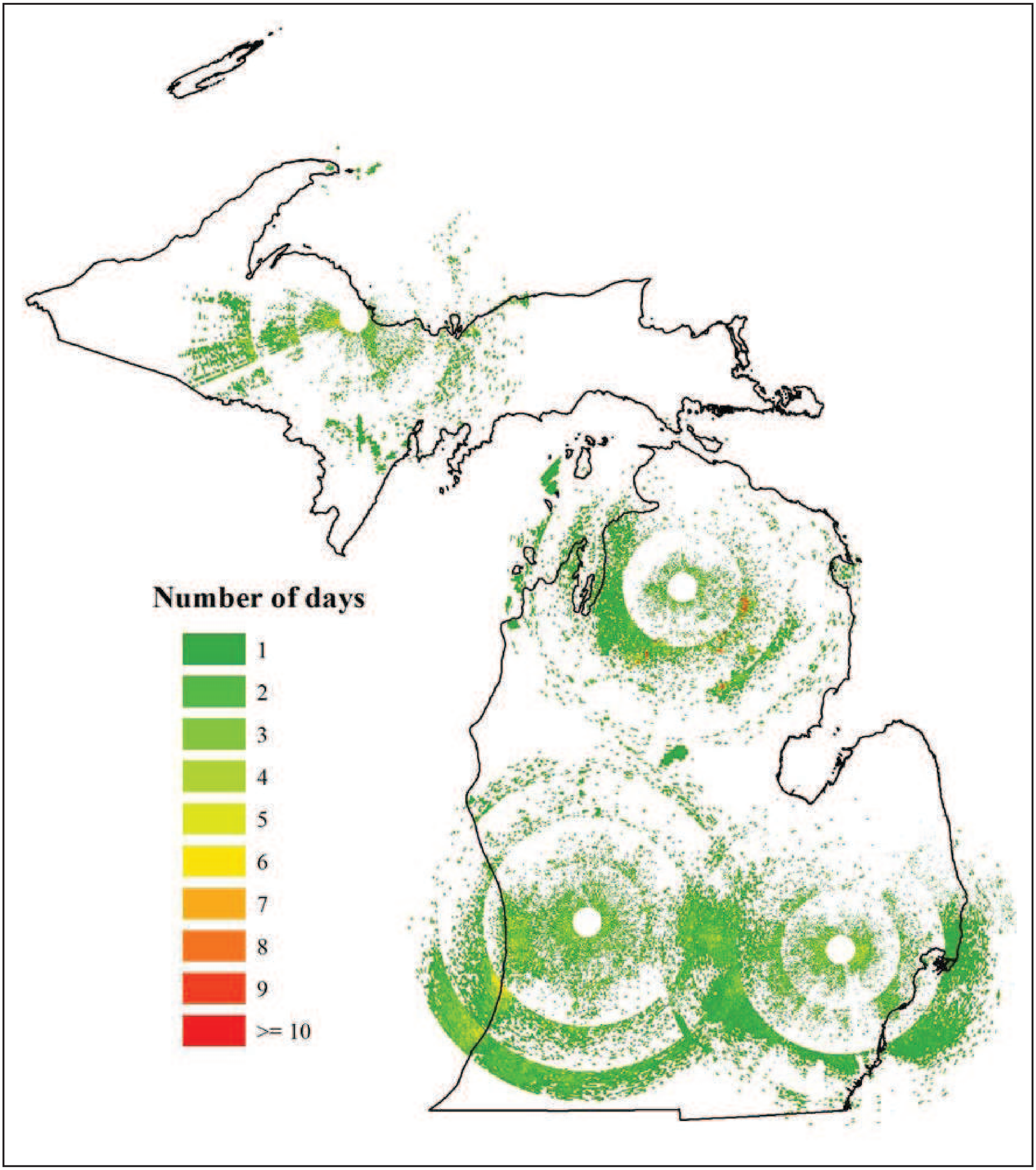


Figure 7. NEXRAD data from four Michigan radar sites in April and May 2008 identify areas with high concentrations of migratory birds over time.

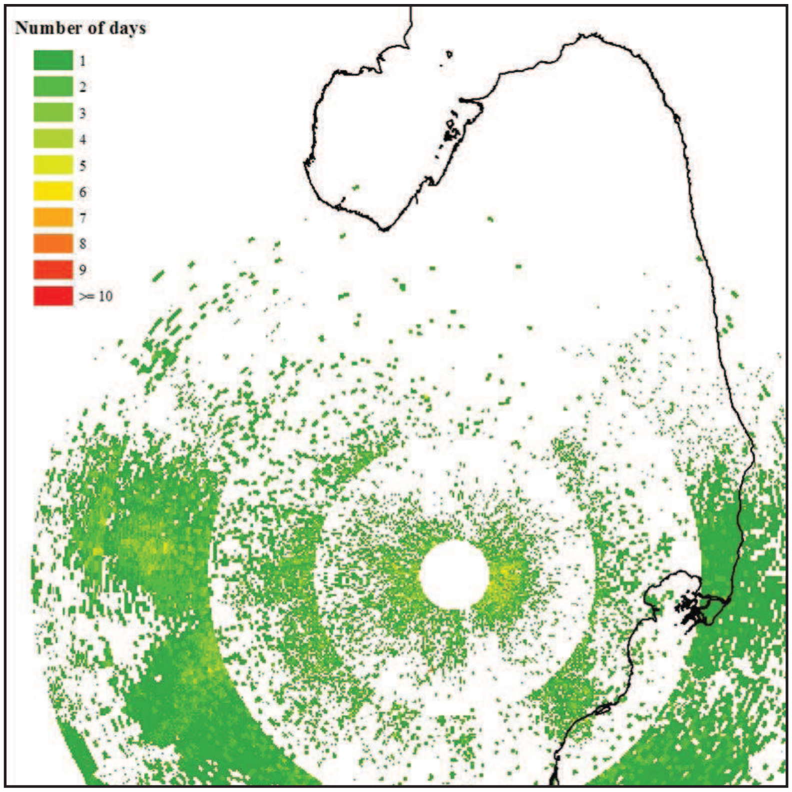


Figure 8. NEXRAD data from northern portion of the KDTX (Detroit) Michigan radar site in April and May 2008 identify areas with high concentrations of migratory birds over time.

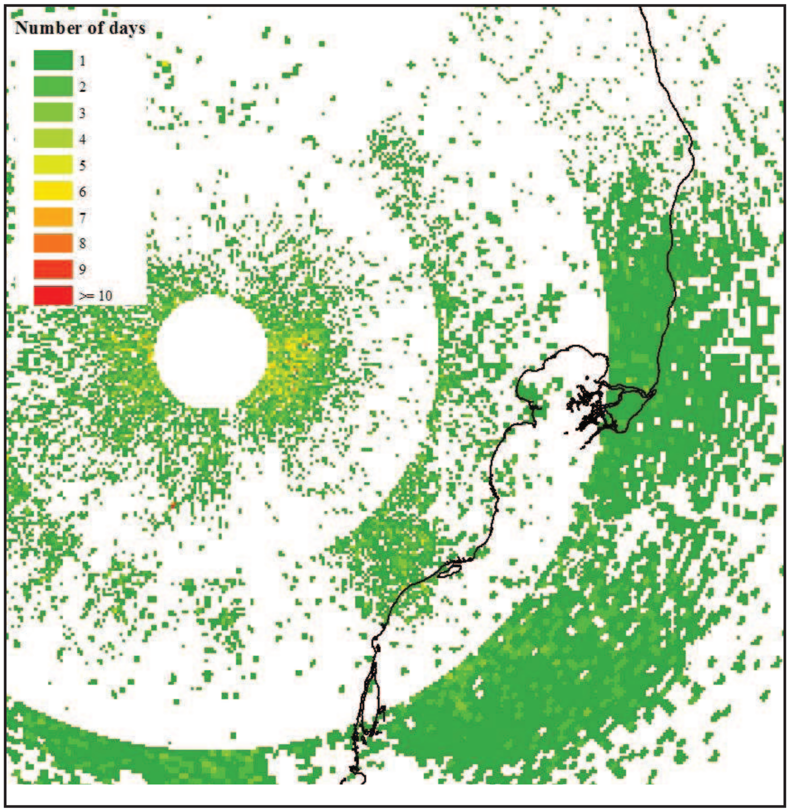


Figure 9. NEXRAD data from southern portion of the KDTX (Detroit) Michigan radar site in April and May 2008 identify areas with high concentrations of migratory birds over time.

The Marquette, MI radar site is not the most useful site for collecting NEXRAD radar ornithology data. The majority of the radar scan area appears to be blocked by topography or another source of interference. Diehl et al. (2003) experienced similar challenges and avoided using these data as well. In an effort to avoid basing management decisions on biased and/or incomplete data we only considered and evaluated data in the eastern-central portion of the radar scan (Fig. 13). While there are some cells with consistently high concentrations of birds it does not appear that these areas are aligned or associated with the Lake Superior lakeshore. The Upper Peninsula of Michigan currently has several proposed wind farms; however, they tend to be more focused in areas not included in this limited NEXRAD scan.

While this analysis can provide decision makers with important information, further research can increase its effectivity. The first improvement would be to increase the spatial resolution of the analysis. We utilized 30-km bands based on established work (Diehl et al. 2003). We feel that a finer resolution of information will be gained by decreasing the band width from 30 km to 20 km. A second improvement would be to include fall migration data in the analysis. It is possible that birds will move differently through the region based on seasonal weather conditions as well as changing the direction and route of their fall migration from their spring migration. A third improvement would be to include multiple years in the analysis to see if the same concentration patterns are observed over time. Finally, there is evidence that birds moving toward the radar or broadside to the radar tend to produce higher reflectivity than birds moving away from the radar site. If so, bird orientation could induce a bias in the analysis and will need to be addressed in further research.

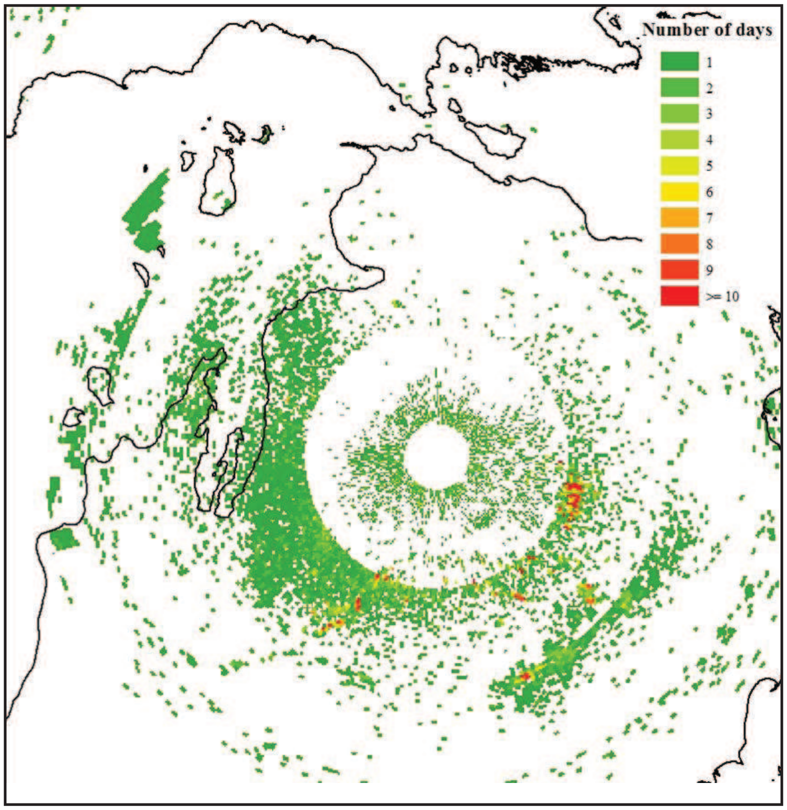


Figure 10. NEXRAD data from the KAPX (Grayling) Michigan radar site in April and May 2008 identify areas with high concentrations of migratory birds over time.

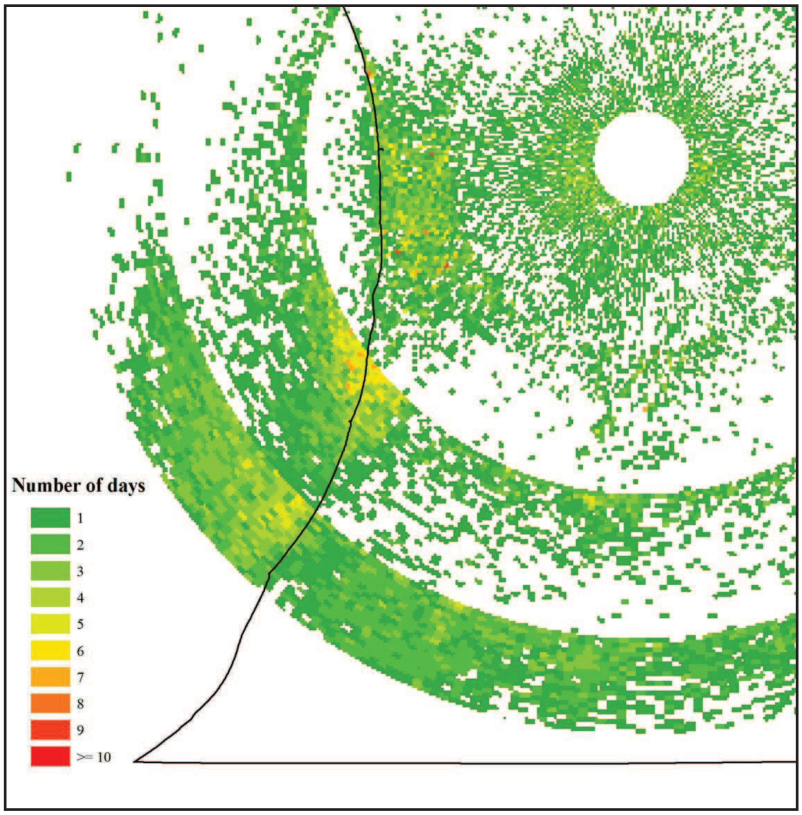


Figure 11. NEXRAD data from the for KGRR (Grand Rapids) Michigan radar site in April and May 2008 identify areas with high concentrations of migratory birds over time.

Figure 12. NEXRAD data from the KGRR (Grand Rapids) and the KDTX (Detroit) Michigan radar sites in April and May 2008 identify areas in the central portion of the state with high concentrations of migratory birds over time.

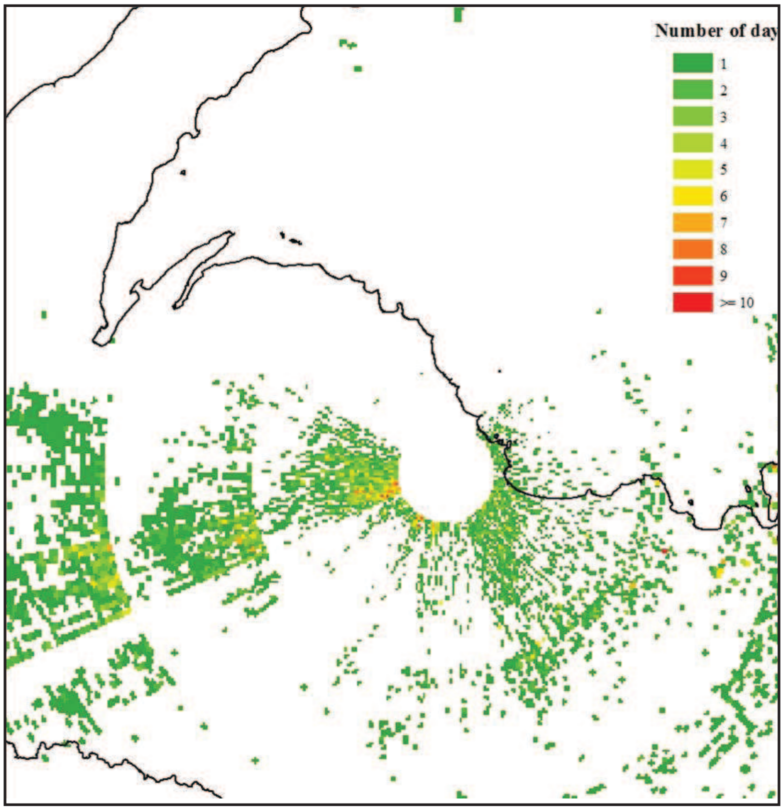


Figure 13. NEXRAD data from the KMQT (Marquette) Michigan radar site in April and May 2008 identify areas with high concentrations of migratory birds over time.

Policy and Management Implications

Federal and State alternative energy incentives and mandates are leading to an increased interest in wind farm development. While wind farms are laudable attempts to produce environmentally friendly energy, improper placement of wind farms can have unintended negative environmental consequences. Carefully planned placement of wind farms in the landscape must be considered to minimize their potentially negative environmental impacts.

The analysis presented here can be utilized at multiple spatial scales by policy makers, wind developers, local decision makers, and natural resource agencies to determine appropriate areas for wind farm development. Those areas with high concentrations of bird migration would be expected to have higher numbers of songbird fatalities than those areas with low concentrations of bird migration. By directing wind farm development to those areas with lower migration densities a potentially negative environmental impact of wind farms can be reduced.

With a better understanding of bird movements in relation to proposed wind energy development, policy makers and resource managers can better delineate appropriate areas for wind energy development. Given the importance of the Great Lakes region, especially coastal areas, to breeding and migrating Neotropical birds these data are critical to future management of landscapes as wind energy continues to supply an increasingly larger portion of our energy needs. While a good first step, further refinements to this analysis can provide better and more refined information to guide the decision making process.

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