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Characteristics of Important Stopover Locations for Migrating Birds: Remote Sensing with Radar in the Great Lakes Basin

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Abstract: *A preliminary stage in developing comprehensive conservation plans involves identifying areas used by the organisms of interest. The areas used by migratory land birds during temporal breaks in migration (stopover periods) have received relatively little research and conservation attention. Methodologies for identifying stopover sites across large geographic areas have been, until recently, unavailable. Advances in weather-radar technology now allow for evaluation of bird migration patterns at large spatial scales. We analyzed radar data (WSR-88D) recorded during spring migration in 2000 and 2001 at 6 sites in the Great Lakes basin (U.S.A.). Our goal was to link areas of high migrant activity with the land-cover types and landscape contexts corresponding to those areas. To characterize the landscapes surrounding stopover locations, we integrated radar and land-cover data within a geographic information system. We compared landscape metrics within 5 km of areas that consistently hosted large numbers of migrants with landscapes surrounding randomly selected areas that were used by relatively few birds during migration. Concentration areas were characterized by 1.2 times more forest cover and 9.3 times more water cover than areas with little migrant activity. We detected a strong negative relationship between activity of migratory birds and agricultural land uses. Examination of individual migration events confirmed the importance of fragments of forested habitat in highly altered landscapes and highlighted large concentrations of birds departing from near-shore terrestrial areas in the Great Lakes basin. We conclude that conservation efforts can be more effectively targeted through intensive analysis of radar imagery.*

Keywords: migration, migratory land bird, radar, stopover sites, WSR-88D

Características de Localidades de Escala Temporal para Aves Migrantes: Percepción Remota con Radar en la Cuenca de los Grandes Lagos

Resumen: *Una etapa preliminar en el desarrollo de planes de conservación integrales implica la identificación de áreas utilizadas por los organismos de interés. Las áreas utilizadas por aves terrestres migratorias durante escalas temporales en la migración (períodos de parada) han recibido relativamente poca atención de investigación y conservación. Hasta hace poco, las metodologías para la identificación de sitios de parada en áreas geográficas extensas han sido escasas. Ahora, los avances en la tecnología de radar meteorológico permiten la evaluación de patrones de migración de aves en escalas espaciales grandes. Analizamos datos de radar (WSR-88D) registrados en seis sitios en la cuenca de los Grandes Lagos (E.U.A.) durante la migración en las primaveras de 2000 y 2001. Nuestra meta fue relacionar áreas con gran actividad migratoria con*

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los tipos de cobertura de suelo y los contextos del paisaje correspondientes a esas áreas. Para caracterizar los paisajes circundantes a las localidades de parada, integramos los datos de radar y de cobertura de suelo a un sistema de información geográfica. Comparamos las medidas del paisaje en un radio de 5 km en las áreas que consistentemente albergaron a grandes números de migrantes con los paisajes circundantes a áreas seleccionadas aleatoriamente y que eran utilizadas por relativamente pocas aves durante la migración. Las áreas de concentración se caracterizaron por tener 1.3 veces más cobertura forestal y 9.3 veces más cobertura de agua que las áreas con poca actividad migratoria. Detectamos una fuerte relación negativa entre la actividad de las aves migratorias y los usos de suelo agrícolas. El examen de eventos migratorios individuales confirmó la importancia de los fragmentos de hábitat boscoso en paisajes muy alterados y resaltó las grandes concentraciones de aves partiendo de áreas terrestres cercanas a la costa en la cuenca de los Grandes Lagos. Concluimos que los esfuerzos de conservación pueden ser abordados más efectivamente mediante el análisis intensivo de imágenes de radar.

Palabras Clave: ave terrestre migratoria, migración, radar, sitios de escala temporal, WSR-88D

Introduction

Migratory birds spend approximately 25–33% of their annual cycle in transit between breeding and wintering areas. Survival challenges encountered on these journeys may be responsible for a majority of annual adult mortality in land birds (Sillett & Holmes 2002). Yet the habitat requirements of birds during migration have not been widely studied. Failure to include stopover habitat requirements in conservation planning may limit the utility of conservation programs that target other segments of the annual cycle. Identifying areas where birds concentrate between migratory flights is the first step toward integrating migration-habitat priorities into avian conservation plans. Analyzing radar data to identify migration stopover areas has been identified as a critical research need (Duncan et al. 2002).

Recent technological advances enable researchers to evaluate entire landscapes and identify areas where birds concentrate during migration (Gauthreaux & Belser 2005). Images from weather-surveillance radar (WSR-88D) display movements of migratory birds as energy from the radar beam comes into contact with birds in the atmosphere and is reflected back to the radar receiver. As birds climb into the sky at the onset of nocturnal migration, radar echoes from the birds map the areas from which they departed. Although individual species cannot be identified with radar, images have been used to reveal stopover concentration areas and to determine the quantity and flight direction of birds aloft (Gauthreaux & Belser 1998, 1999; Diehl et al. 2003). For example, stopover areas on the northern coast of the Gulf of Mexico have been mapped through analysis of WSR-88D imagery (S.A.G., unpublished data), and flight behavior and elevation have been studied with radar in the Great Lakes region (Diehl et al. 2003). We used this technology to identify stopover concentration areas in the Great Lakes basin. Furthermore, we tested for differences in land-cover characteristics between areas hosting large numbers of birds during stopover periods and areas hosting fewer migratory birds.

The relative importance of various areas and land-cover types to birds during migration remains relatively unknown. Previous research suggests that birds may concentrate near geographical barriers to migration, such as large bodies of water (Gauthreaux 1971; Agard & Spellman 1994). The Great Lakes are large geographical barriers to migration, and migrating land birds may concentrate in near-shore terrestrial habitats until weather conditions and their own energetic preparedness allow birds to continue migrating. Food availability may be greater in riparian, wetland, and near-shore habitats, where flying insects that reproduce in water may be more abundant (Smith et al. 1998). Furthermore, landmarks such as rivers and large lakes may be used in orientation and navigation, leading birds to stop at sites close to water. Thus, we hypothesized that concentration areas are located in regions with a greater amount of water and water-edge habitat than in the surrounding landscape.

In addition to proximity to water, forest cover is likely an important habitat feature of landscapes associated with concentration areas. The bulk of land-bird migrants in the Great Lakes basin are forest-breeding species migrating to (spring) or from (autumn) the largely forested habitats that characterize Canada north of the basin. If migrants are selective when choosing stopover sites (Barlein 1983; Ewert & Hamas 1996; Moore et al. 1995; Yong et al. 1998) and undertake morning flights following nocturnal migration in search of suitable areas (Bingman 1980; Wiedner et al. 1992), the radar should detect larger migration exodus events from forested landscapes.

Our objective was to inform conservation action on behalf of migratory birds by integrating WSR-88D imagery with land-cover data in order to link areas of high migratory-bird activity with the corresponding land-cover and landscape characteristics.

Methods

Radar Analyses

We analyzed WSR-88D imagery from 6 radar stations in the Great Lakes basin to identify areas of concentrated bird activity during spring migration in 2000 and 2001. Radar stations were located near Buffalo, New York; Cleveland, Ohio; Alpena, Michigan; Grand Rapids, Michigan; Chicago, Illinois; and Milwaukee, Wisconsin. We included images recorded from 20 April to 31 May in each year in the analyses.

The WSR-88D is an *S*-band radar (10–11 cm wavelength) with a range of 230 km and a resolution of 0.96° by 1 km (pulse volume). The effective range of the WSR-88D for observing birds departing stopover sites is approximately 120 km (Gauthreaux & Belser 1998). Technical details and specifications of the WSR-88D are in Crum and Alberty (1993).

Radar (an acronym for radio detection and ranging) involves the transmission, propagation, scattering, and reception of electromagnetic waves. When energy transmitted by radar comes into contact with an object in the atmosphere, a portion of that energy is reflected back to the radar receiver. The returned energy is known as reflectivity. The greater the density of targets in the atmosphere, the greater the value of reflectivity recorded from that location. For the purposes of monitoring bird movements with radar, greater reflectivity values are related to greater numbers of birds (Gauthreaux & Belser 1998, 1999). Distinguishing bird activity from other biological activity such as the movements of insects and bats, however, can be difficult. The reflectivity value shown in a radar image actually represents a combination of bird and nonbird targets. Discussion of imagery in this study frequently refers to bird activity alone. Nevertheless, the images likely included some nonbird biological activity as well.

The WSR-88D completes scans of the atmosphere every five minutes in precipitation mode and every 10 minutes in clear-air mode. The radar operates in clear-air mode when no precipitation above a threshold level is detected within 230 km of the radar. We limited our analyses to nights when the radar devices were operating in clear-air mode.

All WSR-88D images recorded within 120 minutes following sunset were evaluated for activity of migratory birds. On nights with bird movements, these images displayed the exodus of migrants from stopover sites at the beginning of their nocturnal flight (Gauthreaux et al. 2003). We examined approximately 15 images from each day of the 45-day migration seasons for each of the sites.

Migratory birds can be distinguished from other targets in the atmosphere by the pattern of the reflected images, the speed of the targets relative to the winds aloft, and the direction of movement (Gauthreaux et al. 2003). We analyzed three WSR-88D products to distinguish bird-related activity from other (nonbird) targets in the atmosphere: base reflectivity, base velocity, and velocity-azimuth display images.

The WSR-88D base reflectivity images quantified the relative density of objects in each pulse volume (Fig. 1a). When displaying movement of migratory birds at the onset of nocturnal migration, base reflectivity images mapped the areas from which birds were departing. In images displaying a migration exodus, areas with the highest reflectivity values likely hosted the greatest numbers of birds.

The WSR-88D base velocity images indicated the velocity and direction of movement of objects (Fig. 1b). Birds were assumed to generally move in a seasonally appropriate direction (north in spring) at speeds greater than the velocity of winds aloft.

Velocity azimuth display (VAD) imagery provided estimates of the direction and velocity of winds aloft at 305-m intervals every 10 minutes. These radar-based estimates were generated from the movements of objects in the atmosphere. During a migration exodus event, bird movements detected by VAD imagery can be falsely interpreted as changes in the velocity or direction of winds aloft. Migratory-bird movements were indicated by increases in the speed and shifts in the direction of movement recorded by the VAD imagery during an exodus event.

We compared estimates of speed and direction of winds generated by WSR-88D VAD imagery with estimates generated from radiosonde data collected near each radar location each evening. A radiosonde is a balloon-borne instrument platform used to record atmospheric conditions, including the speed and direction of winds at various levels in the atmosphere. Thus, radiosonde data provided independent measures of the speed and direction of winds aloft that were not influenced by bird activity.

Base reflectivity images from each site were visually inspected to identify possible bird migration events. Corresponding base velocity and VAD images were then examined to confirm or reject the presence of bird activity. A base reflectivity image was rejected if the corresponding base velocity image indicated the velocity of movement was <10 m/s. This was assumed to be a minimal flight speed for most bird species, assuming birds did not fly into a strong headwind (Åkesson et al. 2002). Base reflectivity images were also rejected if the speed of movement indicated by the base velocity imagery was approximately equivalent to the speed of the winds aloft as indicated by radiosonde data. If the objects were traveling at velocities <10 m/s or if the recorded velocities of the objects and the winds aloft were equivalent, objects detected by the radar were unlikely to be birds.

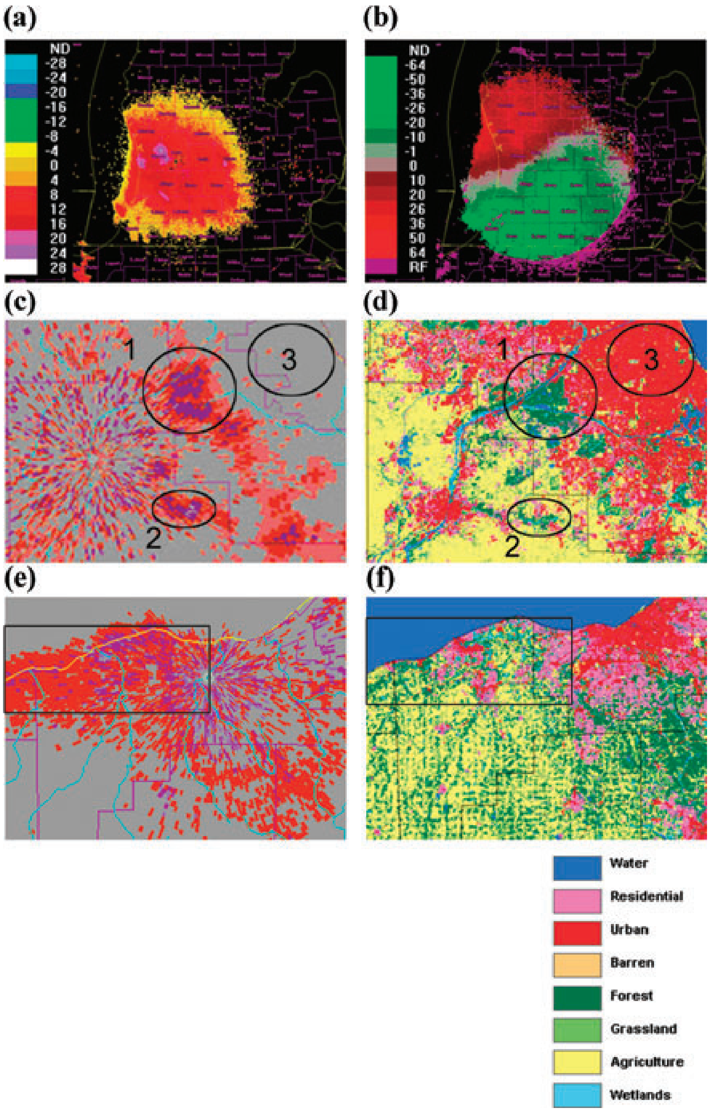

Figure 1. (a) WSR-88D base reflectivity image recorded at the Grand Rapids, Michigan, site on the evening of 20 May 2001 (radar site, center of image; patterns surrounding radar site, a bird migration event; color-coded scale, levels of reflectivity [dBZ scale, the higher the number the more birds departing from an area]; dark red and purple, areas of high concentrations). (b) The WSR-88D base velocity image recorded at the Grand Rapids, Michigan, site on the evening of 20 May 2001 showing the speed and direction of movement of objects displayed on the base reflectivity image (a) (color-coded scale, speed and direction of movement of objects relative to the radar; green, negative velocities [i.e., objects moving toward the radar location in the center of the image]; red, positive velocities [objects moving away from the radar site]; gray between green and red, zero velocity [objects moving perpendicular to the radar beam]). Image indicates movement to the north-northwest. (c) Migration exodus recorded on the Chicago, Illinois, radar and (d) the corresponding land-cover information (imagery recorded 13 May 2001). Concentration areas (labeled 1 and 2 in [c]) correspond with islands of forested habitat (areas 1 and 2 in [d]). Area 3 is the highly urbanized Chicago region. (e) Migration exodus recorded on the Cleveland, Ohio, radar and (f) the corresponding land-cover information (imagery recorded 30 April 2001; rectangle, south shore of Lake Erie).

GIS Analyses

For each evening with confirmed activity of migratory birds, one base reflectivity image from an early stage of the migration exodus was selected for further analysis. In an effort to pinpoint the areas from which the birds were departing, we selected the first image showing significant migrant activity during each exodus event. For each site, we merged these exodus images (n = 6–9 images/site) in ARC GIS (version 8.2) to create a single composite image. Composite images represented mean reflectivity values. This process, therefore, highlighted areas that consistently hosted large numbers of birds during migration throughout the study area.

We identified areas with the highest mean reflectivity values on the composite imagery as concentration areas. We then recorded the coordinates of the geographic center of each concentration area. For each composite scene, we randomly selected between 5 and 8 concentration areas, separated by a minimum of 10 km, for analysis of land-cover characteristics. Concentration areas were paired with randomly selected areas showing relatively little bird activity (nonconcentration areas). Because an inverse relationship existed between reflectivity values and distance from the radar location, paired concentration and nonconcentration areas were created at the same distance from the radar site in an attempt to minimize sampling biases.

We integrated National Land Cover Data (NLCD) derived from Landsat Thematic Mapper satellite imagery with the radar data in ARC GIS to permit analyses of the landscape structure and composition within 5 km of each concentration and nonconcentration point. The NLCD (mean date = 1992) categorized cells following a 21-class land-cover classification scheme applied consistently across the United States. The spatial resolution of the NLCD was 30 m^2, and maps were projected in Albers Conic Equal Area projection, NAD 83 (Vogelmann et al.

Table 1. Land-cover classification scheme derived from the categories available in the National Land Cover Data (NLCD) and used to quantify landscape characteristics surrounding concentration and nonconcentration sites.

Classification	*Description*
Water	all areas of open water with 25% or greater coverage per cell (NLCD categories 11 and 12)
Residential	mixture of developed areas and vegetation; developed areas account for 30–80% of land cover; typically areas of single-family housing units (NLCD category 21)
Urban	developed areas account for 80–100% of land cover; includes apartment complexes, large buildings, most urban areas, and infrastructure (NLCD categories 22 and 23)
Barren	perennially barren areas including rock, desert, quarries, strip mines, and beaches (NLCD categories 31, 32, and 33)
Forest & shrub	characterized by tree cover; canopy typically accounts for 25–75% of cover; includes deciduous, evergreen, and mixed forest, shrub land, and orchards (NLCD categories 41, 42, 43, 51, 61)
Grassland	dominated by upland grasses and forbs (NLCD category 71)
Agriculture	characterized by herbaceous vegetation that has been planted and intensively managed; includes pasture, row crops, grain fields, fallow fields, and intensively managed urban areas such as golf courses (NLCD categories 81–85)
Wetlands	soil or substrate is periodically saturated with or covered with water; includes woody wetlands and emergent herbaceous wetlands (NLCD categories 91, 92)

1998*a*, 1998*b*). To reduce the number of land-cover assignments, we combined several categories (Zhu et al. 2000). For example, all forest categories were combined such that a forested cell was simply a cell dominated by trees, which included the shrub, deciduous forest, evergreen forest, mixed forest, second-growth, and orchard classifications from the original NLCD. The resulting land reclassification created eight land-cover categories (water, residential, urban, barren, forest, grassland, agriculture, and wetlands, Table 1).

Points identified for analyses from the radar imagery were plotted on the NLCD maps within ARC GIS. These points were then encircled by a 5-km radius buffer. This radius was selected because radar imagery could identify only the locations of birds as they intersected the radar beam, not their exact point of departure. Thus, some displacement occurred between the true stopover sites and the areas mapped by the radar. The true locations of concentration areas likely fell within these 5-km-radius landscapes, and analyses at this scale allowed examination of the land-cover characteristics that may influence stopover site selection.

Land-cover data corresponding to the buffered areas were exported to Fragstats (version 3.3) for analysis. Fragstats software was designed to analyze spatial patterns and to quantify landscape structure (McGarigal et al. 2002). We used the software to generate information on the size and spatial relationships of patches of each land-cover type across each landscape. Measures generated by Fragstats were exported to SAS (version 8.02, SAS Institute 1998) for further analyses.

Statistical Analyses

To quantify landscape structure, we selected 3 land-cover measures generated by Fragstats: PLAND (proportion of the landscape in each land-cover class), TE (absolute measure of total edge length of each land-cover type), and CPLAND (core proportion of the landscape farther than 30 m from the patch perimeter for each cover type). We also selected 2 measures of diversity at the landscape scale. Shannon's diversity index is a measure of diversity in community ecology, and we applied it here to measure the diversity of land-cover types in the landscapes. Shannon's evenness index was used to measure the distribution of land-cover types in the landscapes. Higher diversity and evenness scores indicated landscapes that were more diverse in composition.

We tested for differences in the measures generated by Fragstats by area type (concentration or nonconcentration). These analyses, therefore, provided information on site-to-site differences in land-cover characteristics and allowed for comparison of the land-cover and landscape characteristics surrounding concentration and nonconcentration points across the Great Lakes basin. Analyses were conducted with PROC GLM in SAS; least squares means are reported.

Results

Stopover concentration areas were readily identifiable in exodus images from each radar location. Qualitatively, close inspection of exodus images revealed the importance of islands of forested habitat in largely developed and agricultural landscapes, as well as the importance of areas in close proximity to the shores of the Great Lakes. For example, exodus imagery from the Chicago radar site clearly linked migratory-bird activity to fragments of forested habitat in a largely urban and agricultural landscape. Large numbers of birds were recorded departing forest fragments (e.g., areas 1 and 2 in Figs. 1c & 1d). In contrast, few birds departed from the urbanized areas northeast of the radar site (e.g., area 3 in Figs. 1c & 1d), and not many birds departed from the largely agricultural landscapes west of the radar site. Although a mix of urban, forest, and agricultural lands characterized the landscape covered by the Chicago imagery, forested components of the landscapes were clearly the critical stopover areas for migrating land birds.

Exodus imagery from Cleveland demonstrated the "barrier" formed by Lake Erie, showing large numbers of birds departing from near-shore areas on the south shore of the lake (Figs. 1e & 1f). During this exodus event, nearly all migrant activity was located within 10 km of the south shore of Lake Erie, with birds departing from the mix of land-cover types (mostly forest, wetland, and residential) in near-shore areas (Figs. 1e & 1f).

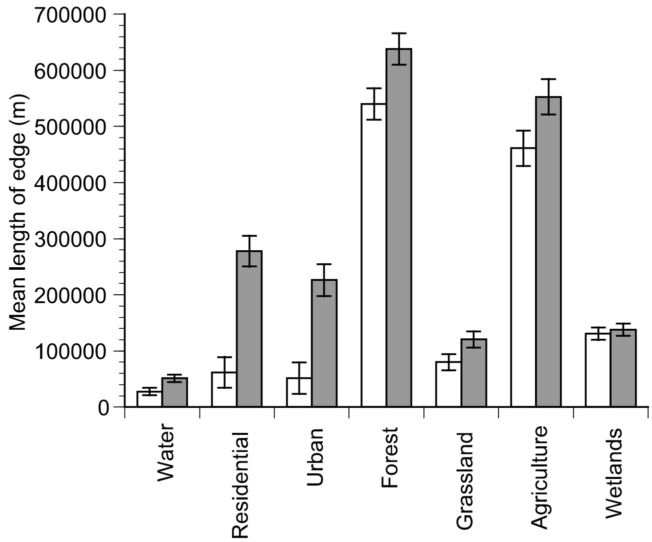

Figure 3. Mean length of edge of various land-cover types for landscapes surrounding areas used by large concentrations of migratory birds (gray bars) and areas used by relatively few birds during stopover periods (open bars). Least-squares means standard errors are reported.

Characteristics of Concentration Areas and Nonconcentration Areas

In an effort to quantify landscape characteristics of areas hosting large concentrations of migrants, we used 45 individual exodus events to generate composite images for 6 radar locations. Eighty points from the 6 composite images were identified for landscape analyses (40 concentration, 40 nonconcentration).

Water comprised a greater proportion of the landscapes surrounding concentrations of migrant activity (12.1% of the total land cover) than landscapes surrounding nonconcentration areas (1.3% of land cover; Fig. 2; $F_{1,68} = 23.28$; $p < 0.001$). The amount of core water area within the landscape (i.e., large water bodies such as lakes) was approximately 15 times greater in areas with high levels of migrant activity than in areas hosting relatively few migrants ($F_{1,68} = 21.69$; $p < 0.001$). The length of water edge was nearly 2 times greater in landscapes surrounding concentration areas than in landscapes surrounding nonconcentration areas (Fig. 3; $F_{1,68} = 6.68$; $p = 0.012$).

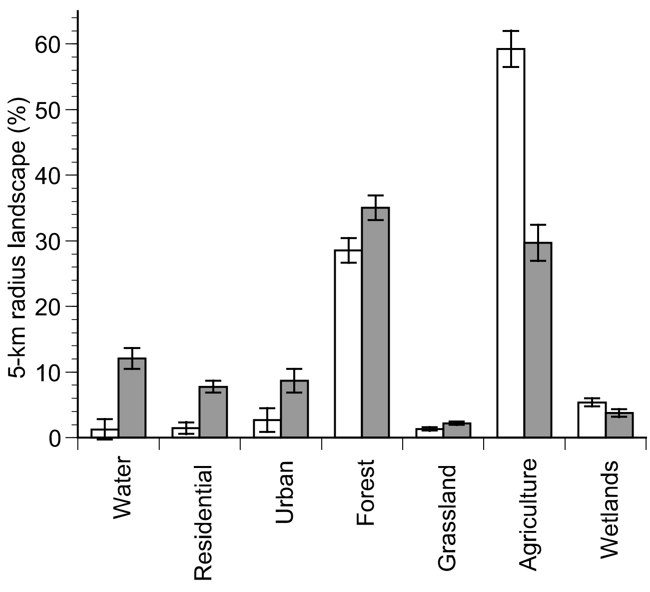

Figure 2. Mean percentage of each land-cover type within landscapes surrounding areas used by large concentrations of migratory birds (gray bars) and areas used by relatively few birds during stopover periods (open bars). Least-squares means and standard errors are reported.

The proportion of forest in the landscape was greater in concentration areas than in nonconcentration areas (Fig. 2; $F_{1,68} = 6.05$; $p = 0.017$). On average, landscapes surrounding concentration areas contained 1.23 times more forested land than did landscapes surrounding nonconcentration areas. Although areas hosting large numbers of birds were located in landscapes with a higher proportion of forest, the patches of forest within these landscapes were not necessarily large. Differences in the mean area of core forested lands between concentration areas (22% of the landscape) and nonconcentration areas (17% of the landscape) were not substantial ($F_{1,68} = 3.21$; $p = 0.078$).

In contrast to water and forest cover, the proportion of the landscape used for agricultural activities was negatively related to the activity of migratory birds (Fig. 2; $F_{1,68} = 57.67$; $p < 0.001$). Agricultural land uses characterized twice as much of the landscapes surrounding nonconcentration areas than landscapes surrounding concentration areas (59 and 30%, respectively).

The remaining land-cover types comprised a relatively small portion of the landscapes, with residential, urban, barren, grassland, and wetland cover types each representing <9%, on average, of the landscapes surrounding the points.

Landscapes surrounding concentration areas were more diverse than landscapes surrounding areas with relatively little migratory-bird activity (Shannon's diversity index, $F_{1,68} = 47.25$; $p < 0.001$). Furthermore, Shannon's evenness index indicated concentration areas were less likely to be dominated by a few land-cover types than nonconcentration areas ($F_{1,68} = 48.25$; $p < 0.001$). The total amount of edge habitat was greater in landscapes surrounding concentration areas than nonconcentration areas (Fig. 3). Because agriculture production is the dominant land use in the basin (44% of all landscapes analyzed), areas with greater diversity were generally characterized by a relatively low amount of agricultural activity.

Discussion

Conservation efforts that focus on stopover habitat for migratory birds can best be informed by examining radar imagery on a site-by-site basis, which leads to identification of key stopover sites that may warrant management attention. Nevertheless, analyses of composite imagery from sites throughout the Great Lakes basin can provide general rules regarding the landscape characteristics associated with the activity of migratory birds during stopover periods. Namely, birds appear to be selecting forested areas and areas in close proximity to water. Birds also appear to avoid agricultural landscapes during stopover periods.

Assuming that the bulk of the migrants passing through the Great Lakes basin were forest-obligate species, we predicted that concentration areas would be located in forested landscapes. Indeed, forest cover was positively associated with concentrations of migrant activity. Nevertheless, residential and urban areas were also positively associated with concentrations of migratory birds (Fig. 2). This result could be due to the confounding of urbanization and proximity to water because urban areas in the basin tend to be located near the Great Lakes. Alternatively, birds may actually be selecting developed areas during migration. Residential areas with parks, gardens, and landscaped yards may meet the requirements of migrants during stopover, particularly in agricultural landscapes with little natural vegetation.

Although forest cover was positively associated with concentration areas, the size of the individual forest patches within the landscape was not identified as a significant factor distinguishing concentration areas from nonconcentration areas. Thus, migrants may not prefer large blocks of forest over fragments during stopover periods. Although our results showed that birds used fragments of forested habitat, we could not assess the relative value of edge and interior forest habitat. Intensive, ground-based surveys are required to identify fine-scale differences in habitat use because the interface between forested and other habitats may provide important resources during stopover periods (e.g., Rodewald & Brittingham 2004). Investigating the quality of edge and interior areas, in terms of survival probabilities and rates of mass gain during stopover, remains a research priority (Bonter et al. 2007).

We predicted that water would comprise a greater proportion of the landscape surrounding concentration areas than surrounding nonconcentration areas, and this prediction was supported by the data. Nevertheless, the mechanisms behind this pattern remain unclear. Large bodies of water may function as a temporary barrier to migration, forcing birds to concentrate in near-shore areas (Gauthreaux & Belser 1998). Birds may also concentrate near water in search of food resources (Smith et al. 1998). Migratory birds may use river basins and large bodies of water as landmarks to assist in navigation, leading to concentrations in riparian and near-shore areas. And, these possible mechanisms are not mutually exclusive. Furthermore, the coarse resolution of the radar and land-cover data sets prevents fine-scale assessment of the importance of narrow riparian corridors and small wetlands to land birds during migration. Field studies are also required to elucidate the importance of these riparian areas (Rodewald & Matthews 2005) and of spatially limited areas that may be critical to the successful migration of specialized species (e.g., wetland or grassland birds).

WSR-88D and Conservation Planning

Radar technologies can help inform conservation plans, but numerous issues must be considered when interpreting radar imagery (Schmaljohann et al. 2008). Challenges confronting the use of this technology include the inability to identify species seen on the radar, coarse resolution of the radar, displacement from true stopover locations, and detection of nonbird targets. Future research is needed to refine these remote-sensing tools (Gauthreaux & Belser 2003, 2005). Despite the limitations of WSR-88D, however, this technology provides an enormous amount of information regarding migration patterns at large spatial scales. Complementing WSR-88D data with data from higher-resolution mobile radar devices, acoustic recordings of nocturnal flight calls, and intensive ground-based research will further elucidate some remaining mysteries of stopover ecology (Gauthreaux & Belser 2003). Combined, these methodologies can better inform the conservation-planning process if WSR-88D data are used to initially define stopover concentration areas within which subsequent, intensive research is conducted.

Broadly speaking, areas of high migrant activity were positively associated with water and forest cover and negatively associated with agricultural land uses throughout the Great Lakes basin. Nevertheless, analysis of imagery on a site-by-site basis is key for informing conservation action. Radar evidence clearly demonstrated that remnants of forested habitat in a highly altered landscape can function as staging areas for land birds between migratory flights. In addition, radar data have been validated by intensive ground-based research (Russell et al. 1998; Brawn & Stotz 2001). Preserving islands of natural habitat in developed and agricultural landscapes should be a priority for conservation plans addressing the stopover requirements of migratory land birds. The WSR-88D data can be useful for identifying such areas.

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