ASSESSING WILDLIFE HABITAT CONTRIBUTIONS OF GREEN ROOFS IN URBAN LANDSCAPES IN MICHIGAN AND ILLINOIS, U.S.A.: MEASURING AVIAN COMMUNITY RESPONSE TO GREEN ROOF FACTORS

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ABSTRACT

ASSESSING WILDLIFE HABITAT CONTRIBUTIONS OF GREEN ROOFS IN URBAN LANDSCAPES IN MICHIGAN AND ILLINOIS, U.S.A.: MEASURING AVIAN COMMUNITY RESPONSE TO GREEN ROOF FACTORS

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Wildlife habitat degradation is a leading cause of biodiversity loss, and largely attributed to urbanization. Green roofs (vegetated roofs) have been identified as a technology having potential to provide wildlife habitat in urban areas by creating vegetation types. Vegetation structure and composition and green space cover were quantified for 12 green roofs and their surrounding landscapes in Michigan and Illinois in 2010 and 2011. Most vegetation variables, including vegetation height and herbaceous cover, were significantly different between intensive green roofs (0-15cm planting media depth) and extensive green roofs (>15cm planting media depth). Herbaceous cover was the dominant cover type on all green roofs. Shrub cover was present on extensive and intensive roofs, and tree and turf cover were only present on some intensive roofs. Green space analysis showed future green roof installations could increase green space area >300% in landscapes immediately surrounding study sites. Twenty-five non-invasive, native bird species were detected on green roofs, and the mean estimated species richness for each green roof (within the range of 36-40 species) was greater than in surrounding landscapes. Our results support the idea that green roof vegetation can contribute to wildlife habitat in urban areas and increase space for wildlife conservation. This information should encourage collaboration of green roof designers and natural resource managers to advance green roof installations towards holistic environmental sustainability that includes wildlife conservation.

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INTRODUCTION

Wildlife managers, land planners, environmental designers, and policy makers increasingly face challenges incorporating wise management of natural resources with the demands of urban areas. Currently over half of the global population lives in urban areas, and it is projected that by 2050 over 6 billion of the world's 9 billion inhabitants will live in urban environments (Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, 2007). As developed areas replace green space, urban environmental quality generally decreases and can negatively affect human health and native plant and wildlife communities (Frumkin, 2002; Grimm et al., 2008; McKinney, 2008). One potential design strategy to minimize urban associated problems is establishing vegetation on roofs, also known as green roofs (Green Roofs for Healthy Cities, 2009). Wildlife managers, land planners, environmental designers, and policy makers tasked with improving human health and environmental quality in urban areas need to enhance their understanding of how green roofs can contribute to biodiversity and wildlife habitat conservation.

The effects of urbanization can impact wildlife species and communities directly and indirectly (Crooks and Soulé, 1999; Bierwagen, 2007; Evans et al., 2009). Development in urban areas can be destructive to natural communities; wildlife habitat is often degraded and fragmented by roads and lawns (Forman, 2000; Keller and Largiader, 2003), groundwater recharge is prevented by impermeable pavement (Rose and Peters, 2001; Walsh et al., 2005; Feminella and Walsh, 2005), and concentrated pollutants are discharged into the air and water (Relyea, 2005). These actions collectively and individually degrade wildlife habitat quality for many native species (Michigan Natural Features Inventory, 2007). Rapid global population growth compounds these issues, causing biodiversity loss, and places environmental degradation at the forefront of conservation and human survival issues around the world (Pimentel et al., 2007; McMichael et al., 2008).

Conservation practices in urban and suburban areas promote wildlife by managing environments that allow ecosystem function to prevail. Even though restoration of native vegetation and wildlife may be impossible after long-term, intense land disturbances (Bakker and Berendse, 1999), environmental remediation projects can return vegetation similar to predevelopment conditions. Planted vegetation can increase species richness and abundance of wildlife (Waltz and Covington, 2004). Green corridors through and between urban areas, such as Emscher Valley in Germany, can transform lands in abandoned industrial areas into greenways for birds and insect communities (Seams, 1995; Miyagi, 2005; Hough, 2007). Human-made corridors can benefit wildlife by creating connections between natural areas (Kohut et al., 2009); however, depending on corridor placement and size, vegetation can also disrupt and fragment landscapes for wildlife movements and ecological processes (i.e., reduction in relative abundance for forest-nesting birds near mowed grass corridors that intersect forest vegetation; Rich et al., 1994). Implementation of green roofs has potential to provide many of the same benefits of other restoration techniques without fragmenting existing vegetation.

Humans have long benefited from green roofs. Traditional Scandinavian sod roofs regulated extreme seasonal temperatures (Peck et al., 1999; Coffman and Davis, 2005; Getter and Rowe, 2006), and in 1914 a green roof was constructed in Switzerland on a water filtration plant to control water temperature (Brenneisen, 2006). Green roofs also have the ability to lessen the urban heat island that causes serious heat related health issues such as heat stroke and asthma (Frumkin, 2002; Banting et al., 2005; Getter and Rowe, 2006). The soil and vegetation of green roofs insulates and shades buildings, which regulates internal temperatures, reduces energy used for heating and cooling (Getter and Rowe, 2006; Oberndorfer et al., 2007; Getter et al., 2011), and increases longevity of roofing membranes that result in fewer roofing materials in landfills (Rowe, 2011). Green roof vegetation also intercepts and filters air pollution (Currie and Bass, 2008) and counteracts carbon dioxide emissions through carbon sequestration (Getter et al., 2009). Green roof vegetation and substrates absorb and filter water, which reduces urban stormwater run-off and improves water quality (Peck et al., 1999; Getter and Rowe, 2006; Getter et al., 2007). Green roofs also offer mental health benefits such as noise reduction and therapeutic views (Frumkin, 2001; Oberndorfer et al., 2007; Van Renterghem and Botteldooren, 2009).

The organization Green Roofs for Healthy Cities acknowledges that even though the tangible benefits of green roofs are not fully valued by the current market, researching these benefits can help advance green roof technologies to the forefront of high performance green building design, implementation, and maintenance (Green Roofs for Healthy Cities, 2011). Comprehensive study of the effect of green roofs on surrounding landscapes and values to biodiversity conservation will allow government and private sector officials, policy makers, green roof designers, and natural resource managers to make informed decisions about how to better implement green roof management strategies and large scale urban planning.

Bird and plant communities can be significant components of biodiversity in urban landscapes. Green roofs may provide habitat for birds in urban landscapes because of the additional green space and fewer disturbances on roof surfaces than at ground level. Nesting attempts by ground nesting birds have been observed on green roofs (Baumann, 2006; Brenneisen, 2006), as have communities of rare and endangered insects affected by land use changes (Jones, 2002; Kadas, 2006). European green roofs designed to promote biodiversity have shown increases in beetle colonization rates, demonstrating the potential for conservation success in green roof designs (Brenneisen, 2006). Also, native grasslands, a rare plant community, can be developed on green roofs without heavy demands on building weight restrictions and structure (Oberndorfer et al., 2007).

Native grasslands in North America, which provide critical habitat to many grassland bird species, have been reduced by at least 80% due to land use conversion and urbanization and are the most threatened and degraded vegetation type in North America (Samson and Knopf, 1994; Herkert et al., 1996; Jones and Bock, 2002). Grassland birds are sensitive to land use conversion (Winter and Faaborg, 1999; Johnson and Igl, 2001; Jones and Bock, 2002) and have exhibited the most consistent, widespread, and rapid declines of any North American bird group (Herkert et al., 1996). Perturbations on native grasslands and other early successional vegetation types can affect landscape connectivity and disrupt ecological processes, such as dispersal or migration (Weber et al., 1999; McCallum and Dobson, 2002; Bierwagen, 2007). Many grassland bird species that have declined in abundance and distribution because of urbanization (Herkert et al., 1996) have the potential to benefit from green roofs (Brenneisen, 2006).

Several factors of green roof design may influence the conservation value of green roofs. Semi-intensive and intensive roofs have deeper substrates than extensive roofs (e.g., generally >15cm, compared to <15; Rowe, 2011) and potentially support a greater range of vegetation conditions that likely contribute more to biodiversity conservation. Placement of green roofs within the landscape matrix may have varying degrees of conservation value dependent on whether placement, size, or quantity of green space patches through urban landscapes is more influential on connectivity of bird populations (Keitt et al., 1997; Donnelly and Marzluff, 2006;

Prugh et al., 2008). A series of green spaces could create a greenway for birds, insects, bats, and other wildlife that perceive habitat from the air (Brenneisen, 2006). Most green roofs are elevated above ground level, which could minimize the effects of ground predators on bird communities (Renfrew et al., 2005; Vergara and Hahn, 2009) and create additional nest and foraging sites that would be beneficial to bird conservation.

The first chapter of this thesis describes and quantifies conditions present on green roofs in Michigan and Illinois, U.S.A. The vegetation characteristics and composition and building structure characteristics are quantified and examined for how they could provide contribute to wildlife habitat, specifically for bird communities. The second chapter quantifies bird community structure and composition on green roofs and the relationships between bird communities and green roof characteristics. These chapters provide information that can be used to design, manage, and create policy promoting green roofs that will benefit wildlife in urban areas.

OBJECTIVES

The following are the objectives of this project:

1) Quantify the composition of bird communities on green roofs and in surrounding landscapes.

2) Quantify the vegetation structure and composition of green roofs and surrounding landscapes and their influence on bird abundance and community composition.

3) Characterize the relationships between green roof and landscape structure on the relative abundance and species composition of bird communities associated with green roofs and the surrounding landscape.

4) Make recommendations for green roof design, composition, and management in relation to the existing landscape context to improve ecosystem function and wildlife habitat quality.

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CHAPTER 1

VEGETATION CHARACTERISTICS OF GREEN ROOFS FOR WILDLIFE: HABITAT POTENTIAL IN MICHIGAN AND ILLINOIS, U.S.A.

As developed areas replace green space, urban environmental quality decreases and can negatively affect native plant and wildlife communities (McKinney, 2008). One potential urban design strategy to minimize this degradation is establishing vegetation on roofs, also known as green roofs (Coffman and Davis, 2005). Green roofs are becoming more common in North America, and some local governments and federal agencies have incentivized green roof construction to make them more economically attractive to consumers. Policies in favor of green roofs have been developed because of potential environmental and economic benefits that accompany green roof installation (Carter and Fowler, 2008; City of Chicago, 2011).

The potential of green roofs to provide economic and environmental benefits has been documented (Oberndorfer et al., 2007; Rowe, 2011). Green roofs help conserve energy (Getter et al., 2011), reduce air pollution (Currie and Bass, 2008), counteract carbon dioxide emissions through carbon sequestration (Getter et al., 2009), reduce the urban heat island (Banting et al., 2005), increase longevity of roofing membranes that result in fewer roofing materials in landfills (Rowe, 2011), improve water quality of storm water runoff (Peck et al., 1999; Getter et al., 2007), and reduce noise pollution (Van Renterghem and Botteldooren, 2009). Some authors have also concluded that green roofs provide wildlife habitat because of the diversity of plants, invertebrates, and birds that have been observed (Brenneisen, 2006; Kadas, 2006; Coffman, 2007). However, the relationships between green roof characteristics (roof structure, vegetation characteristics, surface area, surrounding land use, maintenance, and age) and wildlife communities (abundance, diversity, and richness) have not been quantified.

Green roofs offer potential to develop diverse vegetation types, increase green space in urban areas, increase connectivity with other urban green spaces (reduce ecosystem fragmentation), and provide wildlife habitat. In developed areas, these objectives might otherwise be impossible due to lack of available land, economic impracticality, and public perception of how land should be used. A potential increase in wildlife habitat could result in greater abundance and diversity of wildlife species in urban areas, thus contributing to biodiversity conservation.

The ability of green roofs to provide urban wildlife habitat has not been extensively studied (Coffman and Davis, 2005; Kadas, 2006; Fernandez-Canero and Gonzalez-Redondo, 2010). Plant, bird, and insect communities, which have been observed on green roofs, can be significant components of biodiversity in urban landscapes (Savard et al., 2000). Additionally, lizards with ground access (e.g., through rock filled gabions spanning roof and ground; Cantor, 2008) and squirrels and rabbits (personal observation) on roofs at ground level are examples of other wildlife that use green roofs. However, many green roofs are primarily accessible to wildlife taxa such as birds and bats because they are elevated above ground level and do not have specialized wildlife access structures. Birds (29 species) have been observed breeding on green roofs in parts of Europe and North America (Baumann, 2006; Fernandez-Canero and Gonzalez-Redondo, 2010). Past studies suggest that green roofs may provide habitat for birds in urban landscapes at several spatial scales (i.e., microhabitat to home range scales) (Fig. 1.1) because of the additional green space and less disturbances on roof surfaces (e.g., Brenneisen, 2006; Lundholm, 2006; Oberndorfer et al., 2007). Green space on roofs may not appear contiguous with green space in the landscape; however, green roofs may help increase habitat connectivity and suitability for bird species that perceive habitat at macro scales (e.g., landscape) (Kotliar and Wiens, 1990; Morrison et al., 1992). Increased habitat connectivity may enhance wildlife habitat suitability of landscapes and thereby increase species richness (Goddard et al., 2010).

Since the creation of green spaces and adequate vegetation structure in urban areas can influence bird community composition and richness (Fontana et al., 2011), green roofs should have the same effect. Vegetation structure and composition have a strong role in determining bird habitat suitability, and hence the vegetation on green roofs will likely contribute habitat for bird communities, such as early successional songbirds (Coffman, 2007). Several studies have described vegetation on green roofs (Coffman, 2007; Wolf and Lundholm, 2008; Rowe et al., 2012), but there is a lack of information about the ecological contributions of vegetation represented on green roofs in North America (Dvorak and Volder, 2010) and their potential to provide green space in developed areas.

OBJECTIVES

Objectives for this chapter were to:

1) Describe and quantify vegetation structure and composition for intensive (generally >15cm planting media depth) and extensive (generally <15cm planting media depth) green roofs and their surrounding landscapes.

2) Characterize the types of landscapes where green roofs have been constructed.

3) Describe the potential of green roof implementation to conserve components of biodiversity and fulfill vegetation requirements for wildlife species in the Midwest United States.

METHODS

Site descriptions

We selected 12 green roof study sites described as: 1) Downtown Chicago Park (DCP), 2) the Ford Truck Plant (FOR), 3) McCormick Parking Structure (MCC), 4) Aquascape Headquarters (AQU), 5) Haworth Headquarters (HAW), 6) the Chicago Cultural Center (CCE), 7) the Chicago City Hall (CHA), 8) a Nature Museum (NAM), 9) a Michigan Avenue Structure (MIA), 10) Schwab Rehabilitation Hospital (SCH), 11) Gary Comer Youth Center (GCY), and 12) the Plant and Soil Science Building at Michigan State University (PSS) (Table 1.1). Study sites were located in Illinois and the Lower Peninsula of Michigan in the United States (Fig. 1.2-1.4). All study sites were within the Midwest Broadleaf Forest Province ecoregion; characterized by a climate with "warm to hot summers" that often have brief drought in the late summer, vegetation consisting of "cold-deciduous, hardwood-dominated forests", and "flat to hilly terrain with features associated with former glaciation" (McNab et al., 2007, p. 10). The range of monthly mean temperatures at each study site during the early to peak bird nesting season (April - June) was between 11.3C and 22.2C in 2010 and between 7.9C and 21.5C in 2011 (Table 1.2; National Oceanic and Atmospheric Administration, 2012). The range of monthly mean temperatures at each study site during post-nesting and brood-rearing season (July-September) was between 16.5C and 26.1C in 2010 and between 15.9C and 26.3C in 2011. The range of monthly total precipitation at each study site during the early to peak bird nesting season was between 5.9cm and 20.0cm in 2010 and between 3.5cm and 18.8cm in 2011 (Table 1.3; National Oceanic and Atmospheric Administration, 2012). The range of monthly total precipitation at each study site during post-nesting and brood-rearing season (July-September) was between 1.1cm and 24.4cm in 2010 and between 9.9cm and 18.3cm in 2011. Each study site included the green roof on a building and the landscape area within 200m of a green roof (Fig. 1.5); a minimum of 14ha for our smallest green roof. This size area was based on the size of species' home ranges that have been observed using green roofs in the past (Fernandez-Canero and Gonzalez-Redondo, 2010). Each study site was evaluated to address how wildlife species and communities may respond to the environment.

In 2010, eight green roof study sites were selected to sample a wide range of roof sizes, building heights, vegetation types (annual, perennial *Sedum*, perennial non-*Sedum*, woody), planting media depth (Table 1.4), urban land use (Table 1.1), and accessibility (Table 1.5). Another criterion considered when selecting study sites was that roofs were accessible through building owners. In 2011, four study sites from 2010 were re-sampled along with four new study sites. Green roofs selected for 2011 were elevated above ground level (not on subterranean structures) since the greatest potential for green roof construction in urban areas is on structures above ground level. Also, because patch size is positively related to species-occurrence and density for several grassland bird species (Johnson and Igl, 2001), we selected the largest green roofs possible that met all other selection criteria.

To characterize the attributes of the green roofs for their potential as wildlife habitat (Tables 1.1-1.3), we compiled information from green roof owners and managers, on-line green roof websites, green roof designers and engineers, the NOAA database report (National Oceanic and Atmospheric Administration, 2012), and from personal observation and vegetation sampling (Table 1.6). Vegetation growth and plant species on green roofs are limited by water availability, growing media composition, fertilization rate, slope, and substrate depth

(Monterusso et al., 2005; Rowe et al., 2006). Seven sites were classified as extensive green roofs (planting media depth of 3-15cm), and six sites were intensive green roofs (planting media depth of 15-120cm). Three of the intensive sites had small areas (e.g., edges of planting media mounds) of planting media <15cm deep, but the majority of these roofs were covered with planting media >15cm deep. These roofs were categorized as intensive for analyses (Table 1.4).

Vegetation cover initially planted on the green roofs was based on the intended primary roof function established by owners. Extensive roofs installed primarily for pollution mitigation and energy savings were usually planted with *Sedum* (Tables 1.2 and 1.3): this was the only vegetation planted on three roofs (FOR, HAW, PSS). Planted vegetation species included *S. album, S. kamtschaticum,* and *S. spurium* on five roofs. Green roofs at six study sites supported native plants for their respective regions (Table 1.4). Native perennials such as little bluestem (*Schizachyrium scoparium*), blazing star (*Liatris sp.*), coneflower (*Echinacea sp.*), and aster (*Aster sp.*) were planted on green roofs at SCH, AQU, and DCP. Woody vegetation was present on intensive and extensive roofs, but woody plant varieties on extensive roofs were low-growing and tolerant of dry conditions (e.g., *Juniperus horizontalis* at CCE).

Green roof maintenance requirements were based on the original planted vegetation and the intended roof functions. Irrigation systems were present on nine roofs, scheduled weeding on 10 roofs, and fertilization on six roofs (Table 1.5). Other maintenance included periodic controlled burns on one roof with the goal of maintaining prairie vegetation, regular mowing on one roof that was readily accessible by the public, and vegetable harvest on one roof that functioned as a youth center garden. One roof had no planned maintenance regime beyond the establishment of the original vegetation.

Vegetation sampling

Vegetation sampling was conducted during two periods: one during the early to peak bird nesting season April 22 to May 14, 2010 and April 23 to June 24, 2011; and one post-nesting and brood-rearing season June 30 to August 15, 2010 and July 28 to October 1, 2011. By sampling during the spring (April-June) and summer (July-October), vegetation was representative of that available to bird communities during the beginning and peak of the breeding season and post-nesting during brood-rearing (Short, 1985; Basore et al., 1986; Best et al., 1997).

The sampled portions of landscapes surrounding green roofs were safe, accessible, and included clearly definable vegetation areas (areas with a minimum requirement of exposed soil with potential to support vegetation). Planter boxes attached to buildings, street median vegetation, street trees in grates, and vegetation on other green roofs in the surrounding landscapes were not sampled in the field, however, were represented in the aerial land cover analysis.

The line intercept method (Canfield, 1941) was used to quantify vegetation cover of turf grass, herbaceous perennial cover, and shrub and tree canopy on green roofs and in vegetation areas in surrounding landscapes. One-meter belt transects (Clements, 1905) were used on green roofs and surrounding landscapes to determine species presence and stem density of woody plants. Transects ranged from 3.8-200.0m long and were systematically placed perpendicular to the grain of vegetation types on each roof and landscape area. The length of transects corresponded to the size of green roofs. The length of the transect that intersected mowed lawn, perennial, shrub, and tree cover was recorded and used to calculate the percent cover of each vegetation type. The point intercept method (Heady et al., 1959) was used to calculate percent cover of different vegetation types and quantify mean vegetation height. Every 5m, vegetation intersecting transects was identified by type (perennial sedum, non-sedum perennial, woody vegetation) and the height of the vegetation at the intersecting point was measured.

Aerial land cover

To characterize land cover for each study site (i.e., green roof and the surrounding landscape) we imported Google Earth (Version 6.1; Google Earth, 2011) images into ArcMap (ArcGIS version 9.2; ESRI, 2006), georeferenced the aerial photographs, and digitized and classified land cover as green space and non-green space (Fig. 1.6-1.17). Green space was further classified as studied green roof, other green roof, woody vegetation, or herbaceous vegetation (i.e., turf and perennials). Non-green space was further classified as water or impervious surface, and impervious surface was further classified as non-green roof or other impervious surface (sidewalk, paved roads, paved plazas). At each site, classifications were then used to quantify percent cover of green roof, green space in the surrounding landscape (i.e., herbaceous and woody vegetation), and conventional roofs. We subsequently calculated percent of total green space attributed to the green roof and the potential green space created if all existing conventional roofs were vegetated.

Data analysis

Data were analyzed using SAS version 9.2 (SAS Institute Inc., 2008). Vegetation characteristics (mean percent cover, mean stem density) associated with spring and summer were compared to determine potential differences between seasons (early to peak bird nesting season and post-nesting/brood-rearing season). Data for each variable were checked for normality ($p<0.10$) using the Shapiro-Wilk procedure in PROCUNIVARIATE. Since the data sets for most variables were not normally distributed, the non-parametric Kruskal-Wallis one-way analysis of variance test was used for further comparisons. Spring and summer values of each vegetation variable were compared for all roofs. Spring and summer vegetation variable distributions were not different ($p<0.10$) for most variables, but because some were different, data from the two sampling periods were not pooled. Green space cover before and after green roof installation phases (pre-green roof green space, current green space, potential green space) was also compared. We used the non-parametric Kruskal-Wallis one-way analysis of variance test to determine if the vegetation characteristics associated with roof type (i.e., intensive vs. extensive) differed. If significant differences were identified, we analyzed the data for differences between roof types. Level of significance was set at 0.10 a priori to better identify ecologically significant differences in vegetation on green roofs and in green space cover to reduce the chances of committing a Type I error.

RESULTS

Green roof comparisons

Green roofs (n=12) ranged in size from 9.91ha to 0.03ha with a mean area of 1.83ha; median roof size was 0.19ha. Green roofs were on structures up to 15 stories high, but the median and modal building height was 3 stories from ground level, approximately 10m high (Table 1.4).

Planting media depth leads to inherent differences in vegetation on intensive and extensive green roofs (Fig. 1.18 and 1.19). We found that 83% and 33% of the vegetation variables sampled in 2010 and 2011, respectively, differed between the two roof types (Table 1.7). Tree and shrub cover were generally absent on extensive green roofs, except for some shrub cover on one roof in 2011 (Table 1.7 and 1.8). Vegetation height was only measured in 2011, and we found that perennial vegetation was 208% taller on intensive roofs. On all extensive roofs planted entirely in drought-tolerant *Sedum* we observed ≥99% mean herbaceous cover, while on all extensive roofs planted with a mixture of *Sedum* and/or non-*Sedum* perennials, mean herbaceous cover composed 50-86% of the green roof area (Table 1.8). Mean herbaceous cover on extensive roofs was 40% ($p=0.013$) and 18% ($p=0.462$) higher than on intensive roofs in 2010 and 2011, respectively. Mean percent herbaceous cover on extensive roofs was 78-100% in 2010 and 50-100% in 2011, compared to 48-75% in 2010 and 40-92% in 2011 on intensive roofs (Table 1.8). Shrub cover occurred on 50% and 75% of intensive green roofs in 2010 and 2011, and tree cover occurred on 100% and 75% of intensive green roofs in 2010 and 2011. Regardless of roof type, turf cover was absent from all green roofs except on one roof in 2010 which had 25% turf cover. Planting media depth corresponded with differences in vegetation type; greater shrub and tree cover and taller vegetation was observed on intensive roofs. Herbaceous cover was the dominant cover type on all green roofs, but sedum covered roofs (commonly on extensive roofs) had the highest percent cover (>99%).

Herbaceous vegetation covered the majority of the roofs, with none of the other three vegetation characteristics having a reoccurring order of dominance (Table 1.8). Several roofs planted with a mixture of perennial species, other than *Sedum*, showed differences in herbaceous cover between seasons (2010: DCP $p=0.10$, AQU $p=0.13$, MCC $p=0.05$; 2011: CHA $p=0.01$, CCE $p=0.09$, GCY $p=0.08$, SCH $p=0.02$). No significant difference in shrub or tree cover occurred between seasons ($p \geq 0.26$, and $p \geq 0.32$, respectively) on any roof. Mean percent herbaceous cover on non-*Sedum* roofs was 33% greater in summer, with an increase of 14% mean percent herbaceous cover between seasons.

Surrounding landscape comparisons

All vegetation variables, except percent shrub cover for one landscape, were not significantly different between spring and summer sampling periods. Landscape areas had between 22-78% turf cover, 0-53% herbaceous cover, 0-12% shrub cover, 1-72% tree cover, 53-566 tree/ha, and 0-913 shrubs/ha (Table 1.9). Shrub and tree vegetation characteristic values (i.e., percent cover and stem density) for seven of eight intensive green roofs were within the ranges of those variables measured in the landscapes; however, mean turf cover was 48% lower and mean herbaceous cover was 42% higher than in the landscape. Vegetation characteristics values on extensive green roof were not within the value ranges of those characteristic values for the landscape.

The range of land use intensity within a 200m radius of each green roof ranged from low (lake), to mid (mid-density residential, urban park), to high (railway, highway, industrial complex) (Table 1.1). Our land cover classification indicated that for 67% (8 of 12) of the study sites, non-green roofs and other impervious surfaces were the two main sources of land cover (Table 1.10). Green space area before and after green roof implementation was not significantly different ($p=0.421$). However, if all existing non-green roofs were converted into green roofs, mean green space would increase 306% ($p=0.002$). The difference between green space cover before implementation of any green roofs within a study site and the potential green space cover if all roofs were 'greened' would more than double green space cover ($p=0.001$) for the studied landscapes. This increase in green space does not account for the area occupied by rooftop ventilation utilities not suited to be covered with vegetation. If ventilation utilities halved potential green roof area, green space in the landscape would increase >200%, and at study sites like Chicago City Hall with high percentages of roof cover and low percentages of green space cover, green space would increase at least ten-fold. This dramatic change in the availability of green space in urban areas could provide vegetation with the potential to enhance wildlife habitat.

DISCUSSION

Vegetation structure and composition

Wildlife observations on green roofs have led to conclusions that green roofs provide wildlife habitat, and thus have direct wildlife conservation value (Brenneisen, 2006; Kadas, 2006; Coffman, 2007). However, there has been a lack of quantitative vegetation data available to describe the conditions green roofs may provide as suitable wildlife habitat. Quantifying green roofs' vegetation characteristics and green space contributions in adjacent landscapes is the first step towards assessing wildlife conservation value of green roofs and implementing green roofs with directed wildlife conservation goals. The objectives of our study were to quantify and describe vegetation structure and composition and green space contributions of green roofs and the surrounding landscapes that may contribute to wildlife habitat. This information is vital to assess the potential of green roof construction to increase ecological function and ultimately to help conserve biodiversity in urban areas. Comparisons of vegetation structure and composition observed on green roofs with those required to support wildlife species can be used to assess green roofs' wildlife habitat potential.

Since green roof soil depth is limited by structural support, plants that can withstand shallower growing media (perennials, small shrubs) are likely to comprise the dominant vegetation type on all green roofs. Special planting conditions can be designed to accommodate large shrubs and trees (pockets of extra deep planting media), but providing structural support for the growing media required to support a forest vegetation type on a green roof would normally be cost prohibitive. A difference in vegetation between roof types was expected as extensive green roofs' shallow growing media creates more stressful growing conditions (high soil temperatures and low soil moisture) than the deeper growing media on intensive green roofs (Oberndorfer et al., 2007). Studied intensive roofs had taller perennial and woody species, whereas extensive green roofs generally had low-growing, drought-tolerant perennial or shrub species. Since a greater variety of plant species can be established on intensive roofs, it is not surprising that vegetation cover and structure and the variety of native species were greater on this roof type (Table 1.7). The increased niche opportunities in vegetation on intensive roofs likely can support a greater diversity of wildlife species; however, wildlife species that require shorter vegetation and less woody cover may be better supported on extensive roofs. These differences in vegetation between roof types may result in greater differences between wildlife communities on intensive and extensive green roofs than on the same roof type.

Bird communities

Bird communities comprise the majority of urban wildlife with access to all green roofs, whether at ground level or on top of a high-rise building (Fernandez-Canero and Gonzalez-Redondo, 2010). In terrestrial systems vegetation structure and composition has been used to predict abundance, species richness, and productivity for bird communities (Cody, 1968; Delisle and Savidge, 1997), and the same should hold true for green roofs and their surrounding landscapes. Vegetation characteristics on green roofs that cover a smaller area than the home range of a bird species may contribute to habitat suitability for that species by providing finer scale habitat requirements. As shown in Habitat Suitability Index (HSI) models, each species has a unique set of vegetation characteristics to which it responds at multiple spatial scales (United States Fish and Wildlife Service, 1981). Vegetation characteristic values within specific species-based models can be compared to vegetation conditions at each respective site to evaluate habitat suitability for a particular species. Assuming vegetation characteristic values can similarly be compared to vegetation conditions on green roofs, vegetation on green roofs can satisfy life requisites for specific bird species. According to the life requisite requirements in the red-winged blackbird (*Agelaius phoeniceus*) HSI model (Short, 1985), the Aquascape Headquarters Green Roof (with 78% herbaceous cover) provided low quality nesting habitat (>1ha, woody vegetation or dense stands of perennials >1m tall covering >10% of the site, no grazing, mowing, burning or tilling) (Table 1.4 and 1.5).

The Gary Comer Youth Center Green Roof had vegetation characteristic values within the range of woody vegetation cover and within 6cm of the mean live vegetation height (45cm) reported for Conservation Reserve Program (CRP) study fields throughout the Midwest United States; These values correspond with the highest abundances of American goldfinch (*Carduelis tristis*), barn swallow (*Hirundo rustica*), chipping sparrow (*Spizella passerine*), and song sparrow (*Melospiza melodia*) (Best et al., 1997). CRP fields with live herbaceous cover, composed of grasses and forbs that contributed 46.8% and 27.1%, respectively, and a mean live vegetation height of 68cm, and 0.4% woody cover corresponded with the highest abundances of common yellowthroat (*Geothlypis trichas*) and eastern kingbird (*Tyrannus tyrannus*) (Best et al., 1997). Green roofs that provided herbaceous cover within the range given for highest common yellowthroat and eastern kingbird abundances were SCH and DCP in 2010, and GCY, MIA, and CCE in 2011 (Table 1.8). The green roof that came closest to providing vegetation with an equivalent height was SCH that provided 88% of CRP live vegetation height. No green roof met all three vegetation characteristic values for common yellowthroat and eastern kingbird abundance; however, green roofs' vegetation characteristics demonstrate potential to provide suitable habitat for some bird species.

The Chicago City Hall Green Roof had herbaceous cover (Table 1.8) within 15% and mean vegetation height within 6% of reported vegetation values in Iowa alfalfa fields with highest observed abundance of common yellowthroat (Frawley and Best, 1991). The Chicago Cultural Center Green Roof had vegetation cover (24% shrub cover) that aligned with the percent shrub cover (15-35%) required for optimal habitat suitability for field sparrow (*Spizella pusilla*), according to the HSI model developed by Sousa (1983). However, herbaceous cover height on this green roof (2cm) was less than half that described as suitable in the HSI model for field sparrow (>5cm), illustrating the importance of comparing a diversity of vegetation characteristics on green roofs with those required by target species.

Cover types indicative of bird communities present in the landscape (Anderson and Shugart, 1974) should also hold true on green roofs. Turf grass and low-growing perennials provide foraging opportunities for bird species such as killdeer (*Charadrius vociferus)* and common grackle (*Quizcalus quizcula*), taller perennials such as little bluestem and coneflower provide high perches and dense cover for foraging for species such as red-winged blackbird, and shrub and tree vegetation provide habitat for forest edge species such as blue jay (*Cyanocitta cristata*) and downy woodpecker (*Picoides pubescens*). The presence of these cover types may have similar outcomes on green roofs. Turf was less common on green roofs than in surrounding landscapes; this was likely because most turf varieties require large water inputs which are impractical on most green roofs, and turf cover did not align with the environmental focus of most roofs (Table 1.5). Even though shrub and tree cover for green roofs fell within the range of those variables in the surrounding landscapes, considering the level of development in the landscapes where the green roofs were located, the surrounding landscapes were not a high standard of ecological function with which to compare the green roofs.

The majority of studied green roofs (9 of 13) were planted mainly (>50%) with non-native species. Even though from a quantified structural standpoint, non-native species can fulfill vegetation characteristic requirements for wildlife suitability, they may provide a different level of habitat quality because of their unique plant characteristics (e.g., type of fruit or seed produced, insect communities supported, color and texture providing camouflage, etc.). Even though vegetation characteristics on green roofs may fit the description of suitable habitat for a species, without quantifying the relationships between habitat attributes and species responses it is difficult to know the effect that other factors (i.e., roof height, human presence, non-native plant species, landscape matrix, and lack of mesopredators) have on how birds use a vegetation type on green roofs.

The vegetation conditions in our study support the idea that design intent can influence bird species' presence on green roofs (Fernandez-Canero and Gonzalez-Redondo, 2010). Green roofs designed to provide wildlife habitat such as NAM-intensive, MCC, CHA, and AQU had above average perennial cover and vegetation height and were composed predominantly of native species. Unsurprisingly, green roofs with aesthetics driving the design ranged from vegetation types that provided little vegetation structure (a homogenous mixture of a few *Sedum* species) to roofs with a variety of vegetation structure (areas of trees, shrubs, perennials and turf grass). Where pollution mitigation and energy savings drove green roof design, *Sedum* roofs seemed to prevail. While *Sedum* does not provide structure for perching or dense cover, these open areas may be suitable for foraging bird species and provide cover for some insect communities that are beneficial for foraging birds. Irrigation on some green roofs provides a water source that birds may utilize for drinking or bathing. Other roof maintenance activities such as annual vegetation removal and pruning may decrease important structural characteristics for wildlife. Green roofs that maintain dead perennial cover may provide opportunities (cover, insects, seeds, etc.) for birds. Human access is another factor that could negatively affect wildlife suitability on green roofs, as human presence can reduce foraging and breeding opportunities for birds (Fernández-Juricic, 2002).

Differences in weather between years and locations may have affected observed vegetation conditions on green roofs, and thus altered bird habitat suitability. Temperature and precipitation can influence time and rate of seed germination (Williams, 1983), leaf emergence and cover (Villalobos and Ritchie, 1992), and seed production (Coupland, 1958). Monthly mean temperatures during bird nesting and brood-rearing seasons in 2010 were generally higher than in 2011. Higher temperatures in 2010 may have contributed to earlier leaf emergence and seed production, and may have provided cover and foraging opportunities for seed-eating birds earlier than in 2011.

Wildlife conservation

Past studies have focused on green roofs' ecological contributions separate from the rest of the landscape; however, green roofs are part of complex landscapes and interact with ecological components within landscapes (Oberndorfer et al., 2007). Additional green space provided by green roofs may allow migratory species to traverse barriers typically associated with urban landscapes, and therefore restore habitat connectivity for some species (Goddard et al., 2010). Green space cover can also indicate increased ecological function and biodiversity conservation (Corry and Nassauer, 2005). The mean increase in green space if all roofs within our study sites were 'greened' would more than triple current green space. This affect, if extrapolated throughout a large area of development, could substantially increase green space and connectivity for bird communities. In an urban area where there is a low percent green space cover, the comparative effect of a green roof on green space, and thereby on associated benefits such as storm water runoff mitigation and increased wildlife habitat, is much greater than in a rural area with an already high percent green space. This difference illustrates the potential influence of landscape context on the potential of a green roof to contribute to wildlife habitat through available green space.

Realization of increased wildlife habitat quantity and quality will depend on the management decisions made regarding those green spaces. Implementing green roofs with vegetation appropriate to a bird community targeted for conservation could dramatically enhance wildlife habitat through an urban area. More research is needed to examine how the distribution of green roofs through urban landscapes may affect wildlife habitat connectivity (Donnelly and Marzluff, 2006; Prugh et al., 2008; Evans et al., 2009). Green roof clusters strategically placed as 'stepping stones' throughout landscapes may affect connectivity based on cluster size and distance between clusters, whereas connectivity provided by green roofs in a linear 'roof-top greenway' may be affected by green way direction and size. Research is also needed to address the possibility that green roofs may function as ecological traps (sinks: attracting wildlife without increasing fitness) or function as 'safe havens' that foster increased fitness. Green roofs may also act as sinks due to their potential small size and isolation, thereby maintaining numbers of individuals by recruiting from a nearby source population (Pulliam, 1988). Conversely, wildlife on green roofs may experience greater survival and fitness due to fewer predators (Renfrew et al., 2005; Vergara and Hahn, 2009), additional potential nest sites, abundant food, and elevated position of green roofs, which may reduce negative edge and patch effects (Burke and Nol, 1998; Bollinger and Switzer, 2002). Insight into the effects of green roof design and vegetation type on wildlife species fitness could be used by city planners, resource managers, and policy makers to increase wildlife habitat conservation through green roof development and management.

Our study identified differences between vegetation on intensive and extensive green roofs, demonstrated green roof vegetation's ability to fulfill wildlife habitat requirements and presented potential increases in urban green space through green roof installation in developed areas where green roofs are already an acceptable building strategy in the Midwest United States. These results support the premise that green roof vegetation can contribute to wildlife habitat and increase urban green space important for wildlife conservation. This information should encourage collaboration of green roof designers, city planners, resource managers, and policy makers to advance green roof installations towards environmental sustainability that includes wildlife conservation.

Table 1.1. Location, landscape classification, and year of installation of green roof study sites sampled in Michigan and Illinois, U.S.A., in 2010 and 2011

Study Site	City, State	Land Use Classification*	Year Installed	Year Studied
Downtown Chicago Park (DCP)	Chicago, IL	Urban park, high-density residential, urban central business district, museum, railway	2004	2010
Ford Truck Plant (FOR)	Dearborn, MI	Industrial complex	2003	2010, 2011
McCormick Parking Structure (MCC)	Chicago, IL	Conference center, urban park, lake, highway	2003	2010
Aquascape Headquarters (AQU)	St. Charles, IL	Offices and light manufacturing distribution, residential mid-density, airport	2005	2010
Haworth Headquarters (HAW)	Holland, MI	Industrial complex, commercial complex	2007	2010, 2011
Chicago Cultural Center (CCE)	Chicago, IL	Urban central business district, urban park, high-density residential,	2006	2011
Chicago City Hall (CHA)	Chicago, IL	Urban central business district, urban park, high-density residential	2001	2011
Nature Museum (NAM)	Chicago, IL	Museum, urban park, lake	2002, 2004**	2010, 2011
Michigan Avenue Structure (MIA)	Chicago, IL	Urban central business district, residential high-density	2008	2011
Schwab Rehabilitation Hospital (SCH)	Chicago, IL	Health facilities, urban park, residential mid-density	2003	2010, 2011

Table 1.1. (cont'd)

Study Site	City, State	Land Use Classification*	Year Installed	Year Studied
Gary Comer Youth Center (GCY)	Chicago, IL	School, residential mid-density, commercial strip developments, railway	2006	2011
Plant and Soil Science Building (PSS)	East Lansing, MI	College campus, urban park, railway	2004	2010

*Land Use Classification based on United States Geological Survey (USGS) land use and land cover classification sytems (Anderson et al., 1976). Driveways and surface roads were not included as a land use class because these transportation routes were present at all sites.

**One intensive green roof was installed in 2002 and two extensive green roofs were installed in 2004.

Table 1.2. Monthly mean temperature (degrees Celcius) for green roof study sites sampled in Michigan and Illinois, U.S.A., in 2010 and 2011. Data is provided for green roof study sites during the year each site was sampled.

	January		February		March		April		May		June	
Study Site	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Downtown Chicago Park (DCP)	-3.7	-	-0.9	-	5.5	-	12.4	-	16.2	-	22.2	-
Ford Truck Plant (FOR)	-3.5	-4.6	-2.1	-3.4	4.3	ND	11.6	8.4	16.7	15.3	22.0	21.5
McCormick Parking Structure (MCC)	-3.7	-	-0.9	-	5.5	-	12.4	-	16.2	-	22.2	-
Aquascape Headquarters (AQU)	-7.3	-	-3.9	-	4.3	-	ND	-	16.3	-	21.1	-
Haworth Headquarters (HAW)	-3.8	-5.7	-2.6	-2.9	ND	1.1	11.3	7.9	16.7	ND	20.8	18.0
Chicago Cultural Center (CCE)	-	-3.8	-	-0.7	-	4.5	-	9.6	-	13.9	-	20.9
Chicago City Hall (CHA)	-	-3.8	-	-0.7	-	4.5	-	9.6	-	13.9	-	20.9
Nature Museum (NAM)	-3.7	-3.8	-0.9	-0.7	5.5	4.5	12.4	9.6	16.2	13.9	22.2	20.9
Michigan Avenue Structure (MIA)	-	-3.8	-	-0.7	-	4.5	-	9.6	-	13.9	-	20.9
Schwab Rehabilitation Hospital (SCH)	-3.7	-3.8	-0.9	-0.7	5.5	4.5	12.4	9.6	16.2	13.9	22.2	20.9
Gary Comer Youth Center (GCY)	-	-3.8	-	-0.7	-	4.5	-	9.6	-	13.9	-	20.9
Plant and Soil Science Building (PSS)	-5.1	-	-3.7	-	4.2	-	11.4	-	15.9	-	20.4	-

Table 1.2. (cont'd)

Study Site	July		August		September		October		November		December	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Downtown Chicago Park (DCP)	26.0	-	26.1	-	20.4	-	15.7	-	7.8	-	-2.2	-
Ford Truck Plant (FOR)	24.8	26.1	24.2	22.9	18.4	17.9	13.1	12.0	5.4	7.7	-3.2	2.0
McCormick Parking Structure (MCC)	26.0	-	26.1	-	20.4	-	15.7	-	7.8	-	-2.2	-
Aquascape Headquarters (AQU)	ND	-	23.5	-	17.5	-	12.2	-	4.7	-	-6.8	-
Haworth Headquarters (HAW)	23.9	23.1	23.9	21.2	17.8	15.9	12.0	11.2	6.6	6.4	-2.4	2.1
Chicago Cultural Center (CCE)	-	26.3	-	24.9	-	19.0	-	14.5	-	9.1	-	3.8
Chicago City Hall (CHA)	-	26.3	-	24.9	-	19.0	-	14.5	-	9.1	-	3.8
Nature Museum (NAM)	26.0	26.3	26.1	24.9	20.4	19.0	15.7	14.5	7.8	9.1	-2.2	3.8
Michigan Avenue Structure (MIA)	-	26.3	-	24.9	-	19.0	-	14.5	-	9.1	-	3.8
Schwab Rehabilitation Hospital (SCH)	26.0	26.3	26.1	24.9	20.4	19.0	15.7	14.5	7.8	9.1	-2.2	3.8
Gary Comer Youth Center (GCY)	-	26.3	-	24.9	-	19.0	-	14.5	-	9.1	-	3.8
Plant and Soil Science Building (PSS)	23.7	-	23.3	-	16.5	-	11.2	-	4.8	-	-4.2	-

Table 1.3. Monthly total precipitation in centimeters for green roof study sites sampled in Michigan and Illinois, U.S.A., in 2010 and 2011. Data is provided for green roofs study sites during the year each site was sampled.

	January		February		March		April		May		June	
Study Site	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Downtown Chicago Park (DCP)	2.7	-	4.0	-	4.4	-	9.8	-	17.3	-	20.0	-
Ford Truck Plant (FOR)	2.2	3.5	3.9	7.8	4.7	ND	5.9	15.0	12.4	18.8	17.3	ND
McCormick Parking Structure (MCC)	2.7	-	4.0	-	4.4	-	9.8	-	17.3	-	20.0	-
Aquascape Headquarters (AQU)	2.7	-	2.6	-	4.6	-	8.2	-	14.3	-	17.2	-
Haworth Headquarters (HAW)	ND	ND	ND	ND	ND	ND	7.3	ND	16.4	ND	19.4	3.5
Chicago Cultural Center (CCE)	-	0.7	-	5.0	-	4.5	-	ND	-	13.5	-	18.8
Chicago City Hall (CHA)	-	0.7	-	5.0	-	4.5	-	ND	-	13.5	-	18.8
Nature Museum (NAM)	2.7	0.7	4.0	5.0	4.4	4.5	9.8	ND	17.3	13.5	20.0	18.8
Michigan Avenue Structure (MIA)	-	0.7	-	5.0	-	4.5	-	ND	-	13.5	-	18.8
Schwab Rehabilitation Hospital (SCH)	2.7	0.7	4.0	5.0	4.4	4.5	9.8	ND	17.3	13.5	20.0	18.8
Gary Comer Youth Center (GCY)	-	0.7	-	5.0	-	4.5	-	ND	-	13.5	-	18.8
Plant and Soil Science Building (PSS)	2.2	-	3.4	-	1.1	-	6.3	-	10.6	-	11.6	-

Table 1.3. (cont'd)

Study Site	July		August		September		October		November		December	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Downtown Chicago Park (DCP)	23.4	-	8.8	-	4.2	-	5.6	-	6.3	-	7.1	-
Ford Truck Plant (FOR)	12.6	10.0	1.1	10.3	8.0	16.4	3.5	6.6	8.6	15.4	2.4	6.7
McCormick Parking Structure (MCC)	23.4	-	8.8	-	4.2	-	5.6	-	6.3	-	7.1	-
Aquascape Headquarters (AQU)	24.0	-	9.6	-	9.4	-	2.6	-	6.0	-	5.4	-
Haworth Headquarters (HAW)	24.4	11.3	4.9	18.3	11.5	10.4	5.5	4.0	5.6	8.2	12.2	5.6
Chicago Cultural Center (CCE)	-	13.8	-	10.0	-	9.9	-	5.7	-	9.3	-	6.4
Chicago City Hall (CHA)	-	13.8	-	10.0	-	9.9	-	5.7	-	9.3	-	6.4
Nature Museum (NAM)	23.4	13.8	8.8	10.0	4.2	9.9	5.6	5.7	6.3	9.3	7.1	6.4
Michigan Avenue Structure (MIA)	-	13.8	-	10.0	-	9.9	-	5.7	-	9.3	-	6.4
Schwab Rehabilitation Hospital (SCH)	23.4	13.8	8.8	10.0	4.2	9.9	5.6	5.7	6.3	9.3	7.1	6.4
Gary Comer Youth Center (GCY)	-	13.8	-	10.0	-	9.9	-	5.7	-	9.3	-	6.4
Plant and Soil Science Building (PSS)	5.1	-	1.1	-	12.3	-	7.2	-	5.3	-	4.2	-

Table 1.4. Characteristics for building structure, planting media, planted vegetation, maintenance, and human use for green roof study sites sampled in Michigan and Illinois, U.S.A., in 2010 and 2011.

	Building Structure Characteristics						
Study Site	Type*	Green Roof Size (ha)	Height (# story)	Slope (%)	Media Depth (cm)	Vegetation	Artificial Water Source**
Downtown Chicago Park (DCP)	E and I	9.91	0	1.0 to 5.0	10 to 122	Ornamental and native perennials, turf, shrubs, trees	S, H
Ford Truck Plant (FOR)	E	4.22	3	1.5	2	*Sedum*	S
McCormick Parking Structure (MCC)	I	2.43	0	NA	45 to 61	Native prairie perennials, trees	-
Aquascape Headquarters (AQU)	E	2.38	2 to 4	8.3	10	Native prairie perennials	SB
Haworth Headquarters (HAW)	E	0.42	0 to 4	10.0 to 30.0	10	*Sedum*	S
Chicago Cultural Center (CCE)	E	0.19	8	1.0	9 to 11	*Sedum*, ornamental perennials, low evergreen shrubs	SB
Chicago City Hall (CHA)	E and I	0.19	11	Sculpted terrain	8 to 46	Native perennials, shrubs, vines, small trees	D
Nature Museum - 2 roofs (NAM)	E	0.14	1.5 to 3	7.0	8	*Sedum*, native perennials	-

Table 1.4. (cont'd)

Study Site	Type*	Green Roof Size (ha)	Height (# story)	Slope (%)	Media Depth (cm)	Vegetation	Artificial Water Source**
Nature Museum - 1 roof (NAM)	E and I	0.02	1.5	1.5	5 to 25	Native perennials, one tree	-
Michigan Avenue Structure (MIA)	E	0.16	15	1.0	10 to 15	*Sedum*, ornamental perennials	S
Schwab Rehabilitation Hospital (SCH)	I	0.09	3	1.5, raised beds, potted trees	20 to 46	Ornamental and native perennials, annuals, shrubs, small trees	H, D, W
Gary Comer Youth Center (GCY)	I	0.08	3	1.0	61	Perennials, vegetables, fruits, herbs	S
Plant and Soil Science Building (PSS)	E	0.03	1.5	1.0	3 to 8	*Sedum*	-

* Type: I, intensive; E, extensive; E and I, intensive roofs with shallow media depths in some areas.

** Artificial Water Source: S, sprinkler; SB, subsurface; H, hand-watering; D, drip; W, water feature

Table 1.5. Maintenance regime, primary function, and accessibility of green roof study sites sampled in Michigan and Illinois, U.S.A., in 2010 and 2011.

Study Site	Maintenance*	Primary Function(s)	Accessibility**
Downtown Chicago Park (DCP)	W, R, P, F, M	Recreation	P
Ford Truck Plant (FOR)	F	Pollution mitigation, energy savings	A
McCormick Parking Structure (MCC)	B	Wildlife habitat creation	A
Aquascape Headquarters (AQU)	W	Pollution mitigation, energy savings, wildlife habitat creation	A
Haworth Headquarters (HAW)	W, F	Pollution mitigation, energy savings	A
Chicago Cultural Center (CCE)	W, R	Aesthetics, pollution mitigation, energy savings	A
Chicago City Hall (CHA)	W, R, N	Wildlife habitat creation, pollution mitigation, energy savings	A
Nature Museum - 2 extensive roofs (NAM)	W	Education, wildlife habitat creation, pollution mitigation, energy savings	A
Nature Museum - 1 extensive roof (NAM)	W, R, P	Education, wildlife habitat creation, pollution mitigation, energy savings	A
Michigan Avenue Structure (MIA)	W, R, F	Aesthetics, pollution mitigation, energy savings	A
Schwab Rehabilitation Hospital (SCH)	W, P, F, A	Therapeutic, aesthetics	PR
Gary Comer Youth Center (GCY)	W, F, H	Education, gardening	PR
Plant and Soil Science Building (PSS)	None	Education, pollution mitigation, energy savings	A

* Maintenance: W, weeding; R, removal of dead plant materials; P, pruning; F, fertilizing; M, mowing; B, controlled burning; A, planting annuals; H, harvesting; N, planting new plant species.

** Accessibility: P, public; A, arranged; PR, private.

Table 1.6. Information sources for characteristics of green roof study sites sampled in Michigan and Illinois, U.S.A., in 2010 and 2011. All study sites were a Downtown Chicago Park (DCP), Ford Truck Plant (FOR), McCormick Parking Structure (MCC), Aquascape Headquarters (AQU), Haworth Headquarters (HAW), Chicago Cultural Center (CCE), Chicago City Hall (CHA), Nature Museum (NAM), Michigan Avenue Structure (MIA), Schwab Rehabilitation Hospital (SCH), Gary Comer Youth Center (GCY), and the Plant and Soil Science Building at Michigan State University (PSS).

Characteristic	Roof	Source
Average Annual Temperature	All	National Oceanic and Atmospheric Administration, National Climatic Data Center, 2012.
Average Annual Precipitation	All	National Oceanic and Atmospheric Administration, National Climatic Data Center, 2012.
Size	DCP, FOR, AQU, HAW, CCE, CHA, NAM, MIA, SCH, GCY, PSS	Greenroofs.com, 2011.
Size	MCC	Googlemaps.com, 2010.
Slope	DCP, FOR, AQU, HAW, CCE, CHA, NAM-1 Intensive/Extensive roof, MIA, SCH, GCY, PSS	Greenroofs.com, 2011.
Slope	NAM - 2 Extensive roofs	Steven L. Cantor, 2008. Green roofs in sustainable landscape design.
Soil Depth	DCP	Sylvia Schmeichel, 2010. Personal Correspondence.
Soil Depth	FOR	Steven L. Cantor, 2008. Green roofs in sustainable landscape design.
Soil Depth	AQU	Juana Villagrana, 2010. Personal Correspondence.
Soil Depth	HAW, MIA, GCY	Greenroofs.com, 2011.
Soil Depth	NAM	Steven L. Cantor, 2008. Green roofs in sustainable landscape design.

Table 1.6. (cont'd)

Characteristic	Roof	Source
Soil Depth	CCE	Anthony Pacente, 2011. Personal Correspondence.
Soil Depth	CHA	American Society of Landscape Architects, 2002. "ASLA Press Release for 2002 Award Winners". http://www.asla.org/meetings/awards/awds02/chicagocityhall.html.
Soil Depth	SCH	Greenroofs.com, 2011.
Soil Depth	PSS	D. Brad Rowe, 2010. Personal Correspondence.
Vegetation	DCP	http://luriegarden.org/plantlife-list, 2010.
Vegetation	FOR, NAM	Steven L. Cantor, 2008. Green roofs in sustainable landscape design.
Vegetation	MCC	Brendan Daley, 2011. Personal Correspondence.
Vegetation	AQU	Juana Villagrana, 2010. Personal Correspondence.
Vegetation	HAW	Liveroof Original Planting List, 2007.
Vegetation	CCE	Anthony Pacente, 2011. Personal Correspondence.
Vegetation	CHA	City of Chicago, 2011. "Documents: Plants A – C, Plants D – O, Plants P – Z, and Trees, Shrubs, and Vines". http://www.cityofchicago.org/content/city/en/depts /doe/supp_info/chicago_city_hallrooftopgardenplantsandmaintenance.html
Vegetation	MIA	Tom Paulsen, 2011. Personal Correspondence.

Table 1.6. (cont'd)

Characteristic	Roof	Source
Vegetation	SCH	Laurie Dettmers, 2010. Personal Correspondence.
Vegetation	GCY	http://www.hoerrschaudt.com/rooftop-gardens/gary-comer-youth-center.php#, 2011.
Vegetation	PSS	D. Brad Rowe, 2010. Personal Correspondence.
Year Installed	DCP, FOR, HAW, AQU, CCE, CHA, NAM, MIA, SCH, GCY, PSS	Greenroofs.com, 2011.
Year Installed	MCC	Chicago Park District, 2002. "Nature Areas, McCormick Place Bird Sanctuary". http://www.chicagoparkdistrict.com/index.cfm/fuseaction/custom.natureOasis17.
Maintenance	DCP	Sylvia Schmeichel, 2010. Personal Correspondence.
Maintenance	FOR	Mike Longfellow-Jones, 2010.
Maintenance	MCC	Brendan Daley, 2011. Personal Correspondence.
Maintenance	AQU	Juana Villagrana, 2010. Personal Correspondence.
Maintenance	HAW	Chuck Tubergen, 2010. Personal Correspondence.
Maintenance	MIA	Tom Paulsen, 2011. Personal Correspondence.
Maintenance	GCY	Marjorie Hess, 2011. Personal Correspondence.
Maintenance	NAM - 1 Intensive/Extensive roof	Steven L. Cantor, 2008. Green roofs in sustainable landscape design .

Table 1.6. (cont'd)

Characteristic	Roof	Source
Maintenance	NAM	Doug Taron, 2010. Personal Correspondence.
Maintenance	CCE	Jeff Brink, 2012. Personal Correspondence.
Maintenance	CHA	Kevin Carroll, 2012. Personal Correspondence.
Maintenance	SCH	Laurie Dettmers, 2010. Personal Correspondence.

Table 1.7. Means and standard errors for variables characterizing vegetation structure of green roofs in Michigan and Illinois, U.S.A., in 2010 and 2011. Green roofs are arranged by year and type. Probability levels reported were calculated with the Kruskal-Wallis one-way analysis of variance.

	2010			2011		
	Intensive n=4 Mean (±SE)	Extensive n=5 Mean (±SE)	Probability Level	Intensive n=4[a] Mean (±SE)	Extensive n=5[b] Mean (±SE)	Probability Level
Percent Cover						
Turf cover (%)	6 (6)	0 (0)	0.264	0 (0)	0 (0)	1.000
Herbaceous cover (%)	66* (7)	93 (5)	0.013	67 (12)	79 (9)	0.462
Shrub cover (%)	2* (1)	0 (0)	0.094	4 (2)	5 (5)	0.283
Tree cover (%)	11* (7)	0 (0)	0.007	4* (3)	0 (0)	0.029
Percent Cover						
Perennial cover (%)	-	-	-	77 (10)	85 (9)	0.268
Woody cover (%)	-	-	-	4 (2)	1 (1)	0.180
Mean height (cm)	-	-	-	50* (4)	12 (5)	0.014
Stem density/ha						
Tree	83* (56)	0 (0)	0.094	127* (86.97)	0 (0)	0.029
Shrub	335* (273)	0 (0)	0.094	802 (392)	897 (897)	0.283

* Indicates a significant difference between intensive and extensive green roofs within the same year.

[a] Two of the same intensive green roofs were sampled in 2010 and 2011.

[b] Three of the same extensive green roofs were sampled in 2010 and 2011.

Table 1.8. Means and standard errors for early sampling periods, late sampling periods, and the entire sampling season for variables characterizing vegetation structure of each studied green roof, in Michigan and Illinois, U.S.A., in 2010 and 2011. Probability levels for comparisons between spring and summer within the same year were calculated with the Kruskal-Wallis one-way analysis of variance.

	Downtown Chicago Park (DCP)			
	2010			
	Spring n=9 Mean (±SE)	Summer n=9 Mean (±SE)	Seasonal Mean n=2 Mean (±SE)	Probability Level
Percent Cover				
Turf cover (%)	24 (12)	25 (13)	25 (1)	0.96
Herbaceous cover (%)	33 (9)	62 (16)	48 (15)	0.10[a]
Shrub cover (%)	0 (0)	0 (0)	0 (0)	1.00
Tree cover (%)	25 (12)	38 (13)	31 (6)	0.54
Stem Density/ha				
Tree	267 (221)	202 (109)	234 (32)	0.70
Shrub	0 (0)	0 (0)	0 (0)	1

Table 1.8. (cont'd)

	Ford Truck Plant (FOR)			
	2010			
	Spring n=3	Summer n=3	Seasonal Mean n=2	
	Mean (±SE)	Mean (±SE)	Mean (±SE)	Probability Level
Percent Cover				
Turf cover (%)	0 (0)	0 (0)	0 (0)	1.00
Herbaceous cover (%)	100 (0)	100 (0)	100 (0)	1.00
Shrub cover (%)	0 (0)	0 (0)	0 (0)	1.00
Tree cover (%)	0 (0)	0 (0)	0 (0)	1.00
Stem Density/ha				
Tree	0 (0)	0 (0)	0 (0)	1.00
Shrub	0 (0)	0 (0)	0 (0)	1.00

	Ford Truck Plant (FOR)			
	2011			
	Spring n=18	Summer n=3	Seasonal Mean n=2	
	Mean (±SE)	Mean (±SE)	Mean (±SE)	Probability Level
Percent Cover				
Turf cover (%)	0 (0)	0 (0)	0 (0)	1.00
Herbaceous cover (%)	100 (0)	98 (0)	99 (1)	0.00[a]
Shrub cover (%)	0 (0)	0 (0)	0 (0)	1.00
Tree cover (%)	0 (0)	0 (0)	0 (0)	1.00
Stem Density/ha				
Tree	0 (0)	0 (0)	0 (0)	1.00
Shrub	0 (0)	0 (0)	0 (0)	1.00
Percent Cover		n=9		
Perennial cover (%)	-	97 (3)	-	-
Woody cover (%)	-	0 (0)	-	-
Mean height (cm)	-	6 (1)	-	-
Perennial mean height (cm)	-	6 (1)	-	-
Woody mean height (cm)	-	0 (0)	-	-

Table 1.8. (cont'd)

	McCormick Parking Structure (MCC)			
	2010			
	Spring n=3	Summer n=3	Seasonal Mean n=2	
	Mean (±SE)	Mean (±SE)	Mean (±SE)	Probability Level
Percent Cover				
Turf cover (%)	0 (0)	0 (0)	0 (0)	1.00
Herbaceous cover (%)	53 (6)	98 (1)	75 (23)	0.05[a]
Shrub cover (%)	0 (0)	0 (0)	0 (0)	1.00
Tree cover (%)	0 (0)	1 (1)	0 (0)	0.32
Stem Density/ha				
Tree	0 (0)	0 (0)	0 (0)	1.00
Shrub	0 (0)	0 (0)	0 (0)	1.00

	Aquascape Headquarters (AQU)			
	2010			
	Spring n=3	Summer n=3	Seasonal Mean n=2	
	Mean (±SE)	Mean (±SE)	Mean (±SE)	Probability Level
Percent Cover				
Turf cover (%)	0 (0)	0 (0)	0 (0)	1.00
Herbaceous cover (%)	67 (13)	89 (5)	78 (11)	0.13
Shrub cover (%)	0 (0)	0 (0)	0 (0)	1.00
Tree cover (%)	0 (0)	0 (0)	0 (0)	1.00
Stem Density/ha				
Tree	0 (0)	0 (0)	0 (0)	1.00
Shrub	0 (0)	0 (0)	0 (0)	1.00

Table 1.8. (cont'd)

	Haworth Headquarters (HAW)			
	2010			
	Spring n=3	Summer n=3	Seasonal Mean n=2	
	Mean (±SE)	Mean (±SE)	Mean (±SE)	Probability Level
Percent Cover				
Turf cover (%)	0 (0)	0 (0)	0 (0)	1.00
Herbaceous cover (%)	100 (0)	100 (0)	100 (0)	1.00
Shrub cover (%)	0 (0)	0 (0)	0 (0)	1.00
Tree cover (%)	0 (0)	0 (0)	0 (0)	1.00
Stem Density/ha				
Tree	0 (0)	0 (0)	0 (0)	1.00
Shrub	0 (0)	0 (0)	0 (0)	1.00

	Haworth Headquarters (HAW)			
	2011			
	Spring n=3	Summer n=6	Seasonal Mean n=2	
	Mean (±SE)	Mean (±SE)	Mean (±SE)	Probability Level
Percent Cover				
Turf cover (%)	0 (0)	0 (0)	0 (0)	1.00
Herbaceous cover (%)	100 (0)	100 (0)	100 (0)	0.09[a]
Shrub cover (%)	0 (0)	0 (0)	0 (0)	1.00
Tree cover (%)	0 (0)	0 (0)	0 (0)	1.00
Stem Density/ha				
Tree	0 (0)	0 (0)	0 (0)	1.00
Shrub	0 (0)	0 (0)	0 (0)	1.00
Percent Cover		n=3		
Perennial cover (%)	-	100 (0)	-	-
Woody cover (%)	-	0 (0)	-	-
Mean height (cm)	-	2 (1)	-	-
Perennial mean height (cm)	-	2 (1)	-	-
Woody mean height (cm)	-	NA	-	-

Table 1.8. (cont'd)

	Chicago Cultural Center (CCE)			
	2011			
	Spring n=6	Summer n=6	Seasonal Mean n=2	
	Mean (±SE)	Mean (±SE)	Mean (±SE)	Probability Level
Percent Cover				
Turf cover (%)	0 (0)	0 (0)	0 (0)	1.00
Herbaceous cover (%)	57 (6)	43 (5)	50 (7)	0.09[a]
Shrub cover (%)	23 (7)	24 (6)	24 (1)	0.63
Tree cover (%)	0 (0)	0 (0)	0 (0)	1.00
Stem Density/ha				
Tree	0 (0)	0 (0)	0 (0)	1.00
Shrub	3958 (1190)	5016 (1175)	4487 (529)	0.75
Percent Cover		n=3		
Perennial cover (%)	-	51 (18)	-	-
Woody cover (%)	-	4 (4)	-	-
Mean height (cm)	-	2 (1)	-	-
Perennial mean height (cm)	-	2 (1)	-	-
Woody mean height (cm)	-	21 (NA)	-	-

Table 1.8. (cont'd)

	Chicago City Hall (CHA)			
	2011			
	Spring n=12	Summer n=9	Seasonal Mean n=2	
	Mean (±SE)	Mean (±SE)	Mean (±SE)	Probability Level
Percent Cover				
Turf cover (%)	0 (0)	0 (0)	0 (0)	1.00
Herbaceous cover (%)	88 (3)	97 (2)	92 (4)	0.01[a]
Shrub cover (%)	8 (3)	5 (3)	6 (2)	0.24
Tree cover (%)	1 (1)	0 (0)	1 (1)	0.39
Stem Density/ha				
Tree	59 (40)	39 (39)	49 (10)	0.64
Shrub	951 (506)	185 (185)	568 (383)	0.08[a]
Percent Cover		n=6		
Perennial cover (%)	-	92 (8)	-	-
Woody cover (%)	-	8 (8)	-	-
Mean height (cm)	-	54 (18)	-	-
Perennial mean height (cm)	-	44 (14)	-	-
Woody mean height (cm)	-	169 (NA)	-	-

Table 1.8. (cont'd)

	Nature Museum (NAM) Extensive Green Roof				
	2010	2011			
	Summer n=6 Mean (±SE)	Spring n=12 Mean (±SE)	Summer n=12 Mean (±SE)	Seasonal Mean n=2 Mean (±SE)	Probability Level
Percent Cover					
Turf cover (%)	0 (0)	0 (0)	0 (0)	0 (0)	1.00
Herbaceous cover (%)	86 (3)	75 (5)	74 (6)	74 (1)	0.98
Shrub cover (%)	0 (0)	0 (0)	0 (0)	0 (0)	1.00
Tree cover (%)	0 (0)	0 (0)	0 (0)	0 (0)	1.00
Stem Density/ha					
Tree	0 (0)	0 (0)	0 (0)	0 (0)	1.00
Shrub	0 (0)	0 (0)	0 (0)	0 (0)	1.00
Percent Cover			n=6		
Perennial cover (%)	-	-	91 (4)	-	-
Woody cover (%)	-	-	0 (0)	-	-
Mean height (cm)	-	-	20 (1)	-	-
Perennial mean height (cm)	-	-	22 (2)	-	-
Woody mean height (cm)	-	-	NA	-	-

Table 1.8. (cont'd)

	Nature Museum (NAM) Intensive Green Roof				
	2010	2011			
	Summer n=2 Mean (±SE)	Spring n=4 Mean (±SE)	Summer n=4 Mean (±SE)	Seasonal Mean n=2 Mean (±SE)	Probability Level
Percent Cover					
Turf cover (%)	0 (0)	0 (0)	0 (0)	0 (0)	1.00
Herbaceous cover (%)	78 (3)	82 (1)	80 (2)	81 (1)	0.46
Shrub cover (%)	2 (2)	3 (1)	4 (2)	4 (1)	0.77
Tree cover (%)	3 (3)	2 (1)	3 (2)	3 (0)	0.75
Stem Density/ha					
Tree	99 (99)	100 (58)	50 (50)	75 (25)	0.32
Shrub	197 (197)	1030 (366)	504 (205)	767 (263)	0.19
Percent Cover			n=2		
Perennial cover (%)	-	-	78 (12)	-	-
Woody cover (%)	-	-	5 (5)	-	-
Mean height (cm)	-	-	49 (19)	-	-
Perennial mean height (cm)	-	-	44 (0)	-	-
Woody mean height (cm)	-	-	284 (NA)	-	-

Table 1.8. (cont'd)

	Michigan Avenue Structure (MIA)			
	2011			
	Spring n=6 Mean (±SE)	Summer n=6 Mean (±SE)	Seasonal Mean n=2 Mean (±SE)	Probability Level
Percent Cover				
Turf cover (%)	0 (0)	0 (0)	0 (0)	1.00
Herbaceous cover (%)	63 (10)	82 (4)	73 (10)	0.17
Shrub cover (%)	0 (0)	0 (0)	0 (0)	1.00
Tree cover (%)	0 (0)	0 (0)	0 (0)	1.00
Stem Density/ha				
Tree	0 (0)	0 (0)	0 (0)	1.00
Shrub	0 (0)	0 (0)	0 (0)	1.00
Percent Cover		n=3		
Perennial cover (%)	-	89 (11)	-	-
Woody cover (%)	-	0 (0)	-	-
Mean height (cm)	-	27 (14)	-	-
Perennial mean height (cm)	-	35 (20)	-	-
Woody mean height (cm)	-	NA	-	-

Table 1.8. (cont'd)

	Schwab Rehabilitation Hospital (SCH)				
	2010	2011			
	Summer n=4 Mean (±SE)	Spring n=8 Mean (±SE)	Summer n=8 Mean (±SE)	Seasonal Mean n=2 Mean (±SE)	Probability Level
Percent Cover					
Turf cover (%)	0 (0)	0 (0)	0 (0)	0 (0)	1.00
Herbaceous cover (%)	64 (8)	30 (5)	50 (7)	40 (10)	0.02[a]
Shrub cover (%)	4 (4)	6 (3)	9 (5)	7 (2)	0.78
Tree cover (%)	11 (7)	13 (4)	14 (5)	14 (0)	0.79
Stem Density/ha					
Tree	500 (410)	519 (368)	248 (146)	383 (136)	0.76
Shrub	643 (643)	1606 (965)	2137 (1168)	1872 (265)	0.76
Percent Cover			n=4		
Perennial cover (%)	-	-	47 (8)	-	-
Woody cover (%)	-	-	10 (6)	-	-
Mean height (cm)	-	-	60 (35)	-	-
Perennial mean height (cm)	-	-	36 (7)	-	-
Woody mean height (cm)	-	-	358 (262)	-	-

Table 1.8. (cont'd)

	Gary Comer Youth Center (GCY)			
	2011			
	Spring n=6 Mean (±SE)	Summer n=6 Mean (±SE)	Seasonal Mean n=2 Mean (±SE)	Probability Level
Percent Cover				
Turf cover (%)	0 (0)	0 (0)	0 (0)	1.00
Herbaceous cover (%)	48 (5)	60 (3)	54 (6)	0.11
Shrub cover (%)	0 (0)	0 (0)	0 (0)	1.00
Tree cover (%)	0 (0)	0 (0)	0 (0)	1.00
Stem Density/ha				
Tree	0 (0)	0 (0)	0 (0)	1.00
Shrub	0 (0)	0 (0)	0 (0)	1.00
Percent Cover		n=3		
Perennial cover (%)	-	83 (8)	-	-
Woody cover (%)	-	0 (0)	-	-
Mean height (cm)	-	39 (14)	-	-
Perennial mean height (cm)	-	44 (12)	-	-
Woody mean height (cm)	-	NA	-	-

Table 1.8. (cont'd)

	Plant and Soil Science Building (PSS)			
	2010			
	Spring n=3	Summer n=3	Seasonal Mean n=2	
	Mean (±SE)	Mean (±SE)	Mean (±SE)	Probability Level
Percent Cover				
Turf cover (%)	0 (0)	0 (0)	0 (0)	1.00
Herbaceous cover (%)	100 (0)	100 (0)	100 (0)	1.00
Shrub cover (%)	0 (0)	0 (0)	0 (0)	1.00
Tree cover (%)	0 (0)	0 (0)	0 (0)	1.00
Stem Density/ha				
Tree	0 (0)	0 (0)	0 (0)	1.00
Shrub	0 (0)	0 (0)	0 (0)	1.00

[a] Indicates a significant difference between Spring and Summer within the same year

Table 1.9. Means and standard errors for variables characterizing vegetation structure of the landscape surrounding each green roof during early sampling periods, late sampling periods, and the entire sampling season, in Michigan and Illinois, U.S.A., in 2010 and 2011. Probability levels for comparisons between spring and summer within the same year were calculated with the Kruskal-Wallis one-way analysis of variance

	Downtown Chicago Park (DPC)			
	2010			
	Spring n=9 Mean (±SE)	Summer n=9 Mean (±SE)	Seasonal Mean n=2 Mean (±SE)	Probability Level
Percent Cover				
Turf cover (%)	62 (15)	82 (5)	72 (10)	0.44
Herbaceous cover (%)	0 (0)	0 (0)	0 (0)	1.00
Shrub cover (%)	0 (0)	1 (1)	0 (0)	0.84
Tree cover (%)	68 (15)	75 (9)	72 (4)	0.64
Stem Density/ha				
Tree	674 (303)	299 (189)	486 (187)	0.26
Shrub	79 (79)	34 (34)	57 (23)	0.69

Table 1.9. (cont'd)

	Ford Truck Plant (FOR)			
	2010			
	Spring n=3 Mean (±SE)	Summer n=3 Mean (±SE)	Seasonal Mean n=2 Mean (±SE)	Probability Level
Percent Cover				
Turf cover (%)	53 (14)	62 (6)	58 (4)	0.86
Herbaceous cover (%)	31 (15)	0 (0)	16 (15)	0.40
Shrub cover (%)	2 (1)	3 (2)	3 (0)	0.73
Tree cover (%)	2 (1)	1 (1)	1 (1)	0.25
Stem Density/ha				
Tree	82 (41)	46 (46)	64 (18)	0.36
Shrub	293 (145)	370 (173)	332 (38)	0.65

	Ford Truck Plant (FOR)			
	2011			
	Spring n=18 Mean (±SE)	Summer n=3 Mean (±SE)	Seasonal Mean n=2 Mean (±SE)	Probability Level
Percent Cover				
Turf cover (%)	72 (8)	57 (15)	64 (7)	0.59
Herbaceous cover (%)	17 (8)	27 (13)	22 (5)	0.86
Shrub cover (%)	2 (1)	3 (2)	2 (0)	0.62
Tree cover (%)	2 (1)	3 (2)	2 (1)	0.97
Stem Density/ha				
Tree	111 (43)	74 (52)	92 (19)	0.76
Shrub	379 (164)	213 (122)	296 (83)	0.89

Table 1.9. (cont'd)

	McCormick Parking Structure (MCC)			
	2010			
	Spring n=3	Summer n=3	Seasonal Mean n=2	Probability
	Mean (±SE)	Mean (±SE)	Mean (±SE)	Level
Percent Cover				
Turf cover (%)	63 (9)	59 (15)	61 (2)	0.86
Herbaceous cover (%)	3 (3)	27 (14)	15 (12)	0.11
Shrub cover (%)	3 (1)	4 (2)	4 (1)	0.81
Tree cover (%)	41 (14)	25 (9)	33 (8)	0.66
Stem Density/ha				
Tree	127 (65)	74 (42)	101 (26)	0.58
Shrub	405 (173)	193 (83)	299 (106)	0.54

	Aquascape Headquarters (AQU)			
	2010			
	Spring n=3	Summer n=3	Seasonal Mean n=2	Probability
	Mean (±SE)	Mean (±SE)	Mean (±SE)	Level
Percent Cover				
Turf cover (%)	86 (7)	0 (0)	43 (43)	0.04[a]
Herbaceous cover (%)	7 (4)	86 (8)	47 (39)	0.05[a]
Shrub cover (%)	2 (2)	0 (0)	1 (1)	0.32
Tree cover (%)	8 (4)	1 (1)	5 (4)	0.25
Stem Density/ha				
Tree	119 (119)	137 (137)	128 (9)	0.80
Shrub	97 (97)	137 (137)	49 (20)	0.32

Table 1.9. (cont'd)

	Haworth Headquarters (HAW)			
	2010			
	Spring n=3 Mean (±SE)	Summer n=3 Mean (±SE)	Seasonal Mean n=2 Mean (±SE)	Probability Level
Percent Cover				
Turf cover (%)	29 (14)	37 (14)	33 (4)	0.37
Herbaceous cover (%)	52 (14)	44 (14)	48 (4)	0.50
Shrub cover (%)	0 (0)	0 (0)	0 (0)	1.00
Tree cover (%)	8 (4)	2 (1)	5 (3)	0.45
Stem Density/ha				
Tree	78 (40)	44 (35)	61 (17)	0.08[a]
Shrub	0 (0)	0 (0)	0 (0)	0.20

	Haworth Headquarters (HAW)			
	2011			
	Spring n=3 Mean (±SE)	Summer n=6 Mean (±SE)	Seasonal Mean n=2 Mean (±SE)	Probability Level
Percent Cover				
Turf cover (%)	59 (15)	49 (9)	54 (5)	0.42
Herbaceous cover (%)	33 (16)	43 (10)	38 (5)	0.24
Shrub cover (%)	0 (0)	0 (0)	0 (0)	1.00
Tree cover (%)	6 (3)	7 (3)	7 (0)	0.80
Stem Density/ha				
Tree	52 (35)	25 (12)	39 (14)	0.59
Shrub	73 (61)	42 (32)	57 (15)	0.51

Table 1.9. (cont'd)

	Nature Museum (NAM)				
	2010	2011			
	Summer n=6 Mean (±SE)	Spring n=12 Mean (±SE)	Summer n=12 Mean (±SE)	Seasonal Mean n=2 Mean (±SE)	Probability Level
Percent Cover					
Turf cover (%)	25 (12)	21 (8)	23 (12)	22 (1)	0.96
Herbaceous cover (%)	53 (13)	47 (8)	44 (13)	46 (1)	0.95
Shrub cover (%)	8 (5)	3 (1)	9 (3)	6 (3)	0.07
Tree cover (%)	24 (7)	31 (7)	25 (9)	28 (3)	0.61
Stem Density/ha					
Tree	88 (83)	286 (103)	138 (64)	212 (74)	0.28
Shrub	504 (265)	597 (253)	1220 (490)	909 (312)	0.69

	Schwab Rehabilitation Hospital (SCH)				
	2010	2011			
	Summer n=4 Mean (±SE)	Spring n=8 Mean (±SE)	Summer n=8 Mean (±SE)	Seasonal Mean n=2 Mean (±SE)	Probability Level
Percent Cover					
Turf cover (%)	59 (15)	80 (6)	77 (8)	78 (2)	0.45
Herbaceous cover (%)	0 (0)	0 (0)	0 (0)	0 (0)	1.00
Shrub cover (%)	0 (0)	0 (0)	0 (0)	0 (0)	0.48
Tree cover (%)	25 (6)	24 (6)	22 (7)	23 (1)	0.78
Stem Density/ha					
Tree	93 (43)	112 (45)	48 (48)	80 (32)	0.48
Shrub	0 (0)	13 (13)	0 (0)	7 (7)	0.29

Table 1.9. (cont'd)

	Gary Comer Youth Center (GCY)			
	2011			
	Spring n=6 Mean (±SE)	Summer n=6 Mean (±SE)	Seasonal Mean n=2 Mean (±SE)	Probability Level
Percent Cover				
Turf cover (%)	41 (8)	49 (11)	45 (4)	0.48
Herbaceous cover (%)	6 (5)	6 (6)	6 (0)	0.74
Shrub cover (%)	9 (3)	8 (5)	8 (0)	0.94
Tree cover (%)	34 (12)	37 (17)	35 (2)	0.59
Stem Density/ha				
Tree	480 (206)	653 (256)	566 (87)	0.21
Shrub	1298 (364)	529 (210)	913 (385)	0.49

	Plant and Soil Science Building (PSS)
	2010
	Summer n=3 Mean (±SE)
Percent Cover	
Turf cover (%)	55 (10)
Herbaceous cover (%)	4 (2)
Shrub cover (%)	12 (4)
Tree cover (%)	33 (9)
Stem Density/ha	
Tree	137 (98)
Shrub	339 (207)

[a] Indicates a significant difference between Spring and Summer within the same year

Table 1.10. Percent cover for land cover variables characterizing surrounding landscapes of green roof study sites in Michigan and Illinois, U.S.A., in 2010 and 2011

	DCP	FOR	MCC	AQU	HAW	CCE	CHA
Studied green roof (%)	10	19	9	5	2	1	2
Other green roof (%)	1	0	3	0	0	9	1
Woody vegetation (%)	10	4	17	26	3	1	1
Herbaceous vegetation (%)	5	35	19	49	22	0	0
Water (%)	0	2	29	6	1	0	0
Non-green Roof (%)	33	37	11	14	36	46	55
Other impervious surface (%)	40	3	12	0	35	42	43
Pre-green roof green space (%)	15	40	36	75	26	1	1
Current green space (%)	26	58	48	80	27	12	33
Potential green space (%)	60	98	59	94	64	58	57
Potential green space (% increase)	125	68	22	17	132	399	1990

Table 110. (cont'd)

	NAM	MIA	SCH	GCY	PSS	Mean (±SE)
Studied green roof (%)	1	1	1	0	0	4 (2)
Other green roof (%)	0	0	0	0	0	1 (1)
Woody vegetation (%)	36	5	19	15	19	13 (3)
Herbaceous vegetation (%)	21	0	19	16	19	17 (4)
Water (%)	14	0	0	0	0	4 (3)
Non-green Roof (%)	4	57	23	20	21	30 (5)
Other impervious surface (%)	24	35	38	48	41	30 (5)
Pre-green roof green space (%)	57	5	38	31	38	30 [a] (7)
Current green space (%)	58	8	39	32	38	36 [a] (7)
Potential green space (%)	62	65	61	52	59	66 [b] (4)
Potential green space (% increase)	6	737	59	64	56	306 (165)

[a,b] Means with different letters are significantly different ($p \leq 0.10$).

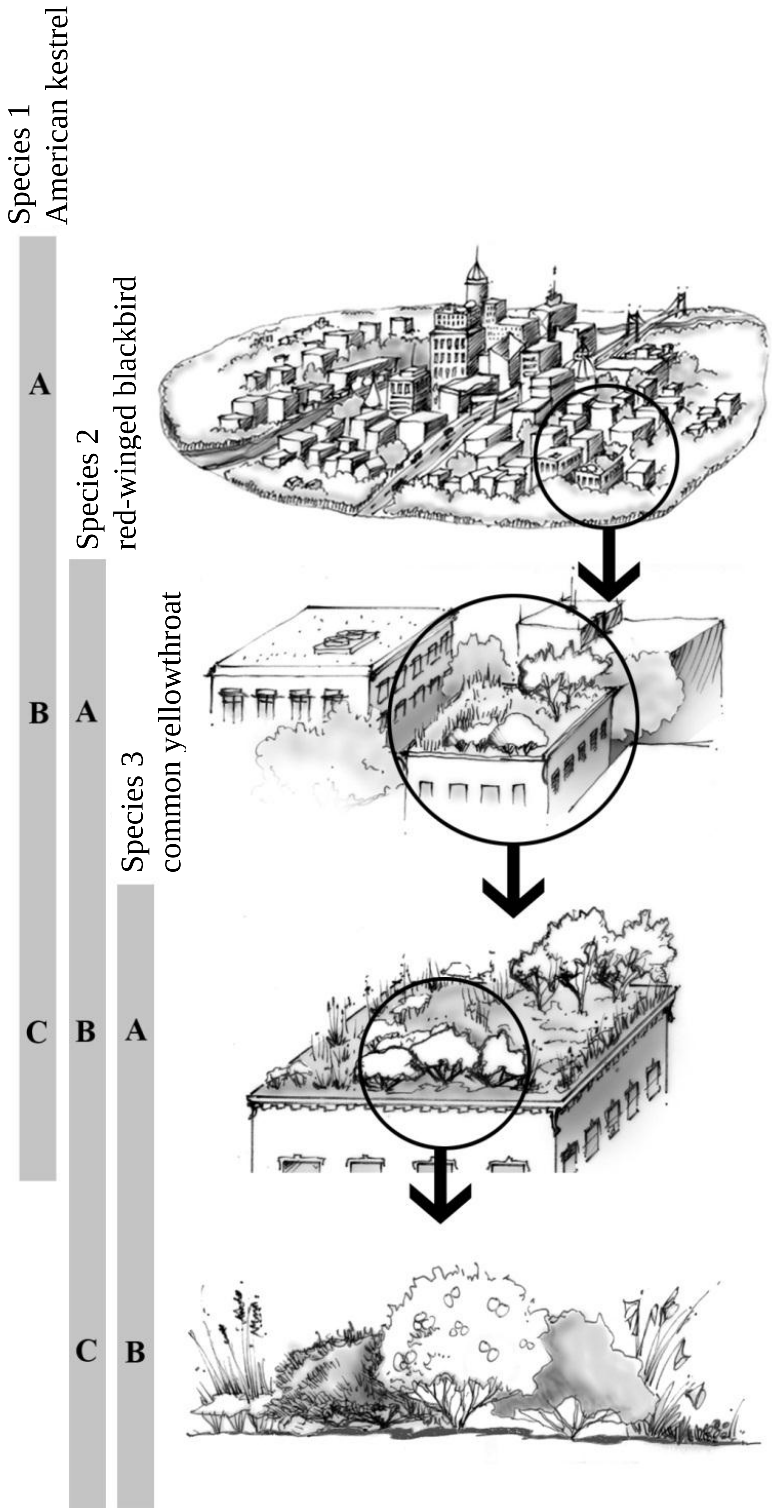

Figure 1.1. Range of scales at which birds may respond to green roof vegetation. The presence of green roof vegetation may invoke a response for some bird species selecting habitat at a broad scale (A – home range), for some at a finer level of patch selection (B - feeding area), or at finer level of microhabitat selection (C - one of many feeding sites).

Figure 1.2*. Map of the Northeast United States depicting study site locations in 2010 and 2011. Location A sites are in the greater Chicago area: the western location marker is a site in St. Charles, Illinois and the eastern marker represents all sites within Chicago, Illinois. Location B is a site in Holland, Michigan, location C is a site in East Lansing, Michigan, and location D is a site in Dearborn, Michigan.

Figure 1.3*. Map of northeast Illinois and southern Michigan depicting study site locations in 2010 and 2011. Location A sites are in the greater Chicago, Illinois area, location B is in Holland, Michigan, location C is in East Lansing, Michigan, and location D is in Dearborn, Michigan.

Figure 1.4*. Map of study sites within Chicago, Illinois in 2010 and 2011. Location A is a site at a Nature Museum (NAM), location B is a site at a Michigan Avenue Structure (NAM), location C is at Chicago City Hall (CHA), location D is at Chicago Cultural Center (CCE), location E is at a Downtown Chicago Park (DCP), location F is at McCormick Parking Structure (MCC), location G is at Schwab Rehabilitation Hospital (SCH), and location H is at Gary Comer Youth Center (GCY).

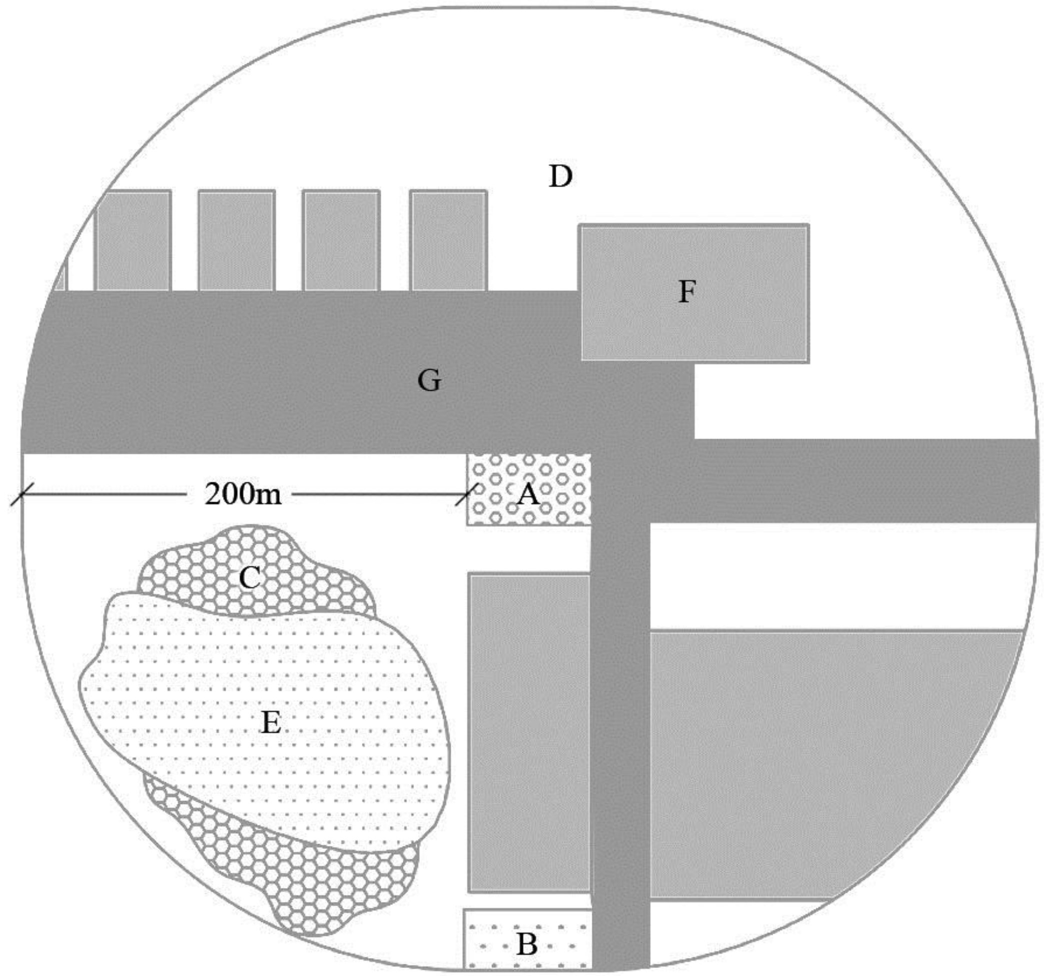

Figure 1.5. Schematic aerial view of a study site includes the studied green roof (A) and all land types cover within a 200m radius of the green roof. Other land cover types include other non-studied green roofs (B), woody vegetation (C), herbaceous vegetation (D), water (E), non-green roofs (F), and other impervious surfaces (G).

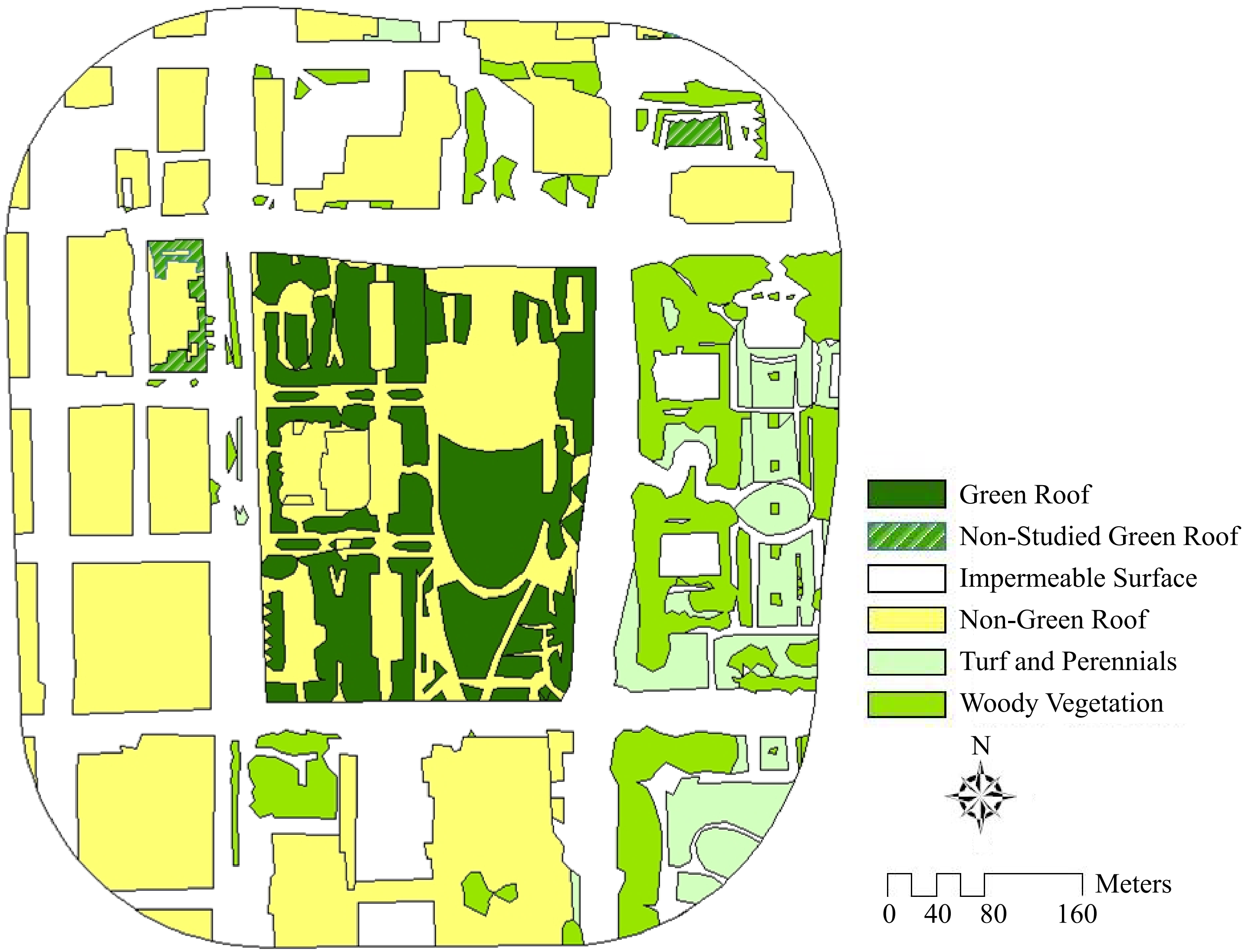

Figure 1.6*. Land cover composition of the Downtown Chicago Park (DCP) study site.
* Some of the figures in the document are presented in color. For interpretation of the references to color in these figures, the reader is referred to the electronic version of this thesis.

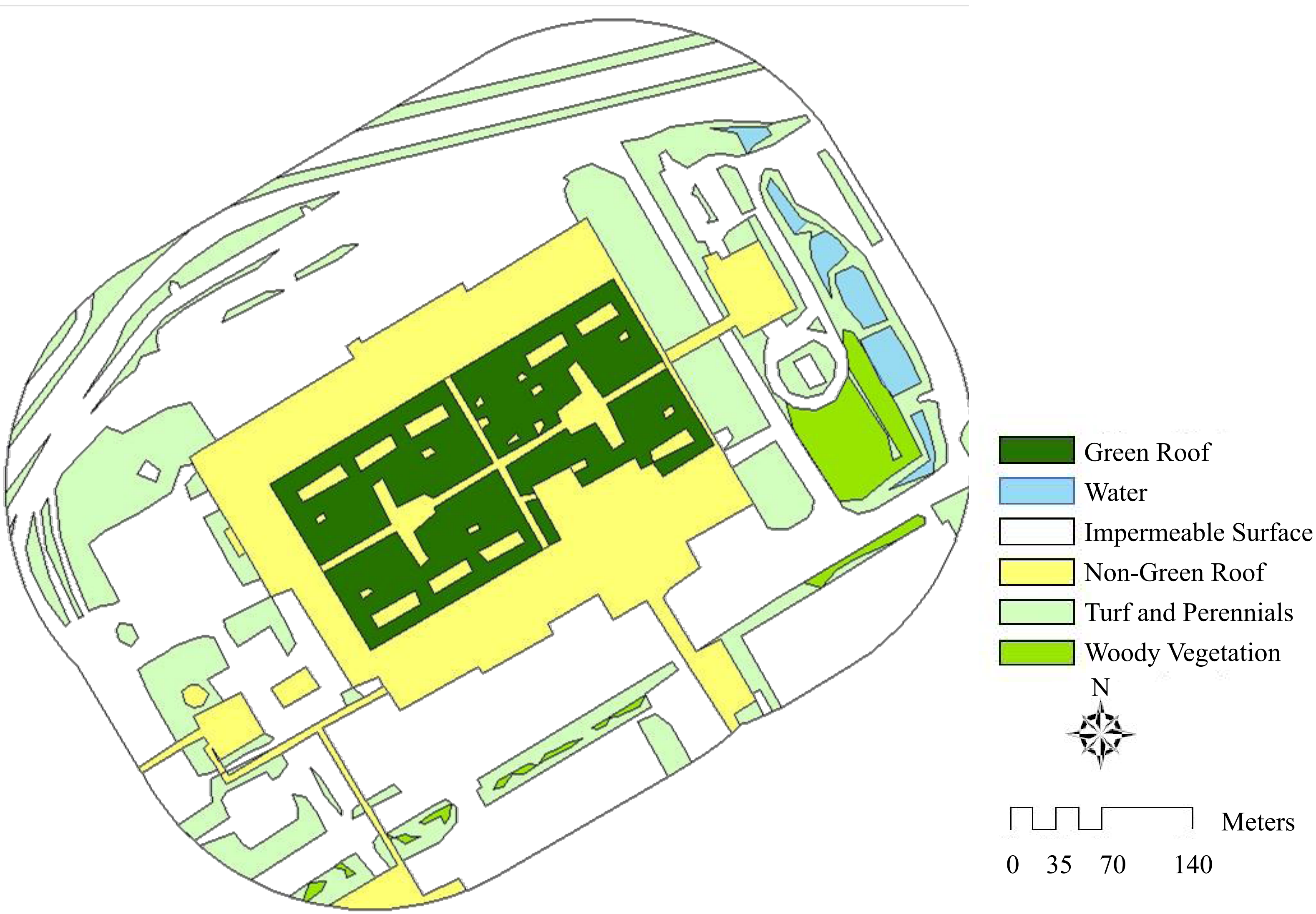

Figure 1.7. Land cover composition of the Ford Truck Plant (FOR) study site.

Figure 1.8. Land cover composition of the Haworth Headquarters (HAW) study site.

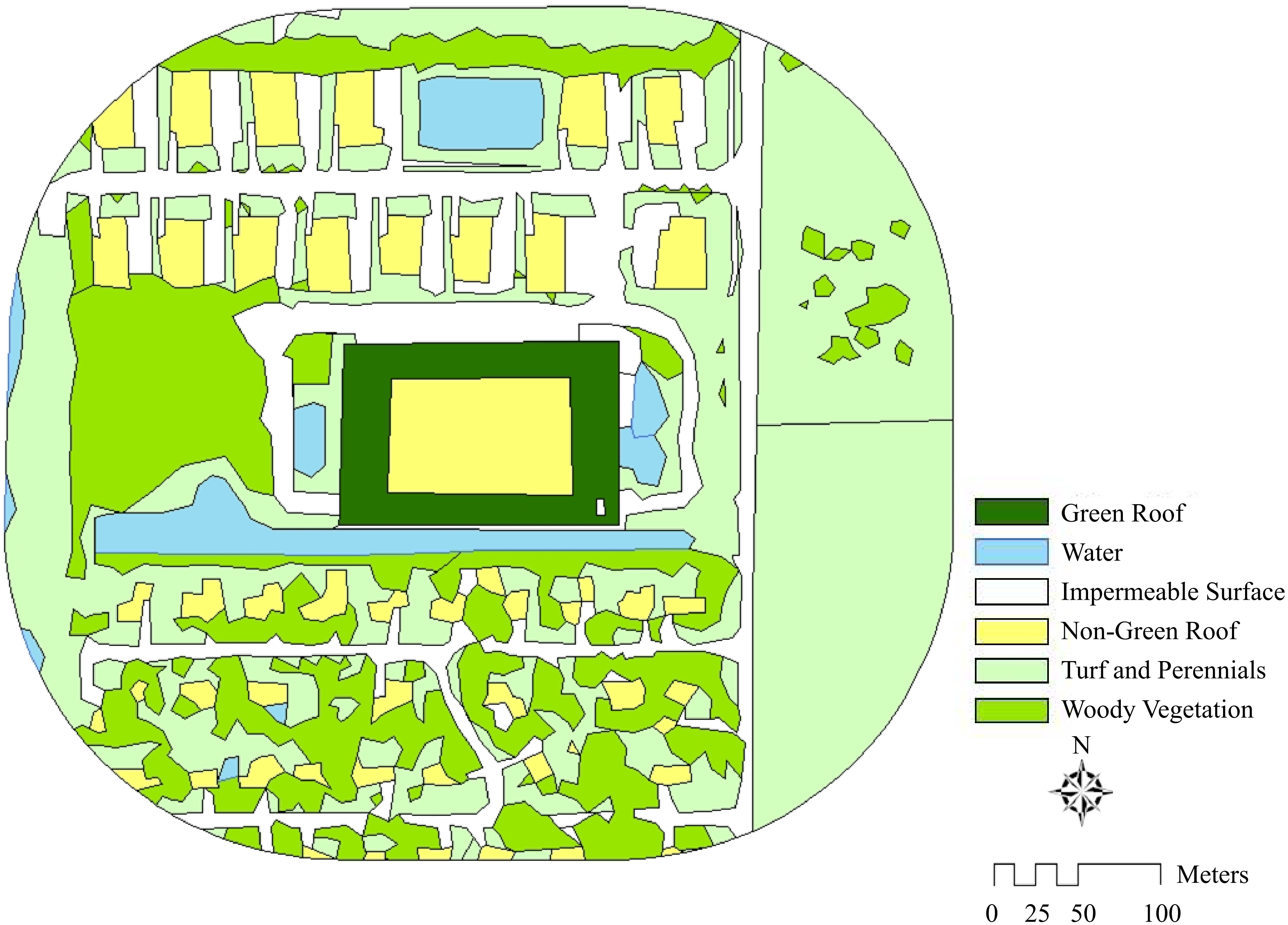

Figure 1.9. Land cover composition of the Aquascape Headquarters (AQU) study site.

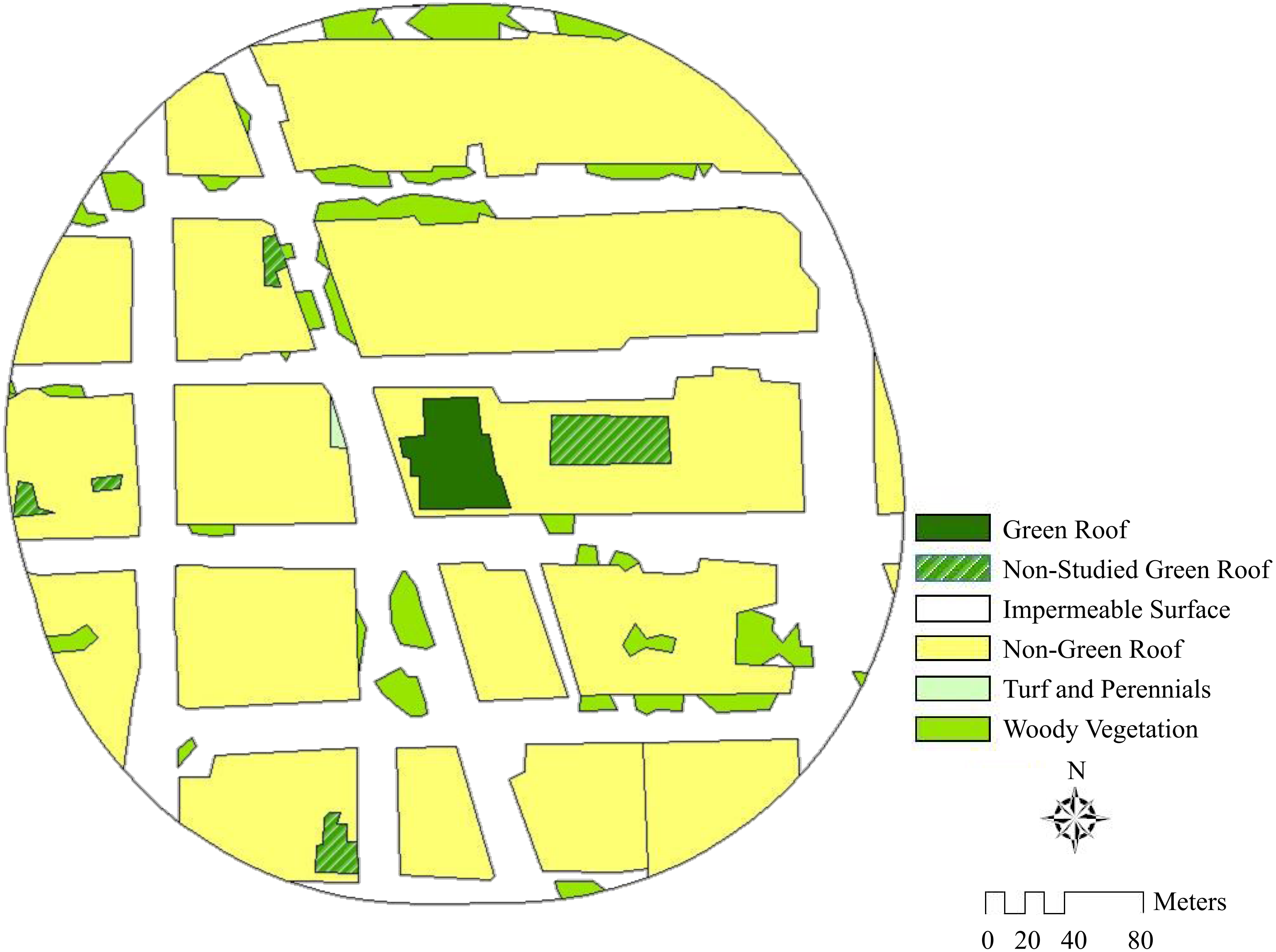

Figure 1.10. Land cover composition of the Michigan Avenue Structure (MIA) study site.

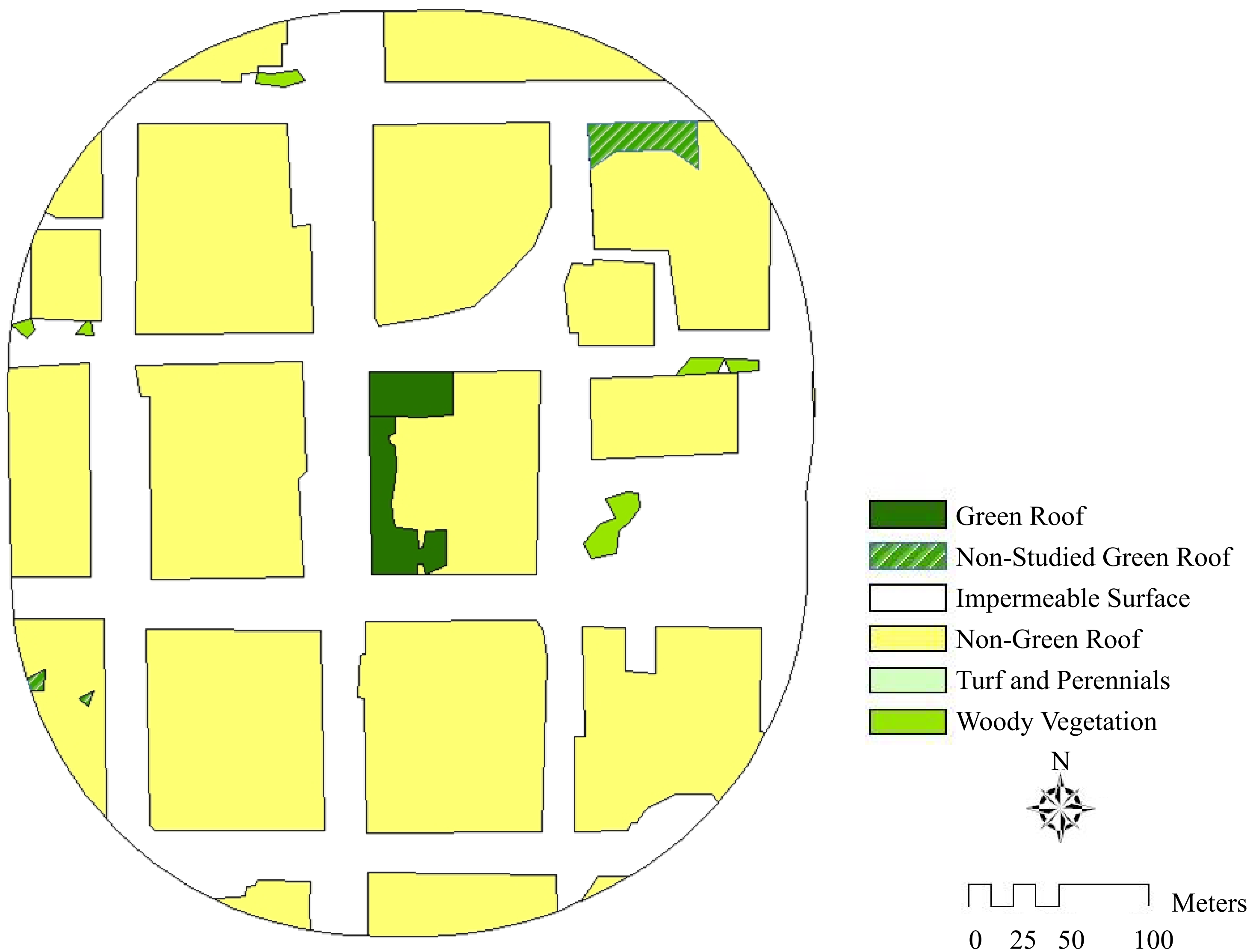

Figure 1.11. Land cover composition of the Chicago City Hall (CHA) study site.

Figure 1.12. Land cover composition of the Chicago Cultural Center (CCE) study site.

Figure 1.13. Land cover composition of the McCormick Parking Structure (MCC) study site.

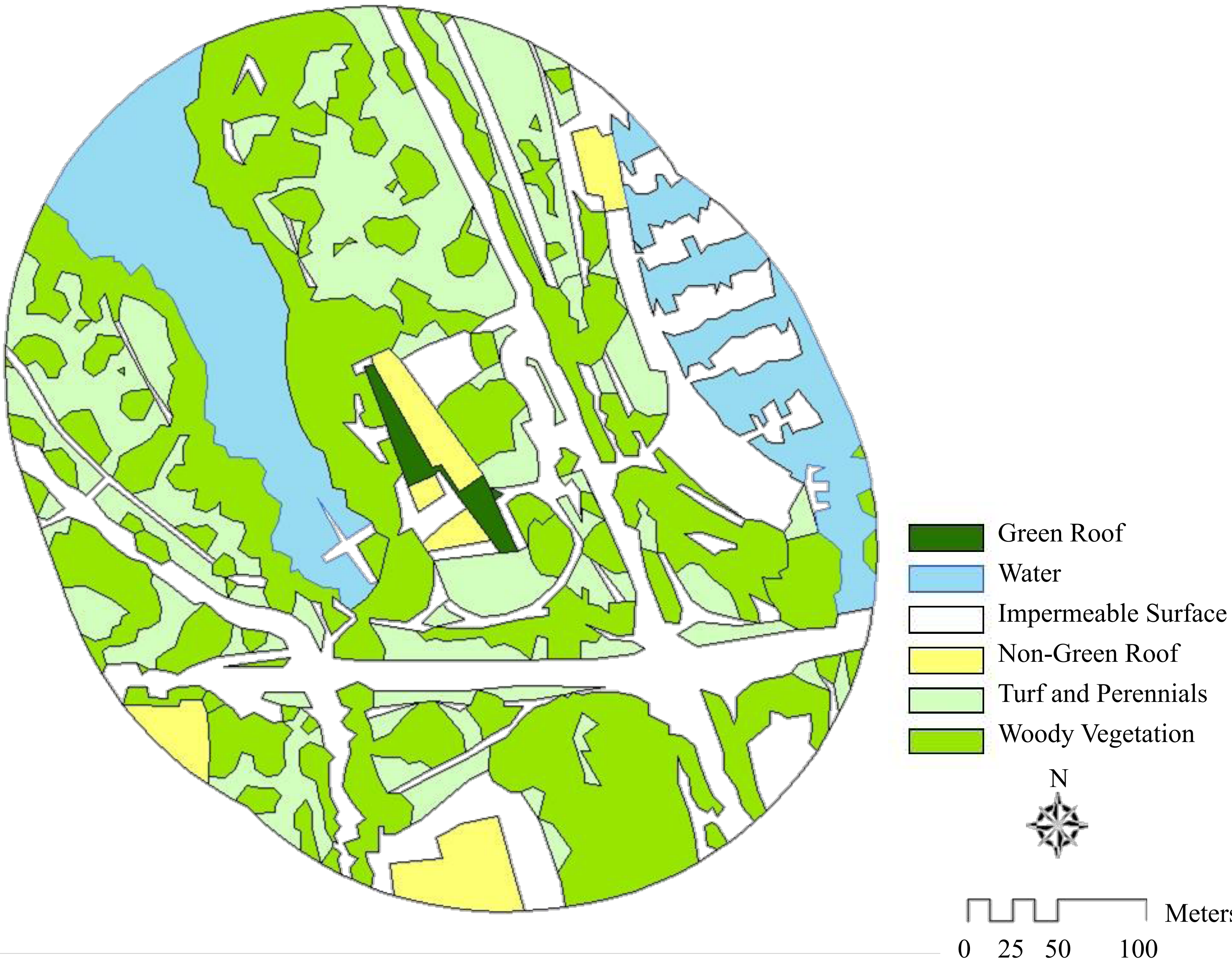

Figure 1.14. Land cover composition of the Nature Museum (NAM) study site.

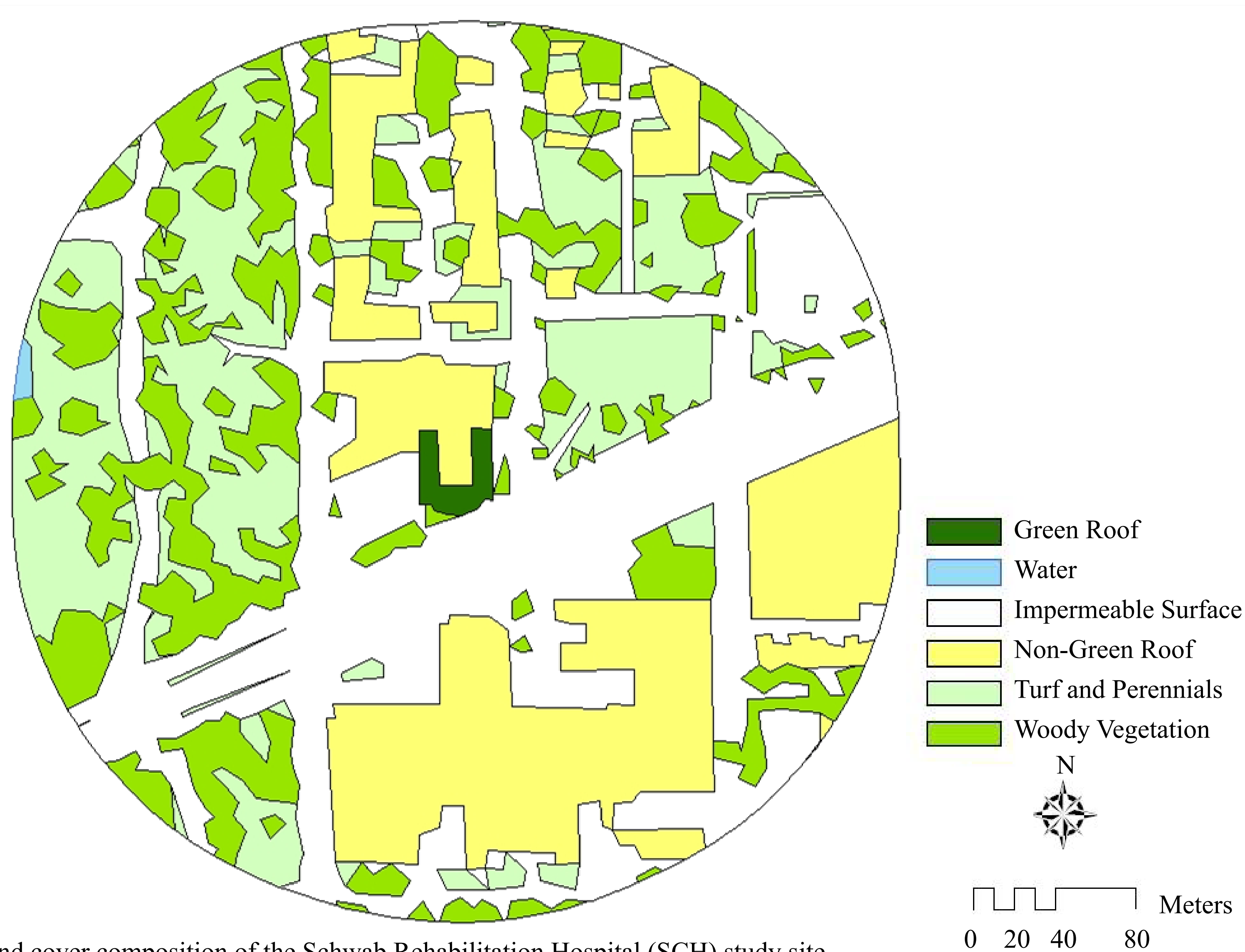

Figure 1.15. Land cover composition of the Schwab Rehabilitation Hospital (SCH) study site.

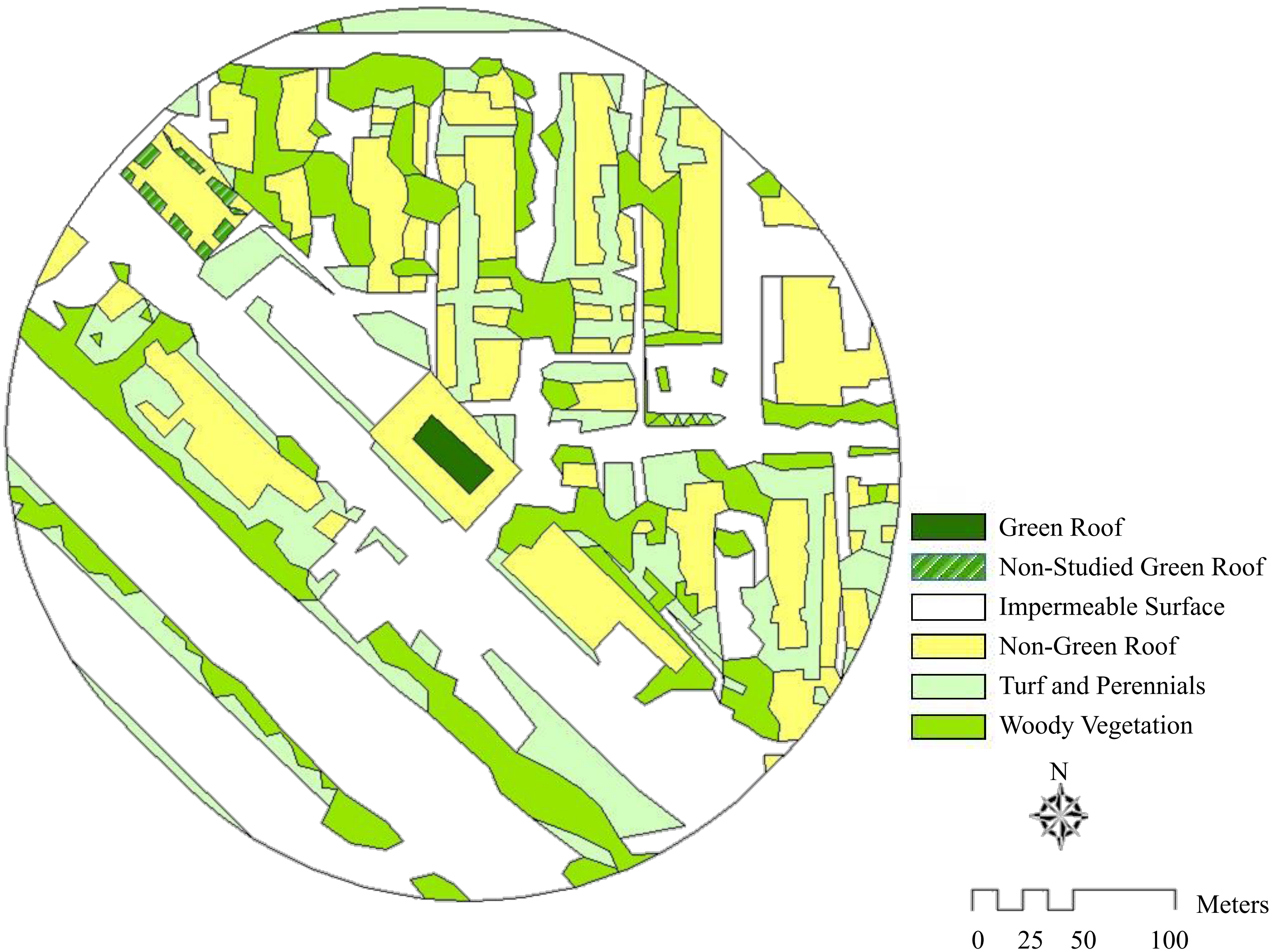

Figure 1.16. Land cover composition of the Gary Comer Youth Center (GCY) study site.

Figure 1.17. Land cover composition of the Plant and Soil Science Building (PSS) study site at Michigan State University.

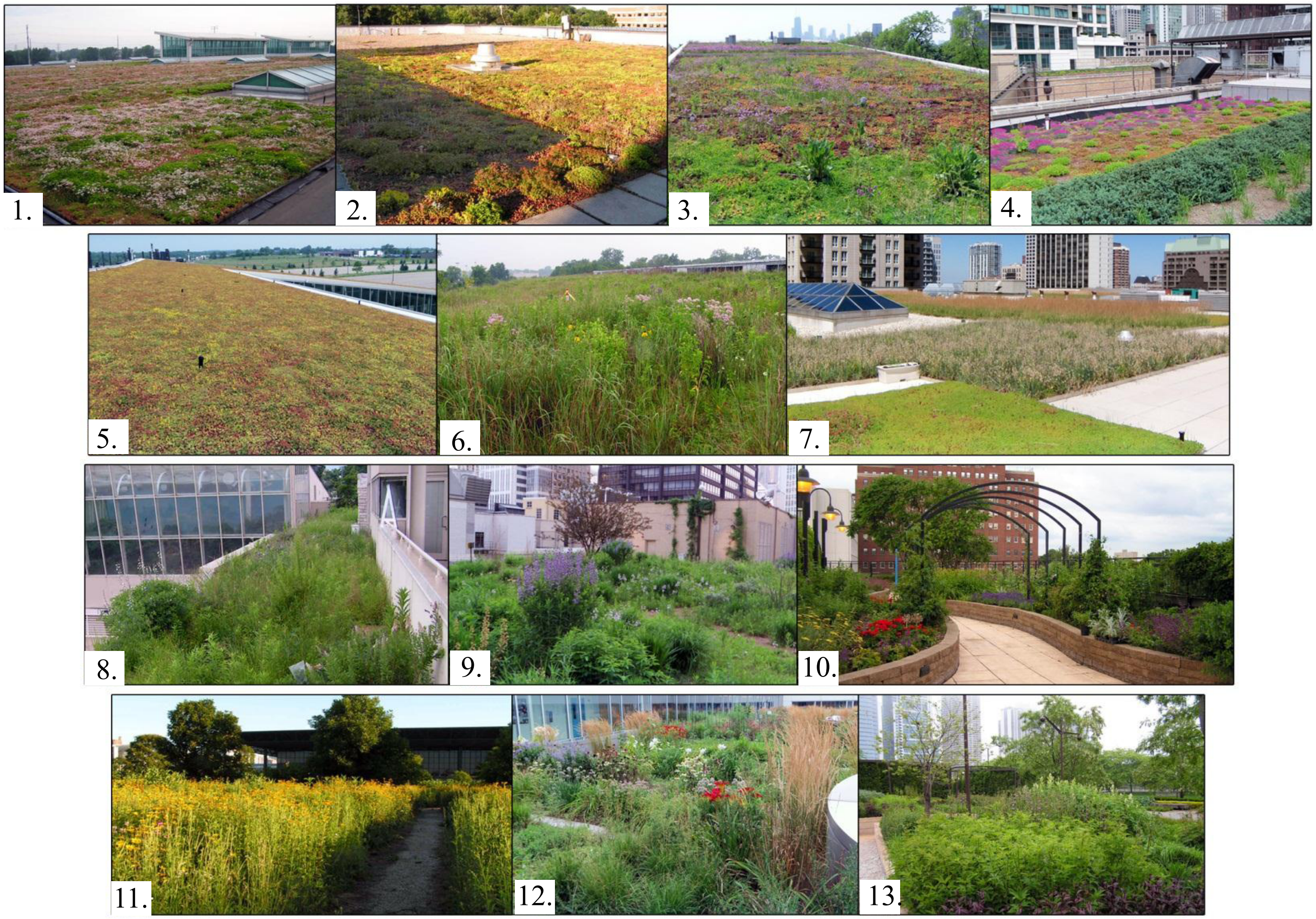

Figure 1.18. Examples of summer green roof vegetation on studied green roofs in 2010 and 2011 in Michigan and Illinois, U.S.A., in order of planting media depth from shallow to deep were (1) Ford Truck Plant, (2) Plant and Soil Science Building, (3) extensive roof on a Nature Museum, (4) Chicago Cultural Center, (5) Haworth Headquarters,(6) Aquascape Headquarters, (7) Michigan Avenue Structure, (8) intensive roof on a Nature Museum, (9) Chicago City Hall, (10) Schwab Rehabilitation Hospital, (11) McCormick Parking Structure, (12) Gary Comer Youth Center, (13) Downtown Chicago Park. As a general trend, extensive roofs (1-7) have less vegetation structure compared to intensive roofs (8-13).

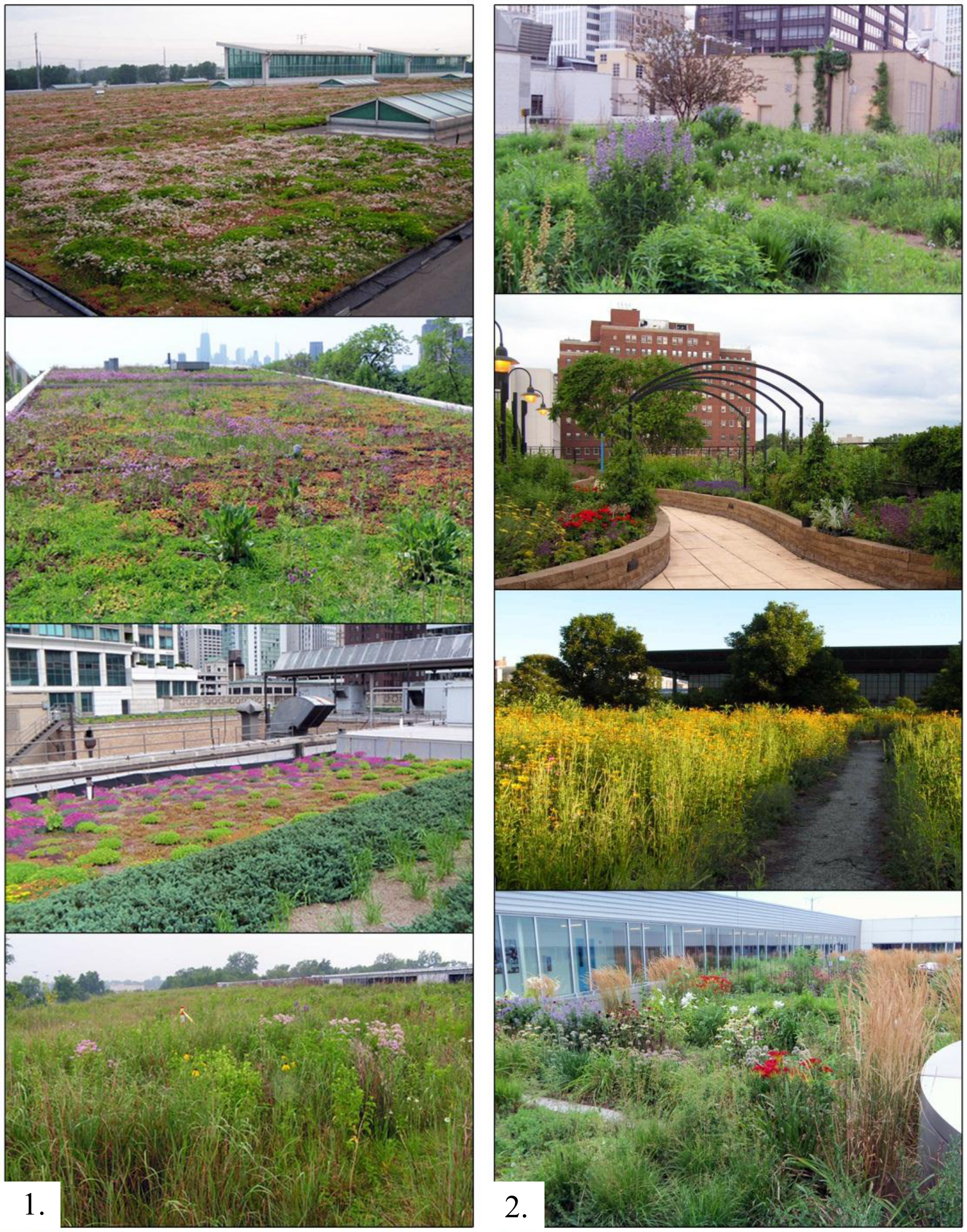

Figure 1.19. Examples of green roof vegetation on (1) extensive and (2) intensive green roofs in 2010 and 2011 in Michigan and Illinois, U.S.A. As a general trend, extensive roofs have less vegetation structure compared to intensive roofs.

APPENDIX

APPENDIX

Table A.1. Planted species on the Downtown Chicago Park (DCP) green roof.

Scientific Name	Common Name	Type (W=woody, P=perennial)
'Violetta'	New England Aster	P
Abies concolor	White Fir	W
Acer freemanii 'Jeffsred'	Autumn Blaze Maple	W
Agastache 'Blue Fortune'	Giant Hyssop	P
Allium 'Summer Beauty'	Ornamental Onion	P
Allium aflatunense 'Purple Sensation'	Ornamental Allium	P
Allium atropurpureum	Ornamental Allium	P
Allium christophii	Star Of Persia	P
Allium sphaerocephalon	Drumstick Allium	P
Amorpha canescens	Leadplant	P
Amsonia 'Blue Ice'	Blue Star	P
Amsonia hubrichtii	Arkansas Blue Star	P
Amsonia tabernaemontana var. salicifolia	Willowleaf Blue Star	P
Anemone blanda 'Blue Shades'	Windflower	P
Anemone hupehensis 'Praecox'	Japanese Anemone	P
Anemone hupehensis 'Splendens'	Japanese Anemone	P
Anemone japonica 'Honorine Jobert'	Japanese Anemone	P
Anemone leveillei	Windflower	P
Arborvitae sp.	Arborvitae	W
Aruncus 'Horatio'	Goatsbeard	P
Asclepias incarnata	Swamp Milkweed	P
Asclepias tuberosa	Butterfly Weed	P
Aster 'October Skies'	Aster	P
Aster divaricatus	White Wood Aster	P

Table A.1. (cont'd)

Scientific Name	Common Name	Type (W=woody, P=perennial)
Aster novae	Angliae	P
Aster oblongifolius 'October Skies'	October Skies Aster	P
Aster tataricus 'Jindai'	Tatarian Aster	P
Astilbe chinensis var. taquetii 'Purpurlanze'	Purple Lance Astilbe	P
Astrantia major 'Claret'	Masterwort	P
Astrantia major 'Roma'	Masterwort	P
Baptisia 'Purple Smoke'	Hybrid Wild Indigo	P
Baptisia leucantha	Wild White Indigo	P
Briza media	Quaking Grass	P
Calamagrostis brachytricha	Korean Feather Reed Grass	P
Calamagrostis x acutiflora 'Karl Foerster'	Feather Reed Grass	P
Calamintha nepeta subsp.nepeta	Calamint	P
Camassia cusickii	Quamash	P
Camassia leichtlinii 'Blue Danube'	Quamash	P
Campanula glomerata 'Caroline'	Clustered Bellflower	P
Carex muskingumensis	Palm Sedge	P
Carex pennsylvanica	Pennsylvania Sedge	P
Carpinus betulus 'Fastigiata'	Hornbeam	W
Caryopteris x clandonensis 'Black Knight'	Bluebeard	W
Cerastostigma plumbaginoides	Plumbago	P
Cercis canadensis	Red Bud	W
Cercis Canadensis	Eastern Redbud	W
Chasmanthium latifolium	Northern Sea Oats	P
Chionodoxa forbesii 'Blue Giant'	Glory Of The Snow	P
Chionodoxa forbesii 'Violet Beauty'	Glory Of The Snow	P
Chionodoxa sardensis	Glory Of The Snow	P

Table A.1. (cont'd)

Scientific Name	Common Name	Type (W=woody, P=perennial)
Coreopsis verticillata 'Golden Showers'	Thread Leaf Tickseed	P
Crataegus sp.	Hawthorn	W
Crocus tommasinianus 'Barrs Purple'	Crocus	P
Dalea purpurea	Purple Prairie Clover	P
Datisca cannabina	Datisca	P
Deschampsia caespitosa 'Goldstaub'	Tufted Hair Grass	P
Digitalis ferruginea	Rusty Foxglove	P
Dodecatheon 'Aphrodite'	Shooting Star	P
Echinacea 'Orange Meadowbrite'	Coneflower	P
Echinacea 'Sunset'	Coneflower	P
Echinacea pallida	Pale Coneflower	P
Echinacea purpurea 'Green Edge'	Coneflower	P
Echinacea purpurea 'Rubinglow'	Coneflower	P
Echinacea tennesseensis	Tennessee Coneflower	P
Echinops bannaticus 'Blue Glow'	Globe Thistle	P
Epimedium grandiflorum 'Lilafee'	Longspur Barrenwort	P
Epimedium x versicolor 'Sulphureum'	Bishop's Hat	P
Eragrostis spectabilis	Purple Love Grass	P
Eryngium bourgatii	Mediterranean Sea Holly	P
Eryngium yuccifolium	Rattlesnake Master	P
Euonymus alatus 'Compacta'	Burning Bush	W
Eupatorium maculatum 'Gateway'	Joe Pye Weed	P
Eupatorium maculatum 'Purple Bush'	Joe Pye Weed	P
Eupatorium rugosum 'Chocolate'	Joe Pye Weed	P
Fagus sylvatica	European Beech	W
Filipendula rubra 'Venusta Magnifica'	Queen Of The Prairie	P

Table A.1. (cont'd)

Scientific Name	Common Name	Type (W=woody, P=perennial)
Fritillaria pallidiflora	Fritillary	P
Gentiana andrewsii	Gentian	P
Geranium 'Brookside'	Cranesbill	P
Geranium 'Dilys'	Cranesbill	P
Geranium 'Jolly Bee'	Cranesbill	P
Geranium phaeum f. album	Dusky Cranesbill	P
Geranium sanguineum 'Max Frei'	Cranesbill	P
Geranium soboliferum	Cranesbill	P
Geranium x cantabrigiense 'Karmina'	Cranesbill	P
Geranium x oxonianum 'Claridge Druce'	Cranesbill	P
Geum rivale 'Flames of Passion'	Avens	P
Geum triflorum	Prairie Smoke	P
Gillenia trifoliata	Bowman's Root	P
Hakenochloa macra	Hakone Grass	P
Helenium 'Rubinzwerg'	Sneezeweed	P
Helleborus orientalis	Lenten Rose	P
Hemerocallis 'Chicago Apache' –	Daylily	P
Hemerocallis 'Gentle Shepherd'	Daylily	P
Heuchera 'Palace Purple'	Coral Flower	P
Heuchera richardsonii	Coral Bells	P
Heuchera villosa 'Autumn Bride'	Coral Bell	P
Hosta 'Blue Angel'	Hosta	P
Hosta 'Halycon'	Hosta	P
Hosta 'Royal Standard'	Hosta	P
Hosta 'White Triumphator'	Hosta	P

Table A.1. (cont'd)

Scientific Name	Common Name	Type (W=woody, P=perennial)
Inula magnifica 'Sonnestrahl'	Fleabane	P
Jeffersonia diphylla	Twinleaf	P
Kalimeris incisa	Cast-iron Plant	P
Knautia macedonica	Knautia	P
Liatris spicata	Blazing Star	P
Liatris spicata 'Alba'	White Blazing Star	P
Limonium latifolium	Sea Lavender	P
Lythrum alatum	Loosestrife	P
Malus 'Sutyzam'	Sugar Thyme Crabapple	W
Mertensia virginica	Virginia Bluebells	P
Miscanthus sinensis 'Malepartus'	Common Eulalia Grass	P
Molinia caerulea 'Dauerstrahl'	Moor Grass	P
Molinia caerulea 'Moorflamme'	Moor Flame Grass	P
Molinia litoralis 'Transparent'	Moor Grass	P
Mondarda didyma 'Scorpion'	Bee-balm	P
Muscari aremeniacum 'Superstar'	Grape Hyacinth	P
Narccis poeticus	Daffodil	P
Narcissus 'Jenny'	Daffodil	P
Narcissus 'Lemon Drops'	Daffodil	P
Narcissus 'Thalia'	Daffodil	P
Nepeta faassenii 'Walker's Low'	Catmint	P
Nepeta subsessilis 'Sweet Dreams'	Catmint	P
Origanum vulgare 'Herrenhausen'	Oregano	P
Paeonia lactiflora 'Jan Van Leeuwen'	Peony	P
Paeonia suffruticosa 'Renkaku'	Tree Peony	W
Panicum virgatum 'Shenandoah'	Red Switch Grass	P

Table A.1. (cont'd)

Scientific Name	Common Name	Type (W=woody, P=perennial)
Pennisetum alopecuroides 'Cassian'	Fountain Grass	P
Perovskia 'Little Spire'	Russian Sage	W
Persicaria amplexicaulis 'Firedance'	Knotweed	P
Persicaria polymorpha	White Dragon Knotweed	P
Phlomis tuberosa 'Amazone'	Phlomis	P
Phlox maculata 'Delta'	Wild Sweet William	P
Polystichum setiferum 'Herrenhausen'	Soft Shield Fern	P
Prunus sargentii	Sargent Cherry	W
Prunus subhirtella 'Autumnalis'	Higan Cherry	W
Pycnanthemum muticum	Mountain Mint	P
Pyrus calleryana 'Chanticleer'	Chanticleer Pear	W
Quercus macrocarpa x bicolor 'Schuettii'	Swamp White Oak	W
Robinia pseudoacacia 'Chicago Blues'	Black Locust	W
Rodgersia pinnata 'Superba'	Featherleaf Rodgersia	P
Rudbeckia occidentalis 'Black Beauty'	Coneflower	P
Ruellia humilis	Wild Petunia	P
Saliva glutinosa	Meadow Sage	P
Salvia azurea	Azure Sage	P
Salvia pratensis 'Pink Delight'	Meadow Sage	P
Salvia verticillata 'Purple Rain'	Meadow Sage	P
Salvia x sylvestirs 'Rugen'	Meadow Sage	P
Salvia x sylvestris 'Amethyst'	Meadow Sage	P
Salvia x sylvestris 'Blue Hill'	Meadow Sage	P
Salvia x sylvestris 'Dear Anja'	Meadow Sage	P
Salvia x sylvestris 'May Night'	Meadow Sage	P
Salvia x sylvestris 'Wesuwe'	Meadow Sage	P

Table A.1. (cont'd)

Scientific Name	Common Name	Type (W=woody, P=perennial)
Sanguisorba canadensis 'Red Thunder'	Canadian Burnet	P
Sanguisorba menziesii	Burnet	P
Saponaria x lempergii 'Max Frei'	Soapwort	P
Schizachyrium scoparium 'The Blues'	Little Bluestem	P
Scilla mischtschenkoana	Squill	P
Scutellaria incana	Skullcap	P
Sedum 'Red Cauli'	Stonecrop	P
Sedum x hybrida 'Bertram Anderson'	Stonecrop	P
Sesleria autumnalis	Autumn Moor Grass	P
Sesleria nitida	Nest Moor Grass	P
Silphium laciniatum	Compass Plant	P
Smilacina racemosa	False Solomon's-seal	P
Solidago 'Fireworks'	Goldenrod	P
Sorghastrum nutans 'Sioux Blue'	Indian Grass	P
Sporobolus heterolepis	Prairie Dropseed	P
Sporobolus heterolepis 'Tara'	Prairie Dropseed	P
Stachys officinalis 'Hummelo'	Betony Or Hedgenettle	P
Stachys officinalis 'Rosea'	Betony Or Hedgenettle	P
Syringa meyeri 'Palibin'	Lilac	W
Taxus cuspidate 'Capitata'	Yew	W
Taxus cuspidate 'Dwarf Bright Gold'	Golden Yew	W
Taxus x media 'Hicksii'	Yew	W
Thalictrum delavayi 'Elin'	Meadow-rue	P
Thuja occidentalis 'Brabant'	Arborvitae	W
Thuja occidentalis 'Nigra'	Arborvitae	W
Thuja occidentalis 'Pyramidalis'	Arborvitae	W

Table A.1. (cont'd)

Scientific Name	Common Name	Type (W=woody, P=perennial)
Thuja occidentalis 'Wintergreen'	Arborvitae	W
Thuja standishii x plicata 'Spring Grove'	Arborvitae	W
Tradescantia 'Concord Grape'	Spiderwort	P
Tricyrtis formosana	Toad-lily	P
Tricyrtis x 'Tojen'	Toad-lily	P
Tulipa 'Ballade'	Tulip	P
Tulipa 'Don Quichotte'	Tulip	P
Tulipa 'Ivory Floradale'	Tulip	P
Tulipa 'Maureen'	Tulip	P
Tulipa 'Purissima'	Tulip	P
Tulipa 'Queen of Night'	Tulip	P
Tulipa 'Spring Green'	Tulip	P
Tulipa 'Tres Chic'	Tulip	P
Tulipa aucheriana	*Species Tulip*	P
Tulipa bakeri 'Lilac Wonder'	Species Tulip	P
Tulipa hageri 'Splendens'	Species Tulip	P
Tulipa polychroma	Species Tulip	P
Tulipa turkestanica	Species Tulip	P
Tulipa urumiensis	Species Tulip	P
Tulipa wilsoniana	Species Tulip	P
Ulmus 'Homestead'	Homestead Elm	W
Veronica longifolia 'Eveline'	Speedwell	P
Veronica longifolia 'Lila Karina'	Speedwell	P
Veronica longifolia 'Pink Damask'	Speedwell	P
Veronica spicata 'Giles Van Hees'	Speedwell	P
Veronicastrum virginicum 'Diane'	Culver's Root	P

Table A.1. (cont'd)

Scientific Name	Common Name	Type (W=woody, P=perennial)
Veronicastrum virginicum 'Rosea'	Culver's Root	P
Veronicastrum virginicum 'Temptation'	Culver's Root	P
Vitex agnus castus	Chaste Tree	W
Zizia aurea	Golden Alexander's	P

Table A.2. List of planted species on the Ford Truck Plant (FOR) green roof.

Scientific Name	Common Name	Type (W=woody, P=perennial)
Sedum 'Coccineum'	Coccineum Two-row Stonecrop	P
Sedum acre	Gold Moss Stonecrop	P
Sedum album	White Stonecrop	P
Sedum floriferum	Gold Stonecrop	P
Sedum kamschaticum	Russian *Or* Orange Stonecrop	P
Sedum kamschaticum ellacombianum	Stonecrop	P
Sedum kamschaticum kamtschaticum	Stonecrop	P
Sedum middendorfianum diffusum	Diffusum Stonecrop	P
Sedum pulchellum	Lime Stonecrop	P
Sedum reflexum	Blue Stonecrop	P
Sedum spurium 'Fulda Glow'	Fulda's Glow Stonecrop	P
Sedum spurium 'Superbum'	Superbum Stonecrop	P
Sedum telephium	Purple Stonecrop	P

Table A.3. List of planted species on the McCormick Parking Structure (MCC) green roof.

Scientific Name	Common Name	Type (W=woody, P=perennial)
Aesculus sp.	Buckeye	W
Allium cernuum	Nodding Wild Onion	P
Andropogon scoparius	Little Bluestem Grass	P
Asclepias tuberosa	Butterfly Milkweed	P
Aster azureus	Sky-blue Aster	P
Aster ericoides	Heath Aster	P
Bouteloua curtipendula	Side-oats Gramma	P
Carex annectens	Large Yellow Fox Sedge	P
Carex bicknellii	Copper-shouldered Oval Sedge	P
Coreopsis palmata	Prairie Coreopsis	P
Coreopsis tripteris	Tall Coreopsis	P
Deschampsia caespitosa	Tufted Hair Grass	P
Echinacea purpurea	Broad-leaved Purple Coneflower	P
Elymus canadensis	Wild Canada Rye	P
Eryngium yuccifolium	Rattlesnake Master	P
Euphorbia corollata	Flowering Spurge	P
Fragaria virginiana	Strawberry	P
Helianthus occidentalis	Western Sunflower	P
Heliopsis helianthoides	False Sunflower	P
Koeleria cristata	June Grass	P
Monarda fistulosa	Wild Bergamot	P
Parthenium integrifolium	Wild Quinine	P
Pedicularis canadensis	Wood Betony	P
Penstemon digitalis	Foxglove Beard Tongue	P
Petalostemum purpureum	Purple Prairie Clover	P
Phlox pilosa	Prairie Phlox	P

Table A.3. (cont'd)

Scientific Name	Common Name	Type (W=woody, P=perennial)
Phystostegia virginiana	False Dragonshead	P
Potentilla arguta	Prairie Cinquefoil	P
Ratibida pinnata	Yellow Coneflower	P
Rudbeckia hirta	Black-eyed Susan	P
Rudbeckia triloba	Brown-eyed Susan	P
Solidago graminifolia	Grass-leaved Goldenrod	P
Vernonia fasciculata	Common Ironweed	P
Zizia aurea	Golden Alexander	P

Table A.4. List of planted species on the Aquascape Headquarters (AQU) green roof.

Scientific Name	Common Name	Type (W=woody, P=perennial)
Allium cernuum	Nodding Onion	P
Aster azureus	Sky Blue Aster	P
Aster ericoides	Heath Aster	P
Aster sericeus	Silky Aster	P
Bouteloua curtipendula	Sideoats Gramma	P
Carex gravida	Heavy Sedge	P
Coreopsis palmata	Prairie Coreopsis	P
Echinacea pallida	Pale Purple Coneflower	P
Heuchera richardsonii	Richardson's Alumroot	P
Koeleria cristata	Junegrass	P
Lespedeza capitata	Round-headed Bushclover	P
Liatris cylindracea	Dwarf Blazing Star	P
Lupinus perennis occidentalis	Sundial Lupine	P
Monarda fistulosa	Wild Bergamot	P
Monarda punctata	Spotted Beebalm	P
Rudbeckia hirta	Black-eyed Susan	P
Rudbeckia subtomentosa	Sweet Coneflower	P
Schizachyrium scoparium	Little Bluestem	P
Solidago nemoralis	Gray Goldenrod	P
Tradescantia ohiensis	Ohio Spiderwort	P

Table A.5. List of planted species on the Haworth Headquarters (HAW) green roof.

Scientific Name	Common Name	Type (W=woody, P=perennial)
Sedum acre 'Aureum'	Goldmoss Stonecrop	P
Sedum album 'Coral Carpet'	Coral Carpet Stonecrop	P
Sedum floriferum 'Weihenstephaner Gold'	Bailey's Gold Stonecrop	P
Sedum hybridum 'Immergrunchen'	Stonecrop	P
Sedum reflexum 'Green Spruce'	Spruce Stonecrop	P
Sedum sexangulare	Six-sided Stonecrop	P
Sedum spurium 'Album Superbum'	Caucasian Stonecrop	P
Sedum spurium 'Dragons Blood'	Dragon's Blood Stonecrop	P
Sedum spurium 'Green Mantle	Stonecrop	P
Sedum spurium 'John Creech'	Two-row Stonecrop	P

Table A.6. List of planted species on the Chicago Cultural Center (CCE) green roof.

Scientific Name	Common Name	Type (W=woody, P=perennial)
Alium cernuum	Nodding Onion	P
Dianthus gratianopolitanus 'Firewitch'	Dianthus	P
Heuchera richardsonii	Alumroot	P
Juniperus horizontalis	Creeping Juniper	W
Mondara didyma	Scarlet Beebalm	P
Sedum acre	Gold Moss Sedum	P
Sedum cauticola 'Lidokense'	Lidakense Sedum	P
Sedum floriferum 'Weihestaphaner Gold'	Weihestaphaner Gold Sedum	P
Sedum kamschaticum	Russian Stonecrop	P
Sedum reflexum	Blue Stonecrop	P
Sedum sexangulare	Sedum Sexangulare	P
Sedum spectabile 'Vera Jameson'	Vera Jameson Sedum	P
Sedum spurium 'Fulda Glow'	Fulda's Glow Stonecrop	P
Sedum spurium 'John Creech'	John Creech Sedum	P
Sedum ternatum	Woodland Stonecrop	P
Sedum x 'Bertam Anderson'	Bertam Anderson Sedum	P
Thymus serphyllum 'Coccineus'	Creeping Thyme	P
Verbena simplex	Narrowleaf Vervain	P

Table A.7. List of planted species on the Chicago City Hall (CHA) green roof.

Scientific Name	Common Name	Type (W=woody, P=perennial)
Achilea millefolium 'Paprika'	Yarrow	P
Achillea millefolium 'Heidi'	Yarrow	P
Achillea sp. 'Schwelienburg'	Yarrow	P
Allium canadense	Wild Onion	P
Amorpha canescens	Leadplant	P
Andropogon scoparius	Little Bluestem Grass	P
Anemone canadensis	Meadow Anemone	P
Anemone patens wolfgangiana	Pasque Flower	P
Anemone virginiana	Tall Anemone	P
Aquilegia canadensis	American Columbine	P
Arabis caucasica 'Flore Pleno'	Fiore Pleno Arabis	P
Artemisia schmidtiana 'Silver Mound'	Silver Mound	P
Artemisia sp. 'Powis Castle'	Powis Castle Artemisia	P
Artemisia stelleriana 'Silver Brocade'	Silver Brocade Sage	P
Asclepias tuberosa	Butterfly Weed	P
Asclepias verticillata	Whorled Milkweed	P
Aster azureus sky	Blue Aster	P
Aster ericoides	Heath Aster	P
Aster laevis	Smooth Blue Aster	P
Aster novae-angliae	New England Aster	P
Aster obiongifolius	Aromatic Aster	P
Aster ptarmicoides	Upland White Aster	P
Aster sericeus	Silky Aster	P
Astragalus canadensis	Milkvetch	P
Baptisia leucophaea	Cream Wild Indigo	P
Blephilia ciliata	Ohio Horse Mint	P

Table A.7. (cont'd)

Scientific Name	Common Name	Type (W=woody, P=perennial)
Bouteloua curtipendula	Side-oats Gramma	P
Bouteloua gracilis	Blue Gramma	P
Boutelous hirsuta	Hairy Gramma	P
Buchloe dactyloides	Buffalo Grass	P
Callirhoe involucrata	Wine Cups	P
Campanula poscharskyana	Serbian Bellflower	P
Campanula rotundifolia	Harebell	P
Carex bicknellii	Bicknell's Sedge	P
Carex cephalophora	Woodbank Sedge	P
Carex gravida	Sedge	P
Carex grayi 'Morning Star'	Morning Star Sedge	P
Carex pennsylvanica	Pennsylvania Sedge	P
Cassia fasciculata	Partridge Pea	P
Ceanothus americanus	New Jersey Tea	W
Celastrus scandens	American Bittersweet	Vine
Ceraatium tomentosum 'Silberteppich'	Silver Carpet	P
Chrysanthemum leucanthemum	Ox-eye Daisy	P
Clematis virginiana	Virgins Bower	Vine
Coreopsis auriculata 'Nana'	Coreopsis	P
Coreopsis lanceolata	Sand Coreopsis	P
Corydalis flexuasa 'Blue Panda'	Blue Corydalis	P
Corydalis lutea	Yellow Corydalis	P
Crataegus crusgalli	Cockspur Hawthorn	W
Danthonia spicata	Poverty Oat Grass	P
Desmanthus illinoensis	Illinois Sensitive Plant	P
Dianthus allwoodii 'Helen'	Pink	P

Table A.7. (cont'd)

Scientific Name	Common Name	Type (W=woody, P=perennial)
Dianthus alpinus	Allwood Pinks	P
Dianthus carthusianorum	Dianthus	P
Dianthus deltoides	Dianthus	P
Dianthus gratianopolitanus 'spotty'	Cheddar Pinks	P
Dianthus gratianopolitanus 'Tiny Rubies'	Dianthus	P
Dianthus gratianopolitanus	Cheddar Pinks	P
Dianthus plumarius	Dianthus	P
Diervilla lonicera	Dwarf Bush Honeysuckle	W
Dodecatheon meadii	Shooting Star	P
Echinacea purpurea	Purple Coneflower	P
Echinops bannaticus 'Blue Glow'	Globe Thistle	P
Elymus canadensis	Canada Wild Rye	P
Elymus villosus	Silky Wild Rye	P
Eryngium yuccifolium	Rattlesnake Master	P
Euphorbia polychroma	Cushion Spurge	P
Festuca amethystina 'Bronzegianz'	Large Blue Fescue	P
Festuca glauca 'Elijah Blue'	Blue Fescue	P
Gaillardia 'Kobold'	Blanket Flower	P
Geranium sanguineum	Cranesbill	P
Geranium sanguineum 'Max Frei'	Cranesbill	P
Geranium sanguineum var. striat	Cranesbill	P
Geum coccineum 'Borisii'	Geum	P
Geum triflorum	Prairie Smoke	P
Gypsophila repens	Creeping Baby's Breath	P
Gypsophila repens 'Rosea'	Pink Trailing Baby's Breath	P
Helianthus mollis	Downy Sunflower	P
Helianthus rigidus	Showy Sunflower	P

Table A.7. (cont'd)

Scientific Name	Common Name	Type (W=woody, P=perennial)
Helictotrichon sempervirons	Blue Oat Grass	P
Hemerocalis 'Anzac'	Daylily	P
Hemerocallis 'Little Wine Cup'	Daylily	P
Hemerocallis 'Stella De Oro' daylily	Stella De Oro	P
Heuchera brizoides 'Red Spangif'	Coralbells	P
Heuchera brizoides 'Huntsman'	Coralbells	P
Heuchera richardsonii	Prairie Alum Root	P
Hieracium pilosella hieracium	Mouse-ear Hawkweed	P
Hystrix patula	Bottlebrush Grass	P
Juncus tenuis	Path Rush	P
Juniperus chinensis 'Sea Greer'	Sea Green Juniper	W
Kerria japonica	Japanese Kerria	W
Knautia macedonia	Knautia	P
Koeleda glauca	Large Blue Hair Grass	P
Koeleria cristata	June Grass	P
Lavandula angustifolia 'Hidecote'	Hidecote Lavender	P
Lavandula angustifolia 'Munstead'	Munstead Lavender	P
lberis sempervirens	Candytuft	P
Lespedeza capitata	Round-headed Bush Clover	P
Leymus arenarius	Blue Lyme Grass	P
Liatris aspera	Rough Blazing Star	P
Liatris cylindracea	Dwarf Blazing Star	P
Linaria vulgaris	Butter-and-eggs	P
Lobelia inflata	Indian Tobacco	P
Lychnis 'Flottbeck'	Campion	P
Malus ioensis	Prairie Crabapple	W
Microbiota decussata	Russian Arborvitae	W

Table A.7. (cont'd)

Scientific Name	Common Name	Type (W=woody, P=perennial)
Miscanthus sinensis var. gracillin	Maiden Grass	W
Monarda 'Cambridge Scarlet'	Bergamot	P
Monarda fistulosa	Wild Bergamot	P
Opuntia humifusa	Prickly Pear Cactus	P
Origanum vulgare	Oregano	P
Panicum leibergii	Prairie Panic Grass	P
Panicum leibergii	Prairie Panic Grass	P
Panicum virgatum	Switch Grass	P
Papaver orientale 'Brilliant'	Poppy	P
Papaver orientate	Poppy	P
Parthenium integrifolium	Wild Quinine	P
Parthenocissus tricuspidata	Boston Ivy	Vine
Penstemon digitalis	Foxglove Beard Tongue	P
Penstemon pailidus	Pale Beard Tongue	P
Penstemon 'Prairie Dusk'	Obedient Plant	P
Penstemon sp. 'Utahensis'	Utah Penstemon	P
Petalostemum candidum	White Prairie Clover	P
Petalostemum purpureum	Purple Prairie Clover	P
Petrorhagia saxigrage	Tunic Flower	P
Phlox bifida	Sand Phlox	P
Phlox sp. 'Emerald Cushion Blue'	Creeping Phlox	P
Phlox sp. 'Emerald Pink'	Creeping Phlox	P
Polemonium reptans	Jacob's Ladder	P
Potentilia argute	Prairie Cinquefoil	P
Prenanthes alba	Lion's Foot	P
Ranunculus rhomboides	Prairie Buttercup	P
Ratibida columnifera	Mexican Hat	P

Table A.7. (cont'd)

Scientific Name	Common Name	Type (W=woody, P=perennial)
Ratibida pinnata	Yellow Coneflower	P
Rhus aromatica 'Gro-low'	Gro-low Sumac	W
Rosa carolina	Pasture Rose	P
Rudbeckia subtomentosa	Sweet Coneflower	P
Ruellia humilis	Hairy Ruellia	P
Salvia nemorosa 'Mainacht'	Purple Salvia	P
Scutelaria parvula	Small Skullcap	P
Sedum acre	Wall Pepper	P
Sedum album	White Sedum	P
Sedum floriferum	Sedum	P
Sedum hybridum	Sedum	P
Sedum kamtschatcum	Orange Stonecrop	P
Sedum 'Mochren'	Mochren Sedum	P
Sedum reflexum	Sedum	P
Sedum sexangulare	Sedum	P
Sedum spectible 'Matrona'	Matrona Sedum	P
Sedum spurium	Two-row Stonecrop	P
Sedum 'Vera Jameson'	Vera Jameson Sedum	P
Sempervivum arachnoideum	Hens And Chicks	P
Sempervivum-Hybriden sepervivum	Hens And Chicks	P
Smilacina racemosa	False Solomon's Seal	P
Solidago flexicaulis	Broad-leaved Goldenrod	P
Solidago juncea	Early Goldenrod	P
Solidago nemoraiis	Old-field Goldenrod	P
Solidago speciosa	Showy Goldenrod	P
Solidago ulmifolia	Elm-leaved Goldenrod	P
Sporobolus heterolepis	Prairie Dropseed	P

Table A.7. (cont'd)

Scientific Name	Common Name	Type (W=woody, P=perennial)
Stachys byzantina 'Helene von Stein'	Lamb's Ear	P
Symphoricarpus alba	Snowberry	W
Thymus praecox 'Albiflorus'	Albifforus Thyme	P
Thymus praecox 'Coccineus'	Coceineus Thyme	P
Thymus serpylium thymus	Thyme	P
Tradescantia ohiensis	Common Spiderwort	P
Tradescantia ohiensis 'Zwanenbi'	Spiderwort	P
Trifolium arvense	Rabbitfoot Clover	P
Viola sororia	Common Blue Violet	P

Table A.8. List of planted species on the Nature Museum (NAM) extensive green roof.

Scientific Name	Common Name	Type (W=woody, P=perennial)
Achillea ‘Schwellenburg’	Schwellenburg Yarrow	P
Achillea millefolium ‘Heidi’	Heidi Yarrow	P
Allium canadense	Wild Onion	P
Allium cernuum	Nodding Wild Onion	P
Amorpha canescens	Leadplant	P
Andropogon scoparius	Little Bluestem	P
Anemone patens wolfgangiana	Pasque Flower	P
Aquilegia Canadensis	American Columbine	P
Asclepias tuberosa	Butterfly Weed	P
Asclepias verticillata	Whorled Milkweed	P
Aster azurenus	Sky Blue Aster	P
Aster laevis	Smooth Blue Aster	P
Aster ptarmicoides	Upland White Aster	P
Aster sericeus	Silky Aster	P
Baptisia leucophaea	Cream Wild Indigo	P
Bouteloua curtipendula	Side Oats Gramma	P
Buchloe dactyloides	Buffalo Grass	P
Campanula rotundifolia	Harebell	P
Carex bicknellii	Bicknell’s Sedge	P
Coreopsis palmata	Prairie Coreopsis	P
Danthonia spicata	Poverty Oat Grass	P
Dianthus gratianopolitanus	Spotty Carnation	P
Dodecatheon meadii	Shooting Star	P
Geum triflorum	Prairie Smoke	P
Helianthus mollis	Downy Sunflower	P
Helianthus occidentalis	Western Sunflower	P

Table A.8. (cont'd)

Scientific Name	Common Name	Type (W=woody, P=perennial)
Heuchera richardsonii	Prairie Alum Root	P
Koeleria cristata	June Grass	P
Lavandula angustifolia 'Hidcote'	Hidcote Lavender	P
Liatris aspera	Rough Blazing Star	P
Petalostemum candidum	White Prairie Clover	P
Petalostemum purpureum	Purple Prairie Clover	P
Phlox bifida	Sand Phlox	P
Phlox pilosa	Downy Phlox	P
Sedum 'Mochren'	Mochren Stonecrop	P
Sedum 'Vera Jameson'	Vera Jameson Stonecrop	P
Sedum acre	Goldmoss Stonecrop	P
Sedum album	White Stonecrop	P
Sedum kamtschaticum	Orange Stonecrop	P
Sedum spurium	Two-row Stonecrop	P
Sempervivium arachnoideum	Hens And Chicks	P
Solidago speciosa	Showy Goldenrod	P
Sporbollus heterolepis	Prairie Dropseed	P
Stachys byzantine	Large-leafed Helene Von Stein Lamb's Ear	P
Thymus serphllus	Creeping Thyme	P

Table A.9. List of planted species on the Nature Museum (NAM) intensive green roof.

Scientific Name	Common Name	Type (W=woody, P=perennial)
Acorus calamus	Sweet Flag	P
Alisma subcordatum	Common Water Plantain	P
Asclepias incarnate	Swamp Milkweed	P
Aster sagitarius drumondii	Drummond’s Aster	P
Blephilia ciliate	Ohio Horse Mint	P
Caltha palustris	Marsh Marigold	P
Carex cristatell	Crested Oval Sedge	P
Carex gravida	Common Sedge	P
Carex lacustris	Common Lake Sedge	P
Carex pennsylvanica	Pennsylvania Sedge	P
Celastrus scandens	American Bittersweet	Vine
Clematis virginiana	Virgin’s Blower	Vine
Echinacea purpurea	Purple Coneflower	P
Elymus villosus	Silky Wild Rye	P
Equisetum arvense	Horsetail	P
Eupatorium maculatum	Joe Pye Weed	P
Geranium sanguineum ‘Max Frei’	Max Frei Cranesbill	P
Geranium sanguineum var. striatum	Bloodred Cranesbill	P
Helenium autumnale	Autumn Sneezeweed	P
Hemerocallis ‘Little Wine Cup’	Little Wine Cup Daylily	P
Hystrix patula	Bottlebrush Grass	P
Iris virginica shrevei	Blue Flag Iris	P
Juncus dudleyi	Dudley’s Rush	P
Juncus effuses	Common Rush	P
Juncus torreyi	Torry’s Rush	P
Lobelia cardinalis	Cardinal Flower	P

Table A.9. (cont'd)

Scientific Name	Common Name	Type (W=woody, P=perennial)
Lobelia siphilitica	Great Blue Lobelia	P
Panicum virgatum	Switch Grass	P
Parthenium intergrifolium	Wild Quinine	P
Penstemon pallidus	Pale Bear Tongue	P
Polemonium reptans	Jacob's Ladder	P
Pontedaria cordata	Pickerel Weed	P
Quercus imbricaria	Shingle Oak	W
Rhus aromatic 'Gro-low'	Gro-low Sumac	W
Sagittaria latifolia	Common Arrowhead	P
Scirpus atroveriens	Dark Green Rush	P
Scutellaria epilobiifolia	Marsh Skullcap	P
Smilacina racemosa	False Solomon's Seal	P
Solidago flexicaulis	Broad-leaved Goldenrod	P
Solidago riddellii	Riddell's Goldenrod	P
Sparganium eurycarpum	Bur Reed	P
Spartina petinata	Prairie Cordgrass	P
Spiraea alba	Meadowsweet	P
Tradescantia ohiensis	Common Spiderwort	P
Vemonia fasciculata	Ironweed	P
Verbana hastata	Blue Verbena	P
Veronicastrum virginicum	Culver's Root	P
Zizia aurea	Golden Alexanders	P

Table A.10. List of planted species on the Michigan Avenue Structure (MIA) green roof.

Scientific Name	Common Name	Type (W=woody, P=perennial)
Allium 'Forescate'	Chive	P
Calamagrostis brachytricha	Feather Reed Grass	P
Calamagrostis 'Karl Forester'	Feather Reed Grass	P
Sedum floriferum 'Weihenstephaner Gold'	Sedum	P
Sedum hybridum 'Immergrunchen'	Sedum	P
Sedum 'Mini Me',	Stonecrop	P
Sedum rupestre 'Angelina'	Sedum	P
Sedum spurium 'Green Mantle'	Sedum	P

Table A.11. List of planted species on the Schwab Rehabilitation Hospital (SCH) green roof.

Scientific Name	Common Name	Type (W=woody, P=perennial)
Aster sp.	Aster	P
Buddleia sp.	Butterfly Bush	P
Campanula sp.	Bellflower	P
Echinacea sp.	Coneflower	P
Hemerocallis sp.	Daylily	P
Iris sp.	Iris	P
Liatris sp.	Blazing Star	P
Linum sp.	Flax	P
Pennisetum alopecuroides 'Little Bunny'	Bunny Fountain	P
Perovskia atriplicifolia	Russian Sage	P
Schizachyrium scoparium	Little Bluestem	P
Sumac sp.	Staghorn Sumac	W

Table A.12. List of planted species on the Gary Comer Youth Center (GCY) green roof.

Scientific Name	Common Name	Type (W=woody, P=perennial)
Abelmoschus esculentus	Okra	P
Allium schoenoprasum	Chives	P
Anethum graveolens	Dill	P
Aster sp.	Aster	P
Brassica oleracea	Broccoli	P
Capitata sp.	Cabbage	P
Capsicum sp.	Yellow Bell Pepper	P
Capsicum spp.	Hot Peppers	P
Cucumis sativus	Cucumber	P
Cucurbita pepo	Zucchini	P
Daucus carota	Carrots	P
Digitalis spp.	Foxglove Mixture	P
Echinacea sp.	Coneflower	P
Helianthus spp.	Sunflowers	P
Ipomoea batatas	Sweet Potato	P
Lactuca sativa	Purple Leaf Lettuce	P
Lactuca sativa L. var. longifolia	Romaine Lettuce	P
Lactuca sativa var. capitata	Butterhead Lettuce	P
Leucanthemum sp.	Daisy	P
Lilium spp.	Lilly Mixture	P
Liriope spicata	Creeping Lilyturf	P
Narcissus spp.	Daffodil Bulbs	P
Ocimum basilicum	Basil	P
Origanum vulgare	Oregano	P
Petroselinum hortense	Parsley	P
Phaseolus vulgaris	Beans	P

Table A.12. (cont'd)

Scientific Name	Common Name	Type (W=woody, P=perennial)
Pisum sativum	Peas	P
Rosmarinus officinalis	Rosemary	P
Solanum lycopersicum	Tomato	P
Solanum tuberosum	Potato	P
Tulipa spp.	Tulip Bulbs	P

Table A.13. List of planted species on the Plant and Soil Science Building (PSS) green roof at Michigan State University.

Scientific Name	Common Name	Type (W=woody, P=perennial)
Sedum acre	Gold Moss Stonecrop	P
Sedum album	White Stonecrop	P
Sedum hispanicum	Spanish Stonecrop	P
Sedum kamtschaticum	Russian Or Orange Stonecrop	P
Sedum pulchellum	Widowscross	P
Sedum reflexum	Blue Stonecrop	P
Sedum spurium 'Tricolor'	Tricolor Stonecrop	P
Sedum spurium	Two-row Stonecrop	P

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CHAPTER 2

AVIAN RESPONSE TO GREEN ROOFS IN URBAN LANDSCAPES IN THE MIDWEST UNITED STATES

Anthropogenic development of land is a threat to native bird species throughout the world. Increasing urbanization is associated with habitat degradation, fragmentation, and loss of landscape connectivity, resulting in shifts in native bird species distribution, richness, and abundance (Blair, 1996; Miller et al., 2003; Lin, 2006). For example, native grasslands in North America, which provide critical habitat to many bird species, have been reduced by up to 99.9% in some areas of North America since European settlement and are the most threatened and degraded habitat type in North America (Samson and Knopf, 1994). Even though agricultural fields can provide habitat for several grassland bird species (e.g., grasshopper sparrow, *Ammodramus savannarum*; Savannah sparrow, *Passerculus sandwichensis*; bobolink, *Dolichonyx oryzivorus*), conversion of agricultural land to urban land uses corresponds with population decreases of 77% in the Midwest United States (Herkert, 1995; Herkert, 1996).

Despite the negative effects of development, bird communities can be significant components of biodiversity in urban landscapes (Savard et al., 2000). Increased development corresponds to declines in species richness of native bird communities (Hohtola, 1978); however, non-native species may prevail despite the lack of native plants because adequate structure is provided by available vegetation and other features (Donnelly and Marzluff, 2004; McKinney, 2006).

Vegetated roofs, also known as green roofs, have been identified as a technology capable of providing habitat for bird communities in urban areas (Gedge, 2003; Baumann, 2006; Brennisen, 2006). In addition to energy conservation (Getter et al., 2011) and economic benefits

(Peck et al., 1999; Banting et al., 2005; Clark et al., 2008) typically associated with green roofs, these structures present an opportunity to develop large areas of vegetation that could provide bird habitat in urban areas (Eakin et al., in review).

Vegetation plays a strong role in determining avian habitat suitability (MacArthur and MacArthur, 1961; Wiens, 1974; Christensen, 1997), hence green roofs that provide appropriate vegetation conditions (e.g., grassland or early successional plant communities) may contribute habitat for the corresponding bird community (e.g., grassland birds). Even though most green roof vegetation is composed of low-growing, shallow-rooted, drought tolerant plant species (e.g. *Sedum spp*.), plants with greater structural diversity such as taller perennials, shrubs, and trees are available to bird communities on some green roofs (Dvorak and Volder, 2010; Eakin et al., in review). Since birds using green roofs may not be subjected to many of the threats present at ground level (e.g. mesopredators, human disturbance), green roofs may provide greater abundance, productivity, and species richness of bird communities compared to ground level areas with similar vegetation characteristics. Green roofs may also provide elements of bird habitat small (i.e., microhabitat) (Brenneisen, 2006; Oberndorfer et al., 2007) and macro scales (i.e., landscape) by increasing connectivity with other urban green spaces to provide bird habitat systems throughout urban areas (Keitt et al., 1997; Lundholm, 2006; Bierwagen, 2007). By establishing habitat connectivity among green roofs and other urban vegetation patches, cities could pose less of a threat for resident and migratory birds passing through or living in developed landscapes.

The potential increase in suitable habitat for bird species due to green roof construction could translate to an increase in species richness and abundance of native bird species in urban areas, indicating improved ecological function. Birds have been observed on green roofs in

Europe and North America, with 29 nesting species recorded and even IUCN red-listed species observed (Baumann, 2006; Fernandez-Canero and Gonzalez-Redondo, 2010); however, little quantitative research on bird community composition has been conducted. Roofs designed for specific bird species have resulted in successful nesting attempts by the targeted species (Gedge, 2003; Baumann, 2006), but the contributions of various design elements to bird communities has not been quantified. Quantitative studies relating bird community composition with green roof characteristics could provide insight into how to best implement green roofs for sustainability in urban design while meeting wildlife conservation objectives. This information would help inform the integration of wildlife conservation strategies with green roof technology, urban planning and policy.

OBJECTIVES

Objectives were to:

1) Quantify the composition of bird communities on green roofs and surrounding landscapes.

2) Quantify the influence of vegetation and non-vegetation structure and composition of green roofs and surrounding landscapes on bird community composition and structure.

3) Quantify the relationship between bird communities observed on green roofs and in landscapes.

4) Make recommendations for green roof design, composition, and management in relation to existing landscapes.

METHODS

Site descriptions

Twelve green roof study sites were located in the Midwest United States in northern Illinois and the Lower Peninsula of Michigan, and were described as: Downtown Chicago Park (DCP), the Ford Truck Plant (FOR), McCormick Parking Structure (MCC), Aquascape Headquarters (AQU), Haworth Headquarters (HAW), the Chicago Cultural Center (CCE), the Chicago City Hall (CHA), a Nature Museum (NAM), a Michigan Avenue Structure (MIA), Schwab Rehabilitation Hospital (SCH), Gary Comer Youth Center (GCY), and the Plant and Soil Science Building at Michigan State University (PSS) (Table 2.1). Green roofs represented a range of conditions for roof area, roof type (i.e., extensive roofs, 0-15cm planting media depth; intensive roofs, >15cm planting media depth; Rowe, 2011), building height, vegetation type, and slope. Land use, accessibility and maintenance, which depended on the intended purpose of the roof (Table 2.2), had the potential to influence bird community response.

Each study site was composed of a green roof and the surrounding landscape within 200m of the roof. This landscape area (≥14ha for all green roofs) encompasses the home range size of several bird species (e.g., killdeer, *Charadrius vociferus*; red-eyed vireo, *Vireo olivaceus*; Cimprich et al., 2000*;* Jackson and Jackson, 2000) that may utilize green roofs and their surrounding landscape to fulfill their life requisites (Eakin et al., in review).

We sampled 8 sites in 2010 and 8 sites in 2011, with 4 sites being sampled both years. All roofs sampled in 2011 were elevated above ground level (not on subterranean structures); the greatest potential for additional green areas on roofs in urban areas is above ground level. Also, because bird communities are affected by patch size and edge effects (Bollinger and Gavin, 1992; Delisle and Savidge, 1997; Johnson and Igl, 2001), care was taken to select the largest green roofs possible that represented a range of vegetation types and conditions and were accessible through the building owner or manager. All study sites sampled in 2010 and 2011were within the administrative and biological Mississippi Flyway Migratory Route (United States Fish and Wildlife Service, 2011). However, Chicago, Illinois, lies on a major flyway, and numerous birds pass through this area during migration compared to other green roof areas in our study.

The range of monthly mean temperatures at each study site during the early to peak bird nesting season (April - June) was between 11.3C and 22.2C in 2010 and between 7.9C and 21.5C in 2011 (Table 1.2; National Oceanic and Atmospheric Administration, 2012). The range of monthly mean temperatures at each study site during post-nesting and brood-rearing season (July-September) was between 16.5C and 26.1C in 2010 and between 15.9C and 26.3C in 2011. The range of monthly total precipitation at each study site during the early to peak bird nesting season was between 5.9cm and 20.0cm in 2010 and between 3.5cm and 18.8cm in 2011 (Table 1.3; National Oceanic and Atmospheric Administration, 2012). The range of monthly total precipitation at each study site during post-nesting and brood-rearing season (July-September) was between 1.1cm and 24.4cm in 2010 and between 9.9cm and 18.3cm in 2011.

Vegetation measurements

Vegetation sampling was conducted during two periods in 2010 and 2011: one during the early to peak bird nesting season and one during post-nesting and brood-rearing season. By sampling during the spring (April-June) and summer (July-October), vegetation was representative of that available to bird communities during both sampling periods (Short, 1985; Basore et al., 1986; Best et al., 1997).

The sampled portions of landscapes surrounding green roofs were safe, accessible, and included clearly definable vegetation areas (areas with exposed soil with potential to support vegetation as the minimum requirement of). Planter boxes attached to buildings, street median vegetation, street trees in grates, and vegetation on other green roofs in the surrounding landscapes were not sampled in the field, however, were represented in the aerial land cover analysis.

The line intercept method (Canfield, 1941) was used to quantify vegetation cover of turf grass, herbaceous perennial cover, and shrub and tree canopy on green roofs and in vegetation areas in surrounding landscapes. One-meter belt transects (Clements, 1905) were used on green roofs and surrounding landscapes to determine species presence and stem densities of woody plants. Transects ranged from 3.8-200.0m long and were systematically placed perpendicular to the gradient of vegetation types on each roof and landscape area. The length of transects corresponded to the size of green roofs. The length of the transect that intersected mowed lawn, perennial, shrub, and tree cover was recorded and used to calculate the percent cover of each vegetation type. The point intercept method (Heady et al., 1959) was used to calculate percent cover of different vegetation types and quantify mean vegetation height. Every 5m, vegetation intersecting transects was identified by type (perennial sedum, non-sedum perennial, woody vegetation) and the height of the vegetation at the intersecting point was measured.

Aerial land cover

Existing and potential green space for each study site were determined by importing Google Earth (Version 6.1; Google Earth, 2011) images into ArcMap using ArcGIS version 9.2 (ArcGIS version 9.2; ESRI, 2006). Images were then georeferenced, digitized, and classified by land cover type (i.e., studied green roofs, other green roofs, woody vegetation, herbaceous vegetation, water, conventional roofs, impermeable surfaces). Green space in each landscape consisted of green roofs and woody and herbaceous vegetation cover types. Potential green space within a study site was calculated assuming that all existing conventional roofs could be vegetated and was portrayed as total area covered by current green space (on roofs and on the ground) and non-green roofs.

Bird surveys

Point count surveys (Bibby et al., 1992) were conducted during the nesting and brood rearing seasons (April - July) during both years on green roofs and in their respective landscapes. In 2010, bird surveys were conducted on four to six sampling dates. The accumulation rate of species detected appeared to level-off near the apparent asymptote at each study site and on each studied green roof after three days of surveys, which indicated that few additional species would be detected regardless of additional sampling effort. In 2011, surveys were decreased to four sampling dates because of a lack of additional species detected after the third sampling date of all green roofs sampled the previous year. One extra sampling date (the fourth day) was included as a contingency for variation between years.

Surveys began at dawn and were conducted for up to 3 hours (Robbins, 1981). Sampling order of green roofs and landscapes was rotated each survey date, when feasible according to building owners, to equalize differences in bird presence and detection related to time of day. The location and number of survey points on green roofs and their surrounding landscapes were assigned to maximize observed roof area, avoid overlapping observations between survey points, and minimize observer disturbance. One to three sampling points were located on each green roof, depending if structures were present that obscured a view of the entire roof from a single point. Up to four landscape survey points were located in each cardinal direction around each roof within 200m of the roof. The vegetation area closest to the green roof was selected where another building obscured the view between vegetation areas within 200m.

Sampling was preceded by a 2-min settling period and followed by three continuous sampling periods of 7-min each (Sauer et al., 1994). The species, number, and behavior (i.e., resting, foraging, nesting, calling/singing, mating, defending/aggressing) of all birds observed were recorded. Sound identification was not used due to varying background noise levels among sites. Incidental observations such as low-flying birds over green roofs and other wildlife on green roofs were noted for anecdotal reference.

We focused on non-invasive, native bird communities (Cornell lab of Ornithology and the American Ornithologists Union, 2012) for data analyses given our study was primarily interested in the conservation opportunities provided by green roofs. Native bird species that present possible harm to other native bird species of greater conservation concern (i.e., brown-headed cowbird, *Molothrus ater;* Walkinshaw, 1991) or that are urban adapted species (i.e., ring-billed gull, *Larus delawarensis;* Pollet et al., 2012; American crow, *Corvus brachyrhyn;* Verbeek and Caffrey, 2002) were excluded from model analysis. Waterfowl and songbirds were analyzed separately because green roofs likely cannot provide a source of water generally required by waterfowl, and songbirds generally do not require large amounts of water (Brewer et al., 1991). Because of limited waterfowl habitat potential on green roofs, waterfowl species were analyzed individually in a single-species model. Comparisons at the sampling point level (i.e., green roof or surrounding landscape) were made for waterfowl species (henceforth WS) observed on 25% or more of the studied green roofs. Because of the potential for green roofs to fulfill life requisites and provide conservation value for several native songbird species (Eakin et al., in review), songbirds were collectively analyzed in a multi-species model. The multi-species model incorporated data for all native bird species, excluding waterfowl and urban adapted species, to estimate species richness and occurrence and use probabilities at the sampling-point and site level on green roofs and surrounding landscapes. Of these bird species, native species (henceforth NS) observed on at least 25% of green roofs and those observed on green roofs that are either listed by the U.S. Fish and Wildlife Service (2010) to be rare or declining species in the Midwest United States, or by Sauer et al. (2011) to have experienced declines from 2000-2010 for the Lower Great Lakes/St. Lawrence Plain, were included in species specific analyses.

All field sampling procedures were exempted by the Michigan State University Institutional Animal Care and Use Committee and did not require animal use form approval.

Descriptive analysis and statistics

Point-count data were used to calculate summary statistics of bird communities observed on green roofs and in surrounding landscapes for each year sampled. Relative abundance, species richness, and feeding guild during the breeding and nesting periods (De Graff et al., 1985) was presented to demonstrate community composition for each study site. Relative abundances were based on the total number of bird observations at each roof or within each landscape. Because these analyses did not account for detection probabilities (the probability that a species present during sampling would be observed), further data analysis that accounted for detection probabilities was conducted.

We applied single-species and multi-species frameworks to the multi-scale occupancy model used by Mordecai et al. (2011) to jointly estimate probabilities of bird species occurrence (ψ, the probability that a species is ever present at a survey site), use (θ, the probability that a species was present during sampling at a survey site), and detection (P, the probability that a species present at a survey site was detected during sampling). Occupancy describes the probability that a species is ever present at a site. Use describes the probability of species presence during a given visit and represents how often a species is present at a site. The model only included data for a single year for each roof. Only the first year of data was included for roofs sampled both years. We constructed detection histories from the point count data that indicated with a 0 or 1 whether a species was detected during a 7-min sampling period for each visit to a point.

Logit-linear models were used to estimate the effects of site-level covariates (i.e., sampling point location) on each parameter in the multi-scale model. Single- and multi-species frameworks were applied to the following logistic regression equations:

$$\text{logit}\ (\psi_i) = \alpha_{0r} + \alpha_1 greenroof_i$$

$$\text{logit}\ (\theta_{ij}) = \beta_{0r} + \beta_1 greenroof_i + \beta_2 date_{ij}$$

$$\text{logit}\ (P_{ijk}) = \delta_0 + \delta_1 greenroof_i + \delta_2 Prev_{ij}$$

where *i* represents site, *j* represents visits, and *k* represents the 7-minute sampling period within a visit; *greenroof* is a binary indicator for whether site *i* is located on a green roof or in the surrounding landscape; *date* is the standardized ordinal date of survey *j*; *Prev* is a binary variable for previous detection; α_{0r} and β_{0r} represent random-effect intercepts for occupancy and use, respectively, which account for spatial dependence between sites located on or near the same roof, *r*; and δ_0 represents the fixed intercept for detection.

The single-species and multi-species models included the same covariates for estimating differences in the likelihood of use and occurrence on roofs and in corresponding landscapes. In the multi-species framework, species are treated as a random effect which interacts with each model parameter to produce species-specific parameter estimates for the logit-linear models of occupancy, use, and detection (Dorzaio et al., 2006; Royle and Dorazio, 2008). Combining the species detection data into one model results in a more parsimonious approach to parameter estimation, in addition to allowing for the incorporation of rarely detected species with sparse data (Royle and Dorazio, 2008). This random effect allows for occupancy and use probabilities to be estimated for all observed species at all points, including those points where a species may have gone undetected (Zipkin et al., 2010).

We estimated the parameters and calculated estimates using WinBUGS (Spiegelhalter et al., 2003) in program R. Each parameter was assigned a set of hyperparameters (i.e., mean and standard deviation) that were given non-informative prior distributions. We standardized all covariates to have a mean of 0 and a unit variance of 1. We examined the single-species model results based on 3 chains of 5,000 iterations after discarding the first 2,500 iterations and thinning by 10; this process resulted in 750 values forming the posterior distribution for each parameter. The multi-species model results were based on 3 chains of 20,000 iterations after discarding the first 5,000 iterations and thinning by 15; this process resulted in 3,000 values forming the posterior distribution for each parameter. These settings provided an acceptable level of Markov chain convergence ($\hat{R}$ statistic, or scale reduction factor, <1.1 for all parameters; Gelman et al., 2003).

RESULTS

Observed and estimated bird community structure and composition

A total of 69 bird species were observed in 2010 and 2011 (Table 2.3). Of those species, 29 were observed on green roofs, with three observed only on green roofs and not in surrounding landscapes (American tree sparrow, *Spizella arborea*; blackburnian warbler, *Setophaga fusca*; Nashville warbler, *Oreothlypis ruficapilla*). The four bird species that were observed on >50% of roofs were American robin (*Turdus migratorius*, 75% of roofs), European starling (*Sturnus vulgaris*, 67% of roofs), house sparrow (*Passer domesticus*, 58% of roofs), and American goldfinch (*Carduelis tristis*, 50% of roofs). Thirty-eight species observed in surrounding landscapes were not observed on green roofs. Eighty-six percent of the bird species (25 species) observed on green roofs were non-invasive, native species, and two were waterfowl species (Canada goose, *Branta canadensis*; mallard, *Anas platyrhynchos*). Of the observed native species, 16 and 22 species represented ground-foraging feeding guilds on green roofs and in the adjacent landscapes, respectively. Six and 15 non-invasive, native species on green roofs and in their surrounding landscapes, respectively, represented shrub-foraging, low-canopy foraging, or bark-gleaning feeding guilds. Most birds observed (>50%) on green roofs were resting and/or foraging. Birds were also observed nesting (Canada goose on the Ford Truck Plant and Nature Museum roofs; mallard on the Nature Museum and Aquascape Headquarters roofs; killdeer on the Ford Truck Plant roof; red-winged blackbird, *Agelaius phoeniceus,* on the Downtown Chicago Park and McCormick Parking Structure roofs), and Canada goose goslings were reared on the Ford Truck Plant roof. Though not counted as bird species observed on green roofs, barn swallows (*Hirundo rustica*) and chimney swifts (*Chaetura pelagica*) were observed to dive over green roofs, presumably to eat bugs attracted to the vegetation.

Mean detection probabilities generated using the single-species model were 88% and 63% for Canada goose and mallard. Similarly, the range of mean detection probabilities for NS generated using the multi-species model was between 66% and 82%. These detection probabilities indicated that bird species that occupied green roofs were often not detected during point-count surveys.

Median species richness was higher on green roofs than in surrounding landscapes when estimated at the sampling-point level and at the site level (Fig. 2.1 and 2.2). At the site level all survey points were grouped (i.e., a roof with three survey points would be grouped together), and thereby increased the uncertainty in estimated species richness for a landscape or roof at a study site. All roofs had similar mean estimated species richness and higher estimated species richness than their respective landscapes (Fig. 2.3), likely because vegetation present on roofs had similar structure, and vegetation present in surrounding landscapes represented a variety of structures and thus increased variability in estimations. Though estimated species richness is similar among roofs, differences in estimated species richness and the number of species observed on roofs indicated differences between bird occupancy and use on green roofs (Fig. 2.4; Table 2.3). Canada goose and mallard were observed on ≥25% of the studied green roofs with mean occurrence probabilities ≥95% and ≥72% at sampling points on green roofs and in surrounding landscapes, respectively; however, occurrence estimates were highly variable, likely suggesting no biological effect (Fig. 2.5). Mean occurrence probabilities for NS were >94% on green roofs and 59-93% in landscapes (Fig. 2.6). Bird species that were observed on green roofs and are listed by the U.S. Fish and Wildlife Service (2010) to be rare or declining species in the Midwest

United States, or by Sauer et al. (2011) to have experienced significant negative trends from 2000-2010 for the Lower Great Lakes/St. Lawrence Plain showed similar trends. Mean occurrence probabilities were >91% on green roofs and were 39-74% in landscapes (Fig. 2.7). These trends suggest that if a species is observed on a green roof, that species will occupy green roofs more consistently than they will the surrounding landscape. The mean occurrence probability for each NS on each green roof was >80% for most species and mean occurrence probabilities in landscapes were >20% (Fig. 2.8). In addition, little difference in mean occurrence probability between species was estimated in the model, and no pattern between roof characteristics (i.e., roof type, roof area, percent green space at the study site) and mean occurrence probability on green roofs was observed; however, during surveys differences in how bird species used green roofs were noted.

Similar to occurrence probabilities, use probabilities for Canada goose and mallard showed no differentiation between roofs and landscapes (Fig. 2.9). Mean use probabilities for NS and rare and declining species were lower on green roofs than in surrounding landscapes, and mean use probabilities were lower than mean occurrence probabilities for these species (NS, 1-11% on green roofs and 5-61% in the surrounding landscapes, Fig. 2.10; rare and declining species, 0-1% on green roofs and 4-17% in the surrounding landscapes, Fig. 2.11). The mean use probabilities of NS for intensive green roofs were distributed more evenly between high and low use probabilities than extensive roofs (Fig. 2.12). Roof size or percent green space of a study site did not have a discernible effect on use probability (Fig. 2.13 and 2.14); however, error margins for all estimates had wide overlaps that demonstrated the uncertainty present in estimates. Mean use probabilities on green roofs remained <30% for most bird species until use probability in the landscape reached 80% (Fig. 2.15).

Our results indicate the amount of time various bird species use green roofs, as estimated by use probability, is positively related to the amount of time those same species use the landscape directly surrounding green roofs. Green roof type also influences how much time birds use green roofs; intensive green roofs generally experience higher bird use probabilities than extensive roofs. Roof size appeared to be related to the number of species (uncorrected for detection probabilities) observed on green roofs (Fig. 2.4); however, use and occurrence probabilities that did account for detection probabilities did not concur with this trend. Other factors, such as roof size, may not demonstrate a clear effect on bird use in our study, but are biologically important (e.g., home range requirements correspond to a certain size area of appropriate conditions) and likely contribute to patterns of bird use of green roofs. Roofs with conditions present that provide mean use probabilities >80% for at least one NS species include MIA, SCH, and NAM (Fig. 2.12). These roofs represent intensive and extensive roof types, have building height ranging 1.9-15 stories, and have vegetation ranging from only herbaceous on MIA to a diversity of herbaceous, shrubs, and trees on SCH (Table 2.1).

DISCUSSION

Bird use

Green roofs present an opportunity to provide large areas of vegetation that could serve as bird habitat in urban areas (Eakin et al., in review). Although green roofs provide vegetation conditions that fulfill the habitat requirements for several bird species native to the Midwest United States, little is known about which birds use green roofs. During our study, 25 non-invasive, native bird species were observed on green roofs during 2010 and 2011. Using a multi-scale occupancy model, we estimated the mean number of species to occur on each roof to be between 36 and 40 (Fig. 2.3); however, the same species likely do not occur on all roofs. The total number of bird species that occur across all green roofs is greater than the average number for any given roof due to differences in vegetation structure and composition on the roofs and landscape attributes surrounding roofs. Our observations support the concept that green roofs can provide habitat for a diversity of birds including those of conservation value.

Birds on green roofs were observed feeding, bathing, using a diversity of vegetation for cover, perching, territory defense, nesting, and rearing young. Ground nesting birds (i.e., Canada goose, mallard, killdeer) were observed nesting on green roofs that were above ground level. The elevated position of green roofs may offer protection from predators typically found at ground level and other ground level disturbances (i.e., human disturbance). Although Canada goose had a relatively high mean probability of occurrence (99%) on green roofs (Fig. 2.5), their low mean use probability (Fig. 2.9) indicates variation in the amount of the time spent on different roofs (i.e., Canada goose were likely constantly present on roofs with successful nesting attempts). Canada geese reared goslings on an extensive green roof established in *Sedum* spp.

three stories above the ground. This roof had several areas of flat, conventional roofing membranes that held water after rain and/or irrigation events that could have provided water goslings. However, Canada geese and mallards nested unsuccessfully on two other extensive roofs, one established with a *Sedum* spp. mixture and herbaceous perennials, and one established with native perennials. Contributing factors to nesting success may be the occasional presence of water from irrigation and the large size of the roof (42,177m^2).

Bird species that forage on the ground and in low tree and shrub canopies have also been observed on green roofs (e.g., killdeer, common yellowthroat, *Geothlypis trichas;* song sparrow, *Melospiza melodia*). Because extensive green roofs typically have shorter vegetation than intensive roofs (Getter and Rowe, 2006; Eakin et al., in review), bird species in ground foraging guilds are likely more prevalent on extensive roofs, while shrub and low canopy foragers and bark gleaners are more likely to occur on intensive roofs. Of the bird species observed on studied green roofs, those in shrub and low canopy foraging and bark gleaning guilds (6 species) were only observed on intensive roofs with shrub and/or tree cover (Table 2.3). However, ground foraging bird species were also observed on all intensive roofs, likely because shrub or tree cover was not the dominant cover type on any intensive roof.

The multi-scale model outputs indicated that green roofs provide bird habitat complementary to that in surrounding landscapes. Point- and site-level species richness estimates for green roofs were higher than in surrounding landscapes, indicating that green roofs are providing bird habitats that attract novel species to urban landscapes. Individual bird species included in the multi-species model also had higher mean occurrence probability on green roofs than in surrounding landscapes (Fig. 2.6, 2.7, and 2.8). This result indicates that more bird species were likely to occur at a green roof point than at a landscape point and some species not present in surrounding landscapes were likely present on roofs (Fig. 2.8). Since mean occurrence probability on green roofs for most observed bird species was >80% (Fig. 2.8), even those not observed on green roofs during the study were likely occurring on the roof at some time. However, the low mean use probabilities on green roof points compared to landscape points (Fig. 2.15) indicate that birds were using green roofs only for a short period of time, assuming use probability is indicative of the proportion of time a bird species is present. Only when a species is present in a landscape >95% of the time is that species present on a green roof >50% of the time. Based on the short time most bird species were on green roofs, it does not appear that these birds use resources on green roofs to fulfill the majority of their life requisites.

Since studied green roofs had a relatively small size compared to their surrounding landscapes, it was expected that birds would be present in surrounding landscapes for a greater proportion of time than on green roofs. Since the most observations on roofs were of birds foraging and resting, our observations suggest that birds are attracted to green roofs as temporary foraging and resting sites. Hence, occupancy is high on green roofs even though occupancy in the landscape is low (Fig. 2.8) because birds are attracted to the foraging substrate and other structure on green roofs. However, because bird use is short-term, the likelihood of documenting use is relatively low, even when use of the landscape is relatively high (Fig. 2.15). The high species richness and high occupancy probability on green roofs suggest that green roofs may have potential to increase habitat connectivity for bird species during the breeding season. Further research is necessary to investigate the potential for green roofs to function as stepping stones for migratory birds to more effectively traverse urban areas. Telemetry equipment could be used to further understand how birds move through the landscape, when they are on green roofs, and where they are nesting. These observations could help determine which structural and vegetation green roof conditions various species prefer.

Our results identified green roof type as a characteristic that may affect habitat availability for native bird communities. Use probabilities between intensive and extensive roofs indicated the ability of intensive roofs to support some bird species for a greater proportion of time than extensive roofs, which may indicate that intensive roofs can provide the majority of resources needed to support these bird species, whereas extensive roofs appear better suited to provide bird habitat complimentary to that in the surrounding landscapes. To better understand the differences in how birds use green roofs compared to the surrounding landscapes (i.e., reduce credible intervals), future studies could examine green roofs with greater variability in roof size and vegetation structural diversity. Conversely, several roofs with similar structure could be studied to hone in on the bird community that uses specific roof types (e.g., intensive, native prairie vegetation with >60% cover, mean height of 1.1m). In addition, percent cover of vegetation on a roof could be studied for possible effect on bird community species richness, as was noted for insect communities on green roofs in a study by Monsma (2011).

Comparisons of expected and observed bird species

Generally, bird communities known to use various vegetation types on the ground also used green roofs with similar vegetation composition and structure: Species in ground foraging guilds, such as killdeer (*Charadrius vociferus*) and common grackle (*Quizcalus quizcula*) (De Graff et al., 1985), were observed feeding on green roofs established with sedum and turf grass; species associated with tall herbaceous vegetation, such as red-winged blackbird (Short, 1985), were observed on roofs established with perennials such as little bluestem (*Schizachyrium scoparium)* and coneflower (*Echinacea sp.)*; and forest edge associated species, such as downy woodpecker (*Picoides pubescens*) (Schroeder, 1982), were observed on roofs established with shrubs and trees.

Based on foraging guilds (De Graff et al., 1985), species expected on individual green roofs were observed on green roofs (Table 2.3), and other species that were not expected based on their foraging guild (i.e., upper canopy foraging species) were also observed on green roofs. The presence of these "unexpected" species may be a result of fewer disturbances on green roofs compensating for the lack of suitable vegetation charateristics, or/and the presence of features on the roof that complement the bird habitat provided by the surrounding landscape. Without ground predators and human disturbance, vegetation that would otherwise be unsuitable may increase in suitability for a species. For example, the Aquascape Headquarters Green Roof in St. Charles, Illinois established with native prairie plant species was expected to provide suitable vegetation for red-winged blackbirds, but other species whose habitat requirements were not fulfilled by this green roof (i.e., American goldfinch; eastern kingbird, *Tyrannus tyrannus*; and song sparrow) were also observed. If these species were present despite that their habitat requirements were only partially fulfilled by the green roof, a green roof and its surrounding landscape likely combine to provide some habitat for species. This and similar findings support the concept that green roofs can contribute to bird species habitat, even if the vegetation does not fulfill all habitat requirements.

Bird community conservation potential

Because species richness on green roofs was greater than in the surrounding landscapes, green roof construction has potential to increase bird species richness in the area immediately surrounding a green roof. The difference between species richness for green roofs and landscapes may vary because of landscape composition. A landscape that does not provide suitable songbird habitat might experience a 'spill-over' affect from a green roof that provides high-quality songbird habitat, or conversely a green roof lacking suitable songbird habitat might function as an ecological 'sink' (i.e., an area with low reproductive success that is reliant on immigration to sustain a population; Thompson, 2005) in a landscape that provides high quality songbird habitat. These potential scenarios demonstrate the need for further research on the population dynamics of selected species associated with green roofs to accurately describe the affect green roof construction will have on species richness of various sites. In our study sites, typically, observed bird species on the green roofs in suburban and semi-rural landscapes were a subset of those observed in the landscapes. However, in highly urban landscapes, green roofs often had a greater species richness and abundance of migratory songbirds than the surrounding landscapes, and the native species observed on green roofs were not observed in the surrounding landscapes. This observation also highlights the potential for creating suitable bird habitat in urban areas.

None of the species observed on green roofs were listed as threatened or endangered; however, Bell's vireo (*Vireo bellii*), field sparrow (*Spizella pusilla*), and northern flicker (*Colaptes auratus*) were observed on studied green roofs and are reported by the U.S. Fish and Wildlife Service (2010) to be rare or declining species in the Midwest United States. In addition, the eastern kingbird was observed on 17% of our green roofs and has experienced significant negative trends from 2000-2010 for the Lower Great Lakes/St. Lawrence Plain (Sauer et al., 2011). Vegetation and other structural features (i.e., log, rock, gravel) could be provided on green roofs to enhance suitable habitat for these species and others in decline. To enhance foraging opportunities for Bell's vireo in the landscape near riparian areas, roofs could be established with shrubs up to 4m tall and other plants that encourage insects (Franzreb, 1989).

Field sparrow and northern flicker are ground foraging species and incorporating plant species that attract insects or produce edible seeds could help provide food for these species. However, because northern flicker are cavity nesters (Lawrence, 1967), unless snags or other artificial structures providing cavities are placed on green roofs, northern flicker will not nest on green roofs. Varying media depth and composition across the roof could help establish these plants. For example, habitat for field sparrow is most suitable when vegetation is comprised of herbaceous cover 16-32cm, 50-90% grass cover, 15-35% shrub cover, and 50-75% of shrubs should be <1.5m tall (Sousa, 1983). Rooftops might also be an ideal location for field sparrow nests since predation by ground level predators has been recorded for up to 78% of nests in central Illinois (Best, 1978). Eastern kingbird numbers may be enhanced by establishing herbaceous vegetation that supports insects on which eastern kingbird feed; however, since eastern kingbird nest in trees, they may not nest on green roofs (Murphy, 1983).

Other rare or declining species that have been reported by green roof owners/managers of MIA and CHA to use these green roofs are: brown thrasher (*Toxostoma rufum*), marsh wren (*Cistothorus palustris*), olive-sided flycatcher (*Contopus cooperi*), peregrine falcon (*Falco peregrinus*), prothonotary warbler (*Protonotaria citrea*), sedge wren (*Cistothorus platensis*), and wood thrush (*Hylocichla mustelina*). Brown thrasher, prothonotary warbler, sedge wren, and wood thrush are all species in ground foraging guilds and thus expected to forage on green roofs. The remaining species are marsh gleaning, air sallier (i.e., birds that forage while in the air during short flights from a perch), and air screener (i.e., birds that fly with their bill open to screen prey from the air) species that may momentarily rest on a green roof between feeding bouts or use a green roof as a stop-over site during migration, however are unlikely to feed directly on a green roof. Dense shrubs up to 6m tall can be planted on green roofs to provide suitable nesting sites for some species, such as the brown thrasher (Brewer, 2010). Shrubs established on two studied green roofs could provide suitable nesting sites for brown thrasher.

Green roofs also have potential to provide suitable vegetation types for several bird species that have not been observed on green roofs, but have experienced significant negative trends from 2000-2010 for the Lower Great Lakes/St. Lawrence Plain (Sauer et al., 2011). Green roofs planted in native grassland species, such as pale purple coneflower (*Echinacea pallida*) and Culver's root (*Veronicastrum virginicum*), could increase the proportion of grassland vegetation in the landscape and increase habitat suitability for grassland bird species even though these bird species may not occupy green roofs. Some of these native grassland species have been planted on green roofs; hence more extensive plantings could be developed if birds such as Henslow's sparrow (*Ammodramus henslowii*) and eastern meadowlark (*Sturnella magna*) were desired in a landscape with green roofs. Grassland bird species likely will not be greatly affected by green roofs in high density urban areas; however, establishment of grassland plants on rooftops of buildings near grasslands may reduce effective grassland bird habitat loss. Green roofs may also be able to provide stopover areas for some neo-tropical migratory bird species, such as common nighthawk (*Chordeiles minor*) by providing open gravel for nesting sites amongst vegetation (Gramza, 1967).

Green roofs are a technology with potential to reduce bird habitat degradation and fragmentation and to increase landscape connectivity (Lundholm, 2006; Bierwagen, 2007; Eakin et al., in review). The implementation of green roofs, especially intensive roofs, designed to address the habitat requirements of specific bird communities or species could help conserve native bird species and increase species richness and abundance in urban landscapes if this is a desirable objective. Wide-spread implementation of green roofs focused on creating bird habitat throughout urban areas could help reverse population declines of various grassland and neo-tropical migratory bird species. Though establishment of grassland vegetation on green roofs is unlikely to compensate for the vast areas of grasslands lost to agriculture during the second half of the twentieth century, any additional grassland vegetation may mitigate some of the effects of grassland bird habitat degradation. Also, several other neo-tropical migratory bird species are subject to urban pressures (Blair 1996), and by implementing green roofs designed for birds (i.e., provide food, perches, cover, nesting sites) these species may be less likely to experience declines in the future.

Our research can be used to inform green roof design for bird habitat conservation while meeting the objectives for green roofs to conserve energy and storm water runoff. Pre- and post-construction bird surveys of these green roofs would help explain how to achieve bird conservation goals (i.e., abundance, species richness, diversity). Further research is needed to better understand how green roofs affect species richness and abundance, nesting success, connectivity through urban areas, and source-sink dynamics for individual species.

Our study quantified the composition of bird communities on green roofs and their surrounding landscapes, demonstrated the influence of vegetation and non-vegetation structure and composition of the surrounding landscapes and of green roofs on bird community composition and structure. In addition, our study quantified the relationship between bird communities in the landscapes with those on green roofs. Since bird species occupied green roofs and demonstrated trends indicate that they respond to vegetation and non-vegetation characteristics, prior knowledge of bird species' habitat requirements should be the basis of recommendations for green roof design, composition, and management in relation to existing landscapes. This information should help green roof designers, city planners, natural resource managers, and policy makers enhance wildlife conservation in urban areas through green technology.

Table 2.1. Location, building structure characteristics, planting media depth, planted vegetation and year of green roof installation at study sites sampled in 2010 and 2011 in Illinois and Michigan, U.S.A.

		Building Structure Characteristics							
Study Site[a]	City, State	Type[b]	Green Roof Size (m^2)	Height (# story)	Slope (%)	Media Depth (cm)	Vegetation	Year Installed	Year Studied
DCP	Chicago, IL	E and I	99,145	0	1.0 to 5.0	10 to 122	Ornamental perennials, turf, shrubs, trees	2004	2010
FOR	Dearborn, MI	E	42,177	3	1.5	2	*Sedum*	2003	2010, 2011
MCC	Chicago, IL	I	24,276	0	16.7	45 to 61	Native prairie perennials, trees	2003	2010
AQU	St. Charles, IL	E	23,782	2 to 4	8.3	10	Native prairie perennials	2005	2010
HAW	Holland, MI	E	4,181	0 to 4	10.0 to 30.0	10	*Sedum*	2007	2010, 2011
CCE	Chicago, IL	E	1,892	8	1.0	9 to 11	*Sedum*, ornamental perennials, low evergreen shrubs	2006	2011
CHA	Chicago, IL	E and I	1,886	11	Sculpted terrain	8 to 46	Perennials, shrubs, vines, small trees	2001	2011
NAM	Chicago, IL	E	1,581	1.9	7.0 and 1.5	8 and 5 to 25	*Sedum*, native perennials, one tree	2002, 2004[c]	2010, 2011

Table 2.1. (cont'd)

Study Site[a]	City, State	Type[b]	Green Roof Size (m^2)	Height (# story)	Slope (%)	Media Depth (cm)	Vegetation	Year Installed	Year Studied
MIA	Chicago, IL	E	1,567	15	1.0	10 to 15	*Sedum*, ornamental perennials	2008	2011
SCH	Chicago, IL	I	929	3	1.5, raised beds, potted trees	20 to 46	Perennials, annuals, shrubs, small trees	2003	2010, 2011
GCY	Chicago, IL	I	758	3	1.0	61	Perennials, vegetables, fruits, herbs	2006	2011
PSS	East Lansing, MI	E	325	1.5	1.0	3 to 8	*Sedum*	2004	2010

[a] Study sites: DCP, Downtown Chicago Park; FOR, Ford Truck Plant; MCC, McCormick Parking Structure; AQU, Aquascape Headquarters; HAW, Haworth Headquarters; CCE, Chicago Cultural Center; CHA, Chicago City Hall; NAM, Nature Museum; MIA, Michigan Avenue Structure; SCH, Schwab Rehabilitation Hospital; GCY, Gary Comer Youth Center; PSS, Plant and Soil Science Building at Michigan State University

[b] Type: I, intensive; E, extensive

[c] One intensive green roof was installed in 2002 and two extensive green roofs were installed in 2004.

Table 2.2. Maintenance regime, primary function, and accessibility of green roof study sites sampled in 2010 and 2011 in Illinois and Michigan, U.S.A.

Study Site[a]	Maintenance[b]	Primary Function(s)	Accessibility[c]	Artificial Water Source[d]	Land cover Classification[e]
DCP	W, R, P, F, M	Recreation	P	S, H	Urban park, high-density residential, urban central business district, museum, railway
FOR	F	Pollution mitigation, energy savings	A	S	Industrial complex
MCC	B	Wildlife habitat creation	A	-	Conference center, urban park, lake, highway
AQU	W	Pollution mitigation, energy savings, wildlife habitat creation	A	SB	Offices and light manufacturing distribution, residential mid-density, airport
HAW	W, F	Pollution mitigation, energy savings	A	S	Industrial complex, commercial complex
CCE	W, R	Aesthetics, pollution mitigation, energy savings	A	SB	Urban central business district, urban park, high-density residential
CCH	W, R, N	Wildlife habitat creation, pollution mitigation, energy savings	A	D	Urban central business district, urban park, high-density residential
NAM	W, R, P	Education, wildlife habitat creation, pollution mitigation, energy savings	A	-	Museum, urban park, lake
MIA	W, R, F	Aesthetics, pollution mitigation, energy savings	A	S	Urban central business district, residential high-density

Table 2.2. (cont'd)

Study Site[a]	Maintenance[b]	Primary Function(s)	Accessibility[c]	Artificial Water Source[d]	Land cover Classification[e]
SCH	W, P, F, A	Therapeutic, aesthetics	PR	H, D, W	Health facilities, urban park, residential mid-density
GCY	W, F, H	Education, gardening	PR	S	School, residential mid-density, commercial strip developments, railway
PSS	None	Education, pollution mitigation, energy savings	A	-	College campus, urban park, railway

[a] Study sites: DCP, Downtown Chicago Park; FOR, Ford Truck Plant; MCC, McCormick Parking Structure; AQU, Aquascape Headquarters; HAW, Haworth Headquarters; CCE, Chicago Cultural Center; CHA, Chicago City Hall; NAM, Nature Museum; MIA, Michigan Avenue Structure; SCH, Schwab Rehabilitation Hospital; GCY, Gary Comer Youth Center; PSS, Plant and Soil Science Building at Michigan State University

[b] Maintenance: W, weeding; R, removal of dead plant materials; P, pruning; F, fertilizing; M, mowing; B, controlled burning; A, planting annuals; H, harvesting; N, planting new plant species

[c] Accessibility: P, public; A, arranged; PR, private

[d] Artificial water source: S, sprinkler; SB, subsurface; H, hand-watering; D, drip; W, water feature

[e] Land Use Classification based on United States Geological Survey (USGS) land use and land cover classification sytems (Anderson et al., 1976). Driveways and surface roads were not included as a land use class because these transportation routes were present at all sites.

Table 2.3. Relative abundance of bird species observed on green roofs and in their surrounding landscapes in Michigan and Illinois, U.S.A. in 2010 and 2011. Relative abundances were based on the total number of bird observations at each roof or landscape. All study sites are a Downtown Chicago Park (DCP), Ford Truck Plant (FOR), McCormick Parking Structure (MCC), Aquascape Headquarters (AQU), Haworth Headquarters (HAW), Chicago Cultural Center (CCE), Chicago City Hall (CHA), Nature Museum (NAM), Michigan Avenue Structure (MIA), Schwab Rehabilitation Hospital (SCH), Gary Comer Youth Center (GCY), and the Plant and Soil Science Building at Michigan State University (PSS).

			DCP		Ford Truck Plant				MCC	
			2010		2010		2011[c]		2010	
Species	Four Letter Abbreviation	Foraging Guild[d]	R[e]	L	R	L	R	L	R	L
American crow[a]	AMCR	GF	0.005	0.035	-	-	-	-	-	0.019
American goldfinch[a]	AMGO	GF	0.024	0.001	-	0.001	-	0.008	0.025	0.042
American kestrel	AMKE	AH	-	-	-	0.004	-	0.008	-	-
American robin[a]	AMRO	GG	0.128	0.054	0.011	0.059	0.017	0.128	0.015	0.032
American tree sparrow[ab]	ATSP	GF	0.001	-	-	-	-	-	-	-
Baltimore oriole	BAOR	UCF	-	0.005	-	-	-	-	-	-
Barn swallow	BARS	ASC	-	0.001	-	0.015	-	-	-	0.030
Bay-breasted warbler	BBWA	UCG	-	-	-	-	-	-	-	-
Bell's vireo[a]	BEVI	LCG/SG	0.003	0.001	-	-	-	-	-	0.002
Belted kingfisher	BEKI	WP	-	-	-	-	-	-	-	-
Blackburnian warbler[a]	BLBW	UCF	0.001	0.001	-	-	-	-	-	-
Black-capped chickadee	BCCH	LCG	-	-	-	-	-	-	-	-
Black-crowned night heron	BCNH	WA	-	-	-	-	-	-	-	-
Black-headed grosbeak	BHGR	UCF	-	0.001	-	-	-	-	-	-
Blue jay	BLJA	GF/UCF	-	0.001	-	-	-	-	-	0.005

Table 2.3. (cont'd)

Species	Four Letter Abbreviation	Foraging Guild[d]	DCP 2010 R[e]	DCP 2010 L	Ford Truck Plant 2010 R	Ford Truck Plant 2010 L	Ford Truck Plant 2011[c] R	Ford Truck Plant 2011[c] L	MCC 2010 R	MCC 2010 L
Blue-winged teal	BWTE	FD	-	-	-	-	-	-	-	-
Brown-headed cowbird	BHCO	GF	-	-	-	-	-	-	-	0.002
Canada goose[a]	CAGO	WD	-	0.003	0.284	0.200	0.633	0.053	-	0.006
Cedar waxwing	CEDW	ASA/UCG	-	-	-	-	-	-	-	0.001
Chestnut-sided warbler	CSWA	LCG	-	-	-	-	-	-	-	0.001
Chimney swift	CHSW	ASC	-	-	-	-	-	-	-	0.015
Chipping sparrow[a]	CHSP	GF	-	0.005	-	-	-	-	0.002	-
Cliff swallow	CLSW	ASC	-	-	-	-	-	-	-	0.010
Common grackle[a]	COGR	GF	0.298	0.118	0.019	0.181	0.242	0.089	-	0.023
Common tern	COTE	WP	-	-	-	-	-	-	-	-
Common yellowthroat[a]	COYE	LCG	0.005	-	-	-	-	-	0.005	0.004
Dark-eyed junco[a]	DEJU	GF	0.002	-	-	-	-	-	-	0.002
Downy woodpecker[a]	DOWO	BG/LCG	-	0.001	-	-	-	-	-	-
Eastern bluebird	EABL	GG	-	0.001	-	-	-	-	-	-
Eastern kingbird[a]	EAKI	ASA	-	-	0.002	0.009	-	-	-	-
Eastern wood-pewee	EAWP	ASA	-	-	-	-	-	-	-	0.006
European starling[a]	EUST	GF	0.089	0.113	0.580	0.511	0.025	0.479	0.002	0.372
Field sparrow[ab]	FISP	GF	-	-	-	-	-	-	-	-
Gray catbird	GRCA	GF/LCF	-	0.003	-	-	-	-	-	0.006

Table 2.3. (cont'd)

Species	Four Letter Abbreviation	Foraging Guild[d]	DCP 2010		Ford Truck Plant 2010		Ford Truck Plant 2011[c]		MCC 2010	
			R[e]	L	R	L	R	L	R	L
Great blue heron	GBHE	WA	-	-	-	-	-	-	-	-
Hermit thrush	HETH	WA	-	0.003	-	-	-	-	-	-
House finch	HOFI	GG	-	0.001	-	-	-	-	-	-
House sparrow[a]	HOSP	GG	0.005	0.134	-	0.004	-	0.008	-	-
House wren[a]	HOWR	GG	-	-	-	-	-	-	-	0.001
Killdeer[a]	KILL	LCG	-	-	0.082	0.008	0.067	0.028	-	-
Magnolia warbler	MAWA	GG	-	-	-	-	-	-	-	-
Mallard[a]	MALL	LCG	0.005	0.005	0.006	-	0.008	-	-	0.010
Mourning dove[a]	MODO	GG	-	-	-	0.015	-	0.006	-	0.002
Mute swan	MUSW	GG	-	-	-	-	-	-	-	-
Nashville warbler[ab]	NAWA	FD	-	-	-	-	-	-	-	-
Northern cardinal[a]	NOCA	LCG	-	0.005	-	-	-	-	0.002	0.007
Northern flicker[a]	NOFL	GF	0.001	0.001	-	-	-	-	-	0.001
Northern waterthrush	NOWA	GG	-	-	-	-	-	-	-	-
Palm warbler	PAWA	BG/GF	-	-	-	-	-	-	-	-
Prothonotary warbler	PROW	GG	-	0.001	-	-	-	-	-	-
Purple finch	PUFI	LCG/BG	-	-	-	-	-	-	-	-
Red-bellied woodpecker	RBWO	UCG	-	0.001	-	-	-	-	-	-
Red-winged blackbird[a]	RWBL	BG/GF	0.294	0.025	0.002	0.149	0.008	0.093	0.904	0.225

Table 2.3. (cont'd)

Species	Four Letter Abbreviation	Foraging Guild[d]	DCP 2010		Ford Truck Plant 2010		Ford Truck Plant 2011[c]		MCC 2010	
			R[e]	L	R	L	R	L	R	L
Ring-billed gull[a]	RBGU	GG	0.054	0.266	0.015	0.005	-	0.028	-	0.016
Rock pigeon[a]	ROPI	GF	0.057	0.126	-	0.019	-	0.043	-	-
Ruby-crowned kinglet	RCKI	LCG	-	-	-	-	-	-	-	-
Scarlet tanager	SCTA	UCG	-	-	-	-	-	-	-	0.001
Snow goose	SNGO	GG	-	-	-	-	-	-	-	-
Song sparrow[a]	SOSP	LCF/GF	0.008	0.001	-	-	-	-	0.022	0.002
Swainson's thrush	SWTH	GF/LCF	-	-	-	-	-	-	-	-
Tree swallow[a]	TRES	ASC	-	-	-	-	-	0.026	0.002	0.009
Warbling vireo	WAVI	UCG	-	0.001	-	-	-	-	-	-
White-crowned sparrow[a]	WCSP	GF	0.003	0.062	-	-	-	-	-	0.031
White-throated sparrow[a]	WTSP	GF	0.014	0.023	-	-	-	0.002	0.02	0.111
Wood duck	WODU	GG/FSG	-	-	-	-	-	-	-	-
Yellow warbler	YWAR	LCG	-	-	-	-	-	-	-	-
Yellow-bellied flycatcher	YBFL	ASA	-	-	-	-	-	-	-	0.002
Yellow-rumped warbler	YRWA	LCG	-	0.001	-	-	-	-	-	0.001
	Species Richness		19	32	9	14	7	14	10	32
	No. Survey Dates		7		7		4		6	

Table 2.3. (cont'd)

Species	Four Letter Abbreviation	Foraging Guild[d]	AQU 2010 R	AQU 2010 L	Haworth Headquarters 2010 R	Haworth Headquarters 2010 L	Haworth Headquarters 2011[c] R	Haworth Headquarters 2011[c] L	CCE 2011 R	CCE 2011 L
American crow[a]	AMCR	GF	-	-	-	-	-	-	-	0.012
American goldfinch[a]	AMGO	GF	0.071	0.016	-	0.037	-	0.010	-	0.003
American kestrel	AMKE	AH	-	-	-	-	-	-	-	-
American robin[a]	AMRO	GG	0.006	0.079	0.041	0.162	0.400	0.086	-	0.006
American tree sparrow[ab]	ATSP	GF	-	-	-	-	-	-	-	-
Baltimore oriole	BAOR	UCF	-	0.005	-	-	-	-	-	-
Barn swallow	BARS	ASC	-	0.019	-	-	-	-	-	-
Bay-breasted warbler	BBWA	UCG	-	-	-	-	-	-	-	-
Bell's vireo[a]	BEVI	LCG/SG	-	-	-	-	-	-	-	-
Belted kingfisher	BEKI	WP	-	-	-	-	-	-	-	-
Blackburnian warbler[a]	BLBW	UCF	-	-	-	-	-	-	-	-
Black-capped chickadee	BCCH	LCG	-	0.005	-	-	-	-	-	0.003
Black-crowned night heron	BCNH	WA	-	-	-	-	-	-	-	-
Black-headed grosbeak	BHGR	UCF	-	-	-	-	-	-	-	-
Blue jay	BLJA	GF/UCF	-	-	-	0.003	-	-	-	-
Blue-winged teal	BWTE	FD	-	-	-	-	-	-	-	-
Brown-headed cowbird	BHCO	GF	-	0.002	-	0.003	-	-	-	-
Canada goose[a]	CAGO	WD	0.030	0.086	-	-	-	-	-	-
Cedar waxwing	CEDW	ASA/UCG	-	0.012	-	0.014	-	-	-	-

Table 2.3. (cont'd)

Species	Four Letter Abbreviation	Foraging Guild[d]	AQU 2010 R	AQU 2010 L	Haworth Headquarters 2010 R	Haworth Headquarters 2010 L	Haworth Headquarters 2011[c] R	Haworth Headquarters 2011[c] L	CCE 2011 R	CCE 2011 L
Chestnut-sided warbler	CSWA	LCG	-	-	-	-	-	-	-	-
Chimney swift	CHSW	ASC	-	-	-	-	-	-	-	-
Chipping sparrow[a]	CHSP	GF	-	-	-	0.028	-	-	-	-
Cliff swallow	CLSW	ASC	-	-	-	-	-	-	-	-
Common grackle[a]	COGR	GF	0.006	0.124	0.408	0.210	0.280	0.038	-	0.028
Common tern	COTE	WP	-	-	-	-	-	-	-	-
Common yellowthroat[a]	COYE	LCG	-	-	-	-	-	-	-	-
Dark-eyed junco[a]	DEJU	GF	-	-	-	0.009	-	-	-	-
Downy woodpecker[a]	DOWO	BG/LCG	-	-	-	-	-	-	-	-
Eastern bluebird	EABL	GG	-	0.002	-	-	-	-	-	-
Eastern kingbird[a]	EAKI	ASA	0.006	-	-	-	-	0.038	-	-
Eastern wood-pewee	EAWP	ASA	-	-	-	-	-	-	-	-
European starling[a]	EUST	GF	-	0.121	0.429	0.145	0.120	0.314	0.250	0.021
Field sparrow[ab]	FISP	GF	-	-	-	-	-	-	0.500	-
Gray catbird	GRCA	GF/LCF	-	-	-	-	-	-	-	-
Great blue heron	GBHE	WA	-	-	-	-	-	-	-	-
Green heron	GRHE	WA	-	-	-	-	-	-	-	-
Hermit thrush	HETH	GG	-	-	-	-	-	-	-	-
House finch	HOFI	GG	-	-	-	0.003	-	-	-	0.009

Table 2.3. (cont'd)

Species	Four Letter Abbreviation	Foraging Guild[d]	AQU 2010 R	AQU 2010 L	Haworth Headquarters 2010 R	Haworth Headquarters 2010 L	Haworth Headquarters 2011[c] R	Haworth Headquarters 2011[c] L	CCE 2011 R	CCE 2011 L
House sparrow[a]	HOSP	GG	-	0.005	0.020	0.003	-	0.019	0.250	0.098
House wren[a]	HOWR	LCG	-	-	-	-	-	-	-	-
Killdeer[a]	KILL	GG	-	0.002	0.102	0.023	0.200	0.029	-	-
Magnolia warbler	MAWA	LCG	-	-	-	-	-	-	-	-
Mallard[a]	MALL	GG	0.024	0.042	-	0.009	-	0.029	-	0.003
Mourning dove[a]	MODO	GG	0.018	0.051	-	0.023	-	0.067	-	-
Mute swan	MUSW	FD	-	-	-	0.065	-	0.086	-	-
Nashville warbler[ab]	NAWA	LCG	-	-	-	-	-	-	-	-
Northern cardinal[a]	NOCA	GF	-	-	-	-	-	-	-	-
Northern flicker[a]	NOFL	GG	-	0.002	-	-	-	-	-	-
Northern waterthrush	NOWA	BG/GF	-	-	-	-	-	-	-	-
Palm warbler	PAWA	GG	-	-	-	-	-	-	-	-
Prothonotary warbler	PROW	LCG/BG	-	-	-	-	-	-	-	-
Purple finch	PUFI	UCG	-	0.007	-	-	-	-	-	0.003
Red-bellied woodpecker	RBWO	BG/GF	-	-	-	-	-	-	-	-
Red-winged blackbird[a]	RWBL	GF	0.821	0.404	-	0.233	-	0.286	-	0.009
Ring-billed gull[a]	RBGU	GG	-	-	-	-	-	-	-	0.009
Rock pigeon[a]	ROPI	GF	-	-	-	-	-	-	-	0.715
Ruby-crowned kinglet	RCKI	LCG	-	-	-	-	-	-	-	-

Table 2.3. (cont'd)

Species	Four Letter Abbreviation	Foraging Guild[d]	AQU 2010 R	AQU 2010 L	Haworth Headquarters 2010 R	Haworth Headquarters 2010 L	Haworth Headquarters 2011[c] R	Haworth Headquarters 2011[c] L	CCE 2011 R	CCE 2011 L
Scarlet tanager	SCTA	UCG	-	-	-	-	-	-	-	-
Snow goose	SNGO	GG	-	-	-	-	-	-	-	-
Song sparrow[a]	SOSP	LCF/GF	0.018	-	-	0.014	-	-	-	-
Swainson's thrush	SWTH	GF/LCF	-	-	-	-	-	-	-	-
Tree swallow[a]	TRES	ASC	-	0.014	-	0.017	-	-	-	-
Warbling vireo	WAVI	UCG	-	-	-	-	-	-	-	-
White-crowned sparrow[a]	WCSP	GF	-	-	-	-	-	-	-	0.003
White-throated sparrow[a]	WTSP	GF	-	-	-	-	-	-	-	0.077
Wood duck	WODU	GG/FSG	-	-	-	-	-	-	-	-
Yellow warbler	YWAR	LCG	-	-	-	-	-	-	-	-
Yellow-bellied flycatcher	YBFL	ASA	-	-	-	-	-	-	-	-
Yellow-rumped warbler	YRWA	LCG	-	-	-	-	-	-	-	-
	Species Richness		9	19	5	18	4	11	3	15
	No. Survey Dates		4		5		4		4	

Table 2.3. (cont'd)

Species	Four Letter Abbreviation	Foraging Guild[d]	CHA 2011 R	CHA 2011 L	NAM 2010 R	NAM 2010 L	NAM 2011[c] R	NAM 2011[c] L	MIA 2011 R	MIA 2011 L
American crow[a]	AMCR	GF	-	-	-	0.014	-	0.035	-	0.042
American goldfinch[a]	AMGO	GF	-	-	0.010	-	-	0.007	-	-
American kestrel	AMKE	AH	-	-	-	-	-	-	-	-
American robin[a]	AMRO	GG	0.031	-	0.010	0.010	-	0.012	-	-
American tree sparrow[ab]	ATSP	GF	-	-	-	-	-	-	-	-
Baltimore oriole	BAOR	UCF	-	-	-	-	-	-	-	-
Barn swallow	BARS	ASC	-	-	-	-	-	-	-	-
Bay-breasted warbler	BBWA	UCG	-	-	-	-	-	0.002	-	-
Bell's vireo[a]	BEVI	LCG/SG	-	-	-	0.001	-	0.003	-	-
Belted kingfisher	BEKI	WP	-	-	-	-	-	0.002	-	-
Blackburnian warbler[a]	BLBW	UCF	-	-	-	-	-	-	-	-
Black-capped chickadee	BCCH	LCG	-	-	-	0.001	-	0.008	-	-
Black-crowned night heron	BCNH	WA	-	-	-	-	-	-	-	-
Black-headed grosbeak	BHGR	UCF	-	-	-	-	-	-	-	-
Blue jay	BLJA	GF/UCF	-	-	-	-	-	-	-	-
Blue-winged teal	BWTE	FD	-	-	-	0.001	-	-	-	-
Brown-headed cowbird	BHCO	GF	-	-	-	-	-	-	-	-
Canada goose[a]	CAGO	WD	-	-	0.089	0.356	0.270	0.200	-	-
Cedar waxwing	CEDW	ASA/UCG	-	-	-	-	-	-	-	-

Table 2.3. (cont'd)

Species	Four Letter Abbreviation	Foraging Guild[d]	City Hall 2011 R	City Hall 2011 L	NAM 2010 R	NAM 2010 L	NAM 2011[c] R	NAM 2011[c] L	MIA 2011 R	MIA 2011 L
Chestnut-sided warbler	CSWA	LCG	-	-	-	-	-	-	-	-
Chimney swift	CHSW	ASC	-	-	-	0.003	-	-	-	-
Chipping sparrow[a]	CHSP	GF	0.046	-	-	-	-	0.002	0.818	-
Cliff swallow	CLSW	ASC	-	-	-	-	-	-	-	-
Common grackle[a]	COGR	GF	-	-	-	0.013	-	0.028	-	-
Common tern	COTE	WP	-	-	-	0.000	-	-	-	-
Common yellowthroat[a]	COYE	LCG	-	-	-	-	-	0.008	-	-
Dark-eyed junco[a]	DEJU	GF	-	-	-	-	-	-	-	-
Downy woodpecker[a]	DOWO	BG/LCG	0.015	-	-	0.002	-	0.003	-	-
Eastern bluebird	EABL	GG	-	-	-	-	-	-	-	-
Eastern kingbird[a]	EAKI	ASA	-	-	-	-	-	0.008	-	-
Eastern wood-pewee	EAWP	ASA	-	-	-	-	-	-	-	-
European starling[a]	EUST	GF	0.062	0.017	0.416	0.215	0.344	0.206	-	-
Field sparrow[ab]	FISP	GF	-	-	-	-	-	-	-	-
Gray catbird	GRCA	GF/LCF	-	-	-	0.000	-	-	-	-
Great blue heron	GBHE	WA	-	-	-	0.000	-	-	-	-
Green heron	GRHE	WA	-	-	-	0.001	-	-	-	-
Hermit thrush	HETH	GG	-	-	-	-	-	-	-	-
House finch	HOFI	GG	-	-	-	-	-	-	-	-

Table 2.3. (cont'd)

			City Hall		NAM				MIA	
	Four Letter	Foraging	2011		2010		2011[c]		2011	
Species	Abbreviation	Guild[d]	R	L	R	L	R	L	R	L
House sparrow[a]	HOSP	GG	0.015	0.168	0.337	0.123	0.361	0.096	-	0.229
House wren[a]	HOWR	LCG	0.092	-	-	-	-	-	-	-
Killdeer[a]	KILL	GG	-	-	-	-	-	-	-	-
Magnolia warbler	MAWA	LCG	-	-	-	-	-	0.002	-	-
Mallard[a]	MALL	GG	-	-	0.040	0.112	-	0.099	-	-
Mourning dove[a]	MODO	GG	-	-	-	0.004	-	-	-	-
Mute swan	MUSW	FD	-	-	-	-	-	-	-	-
Nashville warbler[ab]	NAWA	LCG	0.077	-	-	-	-	-	-	-
Northern cardinal[a]	NOCA	GF	0.015	-	-	0.001	0.008	-	-	-
Northern flicker[a]	NOFL	GG	-	-	-	-	-	0.002	-	-
Northern waterthrush	NOWA	BG/GF	-	-	-	-	-	0.002	-	-
Palm warbler	PAWA	GG	-	-	-	0.000	-	-	-	-
Prothonotary warbler	PROW	LCG/BG	-	-	-	-	-	-	-	-
Purple finch	PUFI	UCG	-	-	-	-	-	-	-	-
Red-bellied woodpecker	RBWO	BG/GF	-	-	-	-	-	-	-	-
Red-winged blackbird[a]	RWBL	GF	-	-	0.059	0.082	0.016	0.097	-	-
Ring-billed gull[a]	RBGU	GG	-	-	-	0.025	-	0.007	-	0.021
Rock pigeon[a]	ROPI	GF	-	0.702	0.040	0.008	-	0.050	-	0.708
Ruby-crowned kinglet	RCKI	LCG	-	-	-	-	-	0.010	-	-

Table 2.3. (cont'd)

Species	Four Letter Abbreviation	Foraging Guild[d]	City Hall 2011 R	City Hall 2011 L	NAM 2010 R	NAM 2010 L	NAM 2011[c] R	NAM 2011[c] L	MIA 2011 R	MIA 2011 L
Scarlet tanager	SCTA	UCG	-	-	-	-	-	-	-	-
Snow goose	SNGO	GG	-	-	-	0.001	-	0.007	-	-
Song sparrow[a]	SOSP	LCF/GF	-	-	-	-	-	-	-	-
Swainson's thrush	SWTH	GF/LCF	-	-	-	0.000	-	-	-	-
Tree swallow[a]	TRES	ASC	-	-	-	-	-	-	-	-
Warbling vireo	WAVI	UCG	-	-	-	-	-	-	-	-
White-crowned sparrow[a]	WCSP	GF	0.046	0.027	-	-	-	0.079	0.091	-
White-throated sparrow[a]	WTSP	GF	0.600	0.086	-	0.008	-	-	0.091	-
Wood duck	WODU	GG/FSG	-	-	-	0.014	-	0.020	-	-
Yellow warbler	YWAR	LCG	-	-	-	0.001	-	-	-	-
Yellow-bellied flycatcher	YBFL	ASA	-	-	-	-	-	-	-	-
Yellow-rumped warbler	YRWA	LCG	-	-	-	-	-	0.008	-	-
	Species Richness		10	5	8	27	5	27	3	4
	No. Survey Dates		4		4		4		4	

Table 2.3. (cont'd)

Species	Four Letter Abbreviation	Foraging Guild[d]	SCH 2010 R	SCH 2010 L	SCH 2011[c] R	SCH 2011[c] L	GCY 2011 R	GCY 2011 L	PSS 2010 R	PSS 2010 L
American crow[a]	AMCR	GF	-	0.006	-	0.008	-	-	-	-
American goldfinch[a]	AMGO	GF	-	0.022	0.048	0.038	-	-	0.500	0.212
American kestrel	AMKE	AH	-	-	-	-	-	-	-	-
American robin[a]	AMRO	GG	0.400	0.076	0.810	0.180	-	0.216	0.500	0.257
American tree sparrow[ab]	ATSP	GF	-	-	-	-	-	-	-	-
Baltimore oriole	BAOR	UCF	-	-	-	-	-	-	-	-
Barn swallow	BARS	ASC	-	-	-	-	-	-	-	-
Bay-breasted warbler	BBWA	UCG	-	-	-	-	-	-	-	-
Bell's vireo[a]	BEVI	LCG/SG	-	-	-	-	-	-	-	-
Belted kingfisher	BEKI	WP	-	-	-	-	-	-	-	-
Blackburnian warbler[a]	BLBW	UCF	-	-	-	-	-	-	-	-
Black-capped chickadee	BCCH	LCG	-	-	-	0.010	-	-	-	0.001
Black-crowned night heron	BCNH	WA	-	-	-	0.003	-	-	-	-
Black-headed grosbeak	BHGR	UCF	-	-	-	-	-	-	-	-
Blue jay	BLJA	GF/UCF	-	-	-	-	-	-	-	0.001
Blue-winged teal	BWTE	FD	-	-	-	-	-	-	-	-
Brown-headed cowbird	BHCO	GF	-	-	-	0.018	-	-	-	0.001
Canada goose[a]	CAGO	WD	-	0.155	-	0.083	-	-	-	-
Cedar waxwing	CEDW	ASA/UCG	-	-	-	-	-	-	-	0.023

Table 2.3. (cont'd)

Species	Four Letter Abbreviation	Foraging Guild[d]	SCH 2010 R	SCH 2010 L	SCH 2011[c] R	SCH 2011[c] L	GCY 2011 R	GCY 2011 L	PSS 2010 R	PSS 2010 L
Chestnut-sided warbler	CSWA	LCG	-	-	-	-	-	-	-	-
Chimney swift	CHSW	ASC	-	-	-	-	-	-	-	-
Chipping sparrow[a]	CHSP	GF	-	-	0.095	0.003	-	-	-	0.039
Cliff swallow	CLSW	ASC	-	-	-	-	-	-	-	-
Common grackle[a]	COGR	GF	0.267	0.133	-	0.043	-	-	-	0.184
Common tern	COTE	WP	-	-	-	-	-	-	-	-
Common yellowthroat[a]	COYE	LCG	-	-	-	-	-	-	-	-
Dark-eyed junco[a]	DEJU	GF	-	-	-	-	-	-	-	-
Downy woodpecker[a]	DOWO	BG/LCG	-	-	-	0.003	-	-	-	-
Eastern bluebird	EABL	GG	-	-	-	-	-	-	-	-
Eastern kingbird[a]	EAKI	ASA	-	-	-	-	-	-	-	-
Eastern wood-pewee	EAWP	ASA	-	-	-	-	-	-	-	-
European starling[a]	EUST	GF	0.267	0.386	-	0.326	-	0.265	-	0.056
Field sparrow[ab]	FISP	GF	-	-	-	-	-	-	-	-
Gray catbird	GRCA	GF/LCF	-	-	-	-	-	-	-	-
Great blue heron	GBHE	WA	-	-	-	-	-	-	-	-
Green heron	GRHE	WA	-	-	-	-	-	-	-	-
Hermit thrush	HETH	GG	-	-	-	-	-	-	-	-
House finch	HOFI	GG	-	-	-	-	-	-	-	0.010

Table 2.3. (cont'd)

Species	Four Letter Abbreviation	Foraging Guild[d]	SCH 2010 R	SCH 2010 L	SCH 2011[c] R	SCH 2011[c] L	GCY 2011 R	GCY 2011 L	PSS 2010 R	PSS 2010 L
House sparrow[a]	HOSP	GG	0.067	0.026	-	-	1.000	0.480	-	0.114
House wren[a]	HOWR	LCG	-	-	-	-	-	-	-	-
Killdeer[a]	KILL	GG	-	-	-	-	-	-	-	-
Magnolia warbler	MAWA	LCG	-	-	-	-	-	-	-	-
Mallard[a]	MALL	GG	-	0.018	-	0.033	-	-	-	0.008
Mourning dove[a]	MODO	GG	-	-	-	-	-	-	-	0.035
Mute swan	MUSW	FD	-	-	-	-	-	-	-	-
Nashville warbler[ab]	NAWA	LCG	-	-	-	-	-	-	-	-
Northern cardinal[a]	NOCA	GF	-	-	-	0.018	-	0.039	-	0.048
Northern flicker[a]	NOFL	GG	-	0.002	-	-	-	-	-	-
Northern waterthrush	NOWA	BG/GF	-	-	-	-	-	-	-	-
Palm warbler	PAWA	GG	-	-	-	-	-	-	-	-
Prothonotary warbler	PROW	LCG/BG	-	-	-	-	-	-	-	-
Purple finch	PUFI	UCG	-	-	-	-	-	-	-	0.001
Red-bellied woodpecker	RBWO	BG/GF	-	-	-	-	-	-	-	-
Red-winged blackbird[a]	RWBL	GF	-	0.070	-	0.058	-	-	-	0.007
Ring-billed gull[a]	RBGU	GG	-	0.080	-	0.083	-	-	-	-
Rock pigeon[a]	ROPI	GF	-	0.026	0.048	0.078	-	-	-	-
Ruby-crowned kinglet	RCKI	LCG	-	-	-	-	-	-	-	-

Table 2.3. (cont'd)

Species	Four Letter Abbreviation	Foraging Guild[d]	SCH 2010 R	SCH 2010 L	SCH 2011[c] R	SCH 2011[c] L	GCY 2011 R	GCY 2011 L	PSS 2010 R	PSS 2010 L
Scarlet tanager	SCTA	UCG	-	-	-	-	-	-	-	0.001
Snow goose	SNGO	GG	-	-	-	-	-	-	-	-
Song sparrow[a]	SOSP	LCF/GF	-	-	-	-	-	-	-	-
Swainson's thrush	SWTH	GF/LCF	-	-	-	-	-	-	-	-
Tree swallow[a]	TRES	ASC	-	-	-	-	-	-	-	-
Warbling vireo	WAVI	UCG	-	-	-	-	-	-	-	-
White-crowned sparrow[a]	WCSP	GF	-	-	-	0.003	-	-	-	-
White-throated sparrow[a]	WTSP	GF	-	-	-	0.013	-	-	-	-
Wood duck	WODU	GG/FSG	-	-	-	0.005	-	-	-	-
Yellow warbler	YWAR	LCG	-	-	-	-	-	-	-	-
Yellow-bellied flycatcher	YBFL	ASA	-	-	-	-	-	-	-	-
Yellow-rumped warbler	YRWA	LCG	-	-	-	-	-	-	-	-
	Species Richness		4	12	4	19	1	4	2	17
	No. Survey Dates		5		4		4		6	

[a] Species observed on green roofs

[b] Species only observed on green roofs

[c] Study site for this year was not included in the model

[d]Feeding guilds: AH, Air Hawker; ASC, Air Screener ; ASA, Air Sallier; BG, Bark Gleaner; FD, Freshwater Dabbler; FSG, Freshwater Surface Gleaner; GF, Ground Forager; GG, Ground Gleaner; LCF, Lower Canopy Forager; LCG, Lower Canopy Gleaner ; GF, Ground Forager; GG, Ground Gleaner; LCF, Lower Canopy Forager ; LCG, Lower Canopy Gleaner; SG, Shrub Gleaner; UCF, Upper Canopy Forager; UCG, Upper Canopy Gleaner; WA, Water Ambusher; WD, Water Dabbler; WP, Water Plunger

[e] Bird survey areas: R, Green roof; L, Landscape

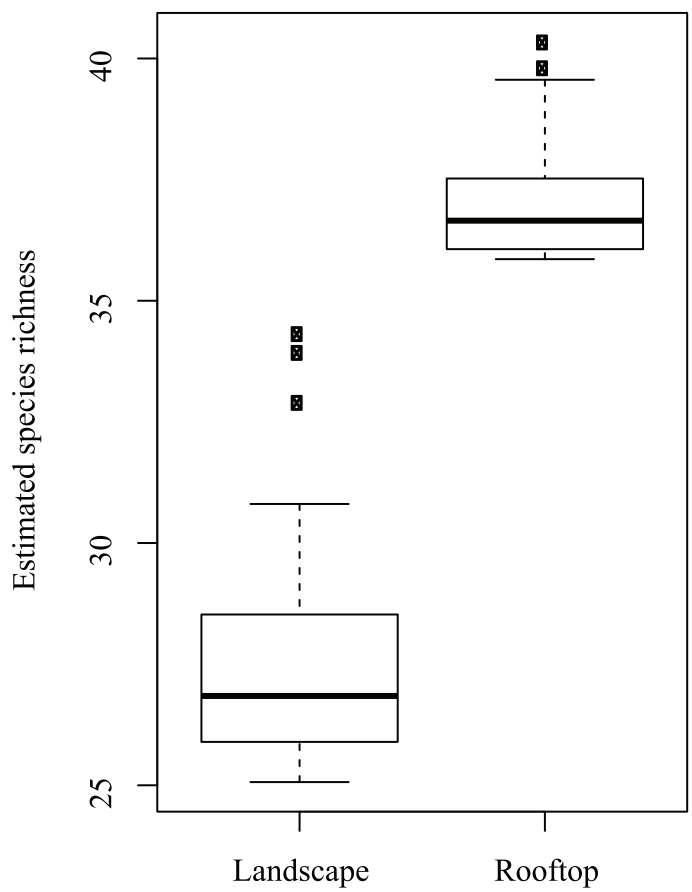

Figure 2.1. Estimated species richness of non-invasive, native bird species, excluding waterfowl and urban associated species, at the point-level for green roof sites in Illinois and Michigan, U.S.A. during sampling in 2010 and 2011. Mean estimated species richness and quartiles shown are estimated using a multi-species hierarchical Bayes multi-scale model.

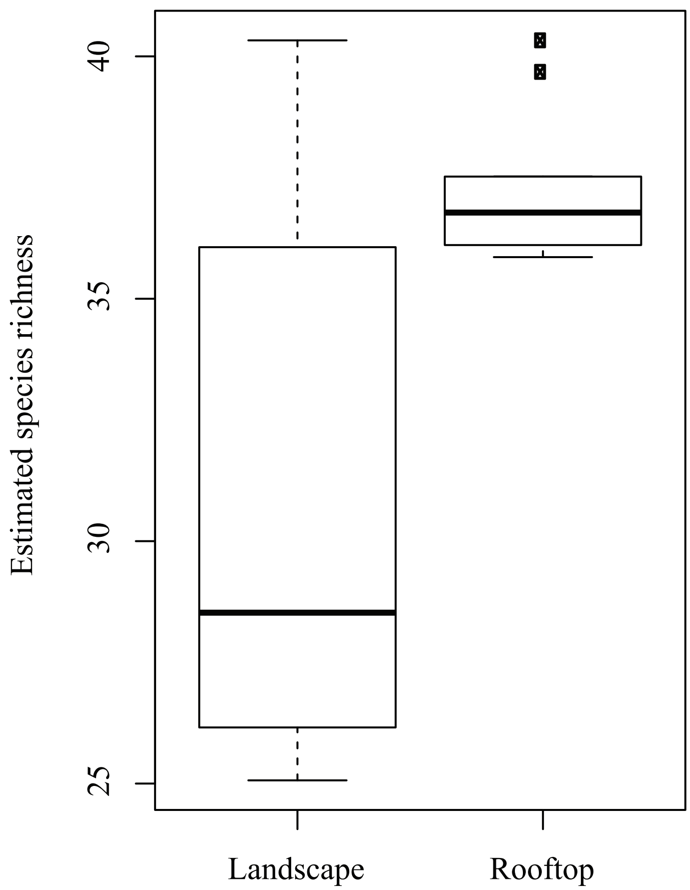

Figure 2.2. Estimated species richness of non-invasive, native bird species, excluding waterfowl and urban associated species, at the site-level for green roof sites in Illinois and Michigan, U.S.A. during sampling in 2010 and 2011. Mean estimated species richness and quartiles shown are estimated using a multi-species hierarchical Bayes multi-scale model.

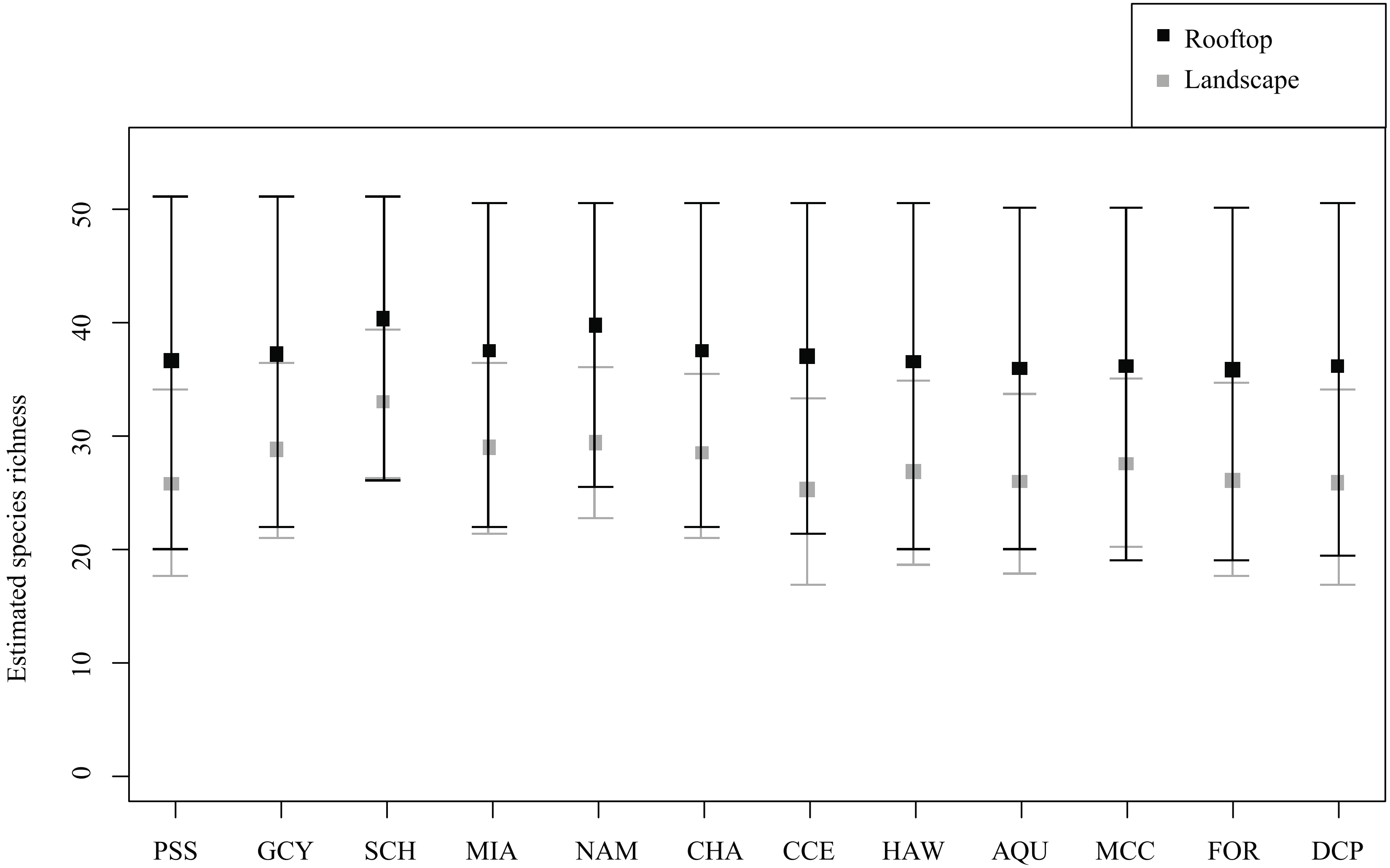

Figure 2.3. Estimated species richness of non-invasive, native bird species, excluding waterfowl and urban associated species, for green roofs and surrounding landscapes in Illinois and Michigan, U.S.A. during sampling in 2010 and 2011. Mean richness and 95% credible intervals shown are estimated using a multi-species hierarchical Bayes multi-scale model.

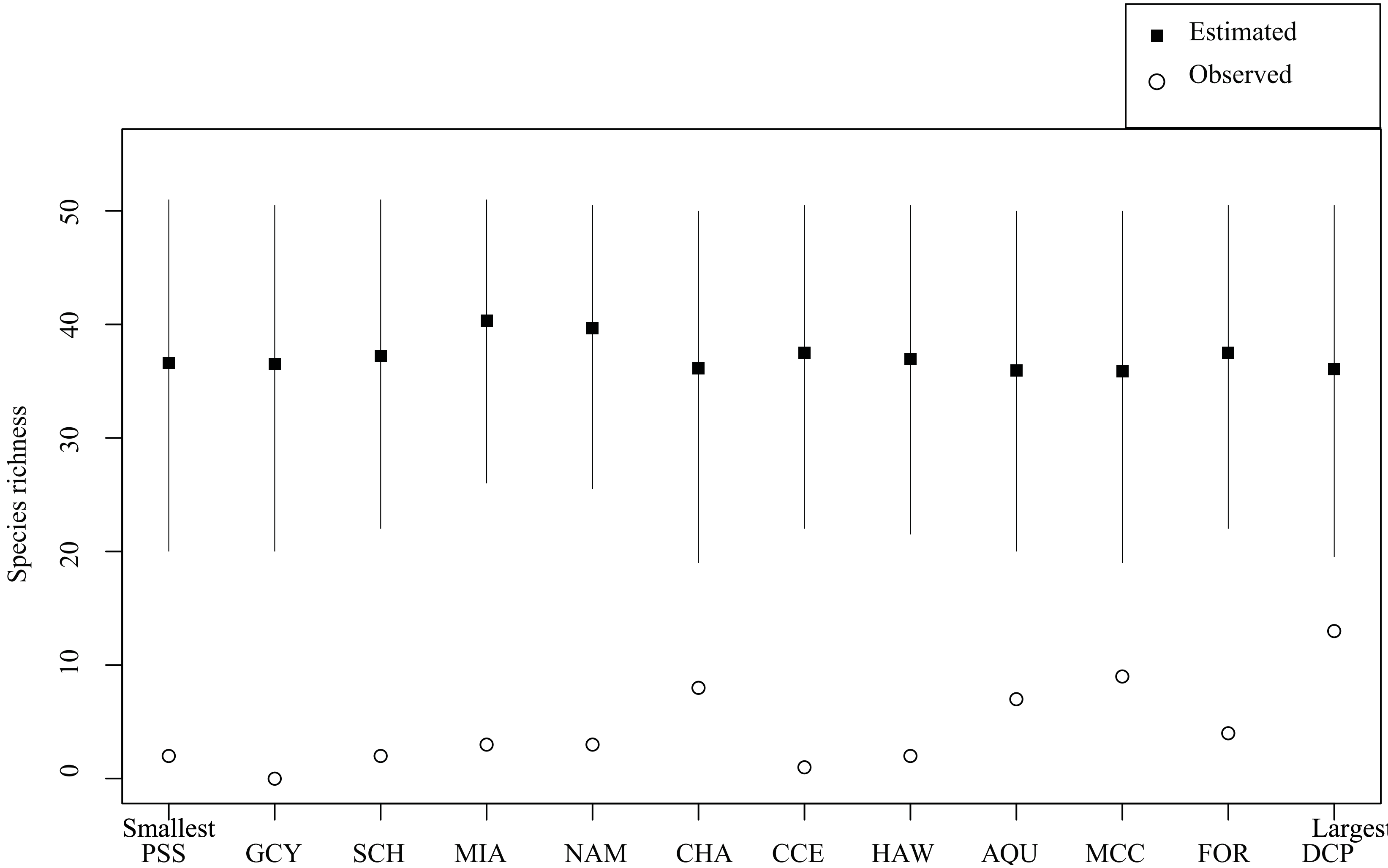

Figure 2.4. Estimated and observed (uncorrected for detection probabilities) species richness of non-invasive, native bird species, excluding waterfowl and urban associated species, from the first year of sampling of green roofs and surrounding landscapes in Illinois and Michigan, U.S.A. in 2010 and 2011. Mean richness and 95% credible intervals shown are estimated using a multi-species hierarchical Bayes multi-scale model.

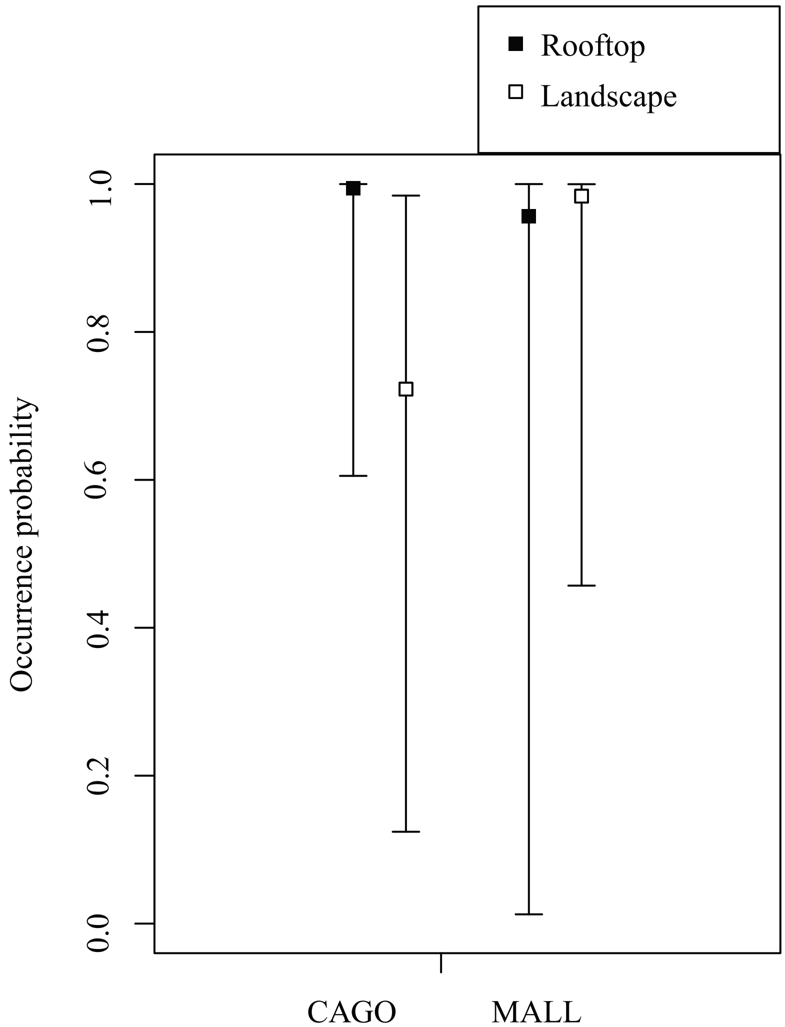

Figure 2.5. Occurance probabilities of native waterfowl bird species, excluding urban-associated species, observed on three or more green roofs in Illinois and Michigan, U.S.A. during sampling in 2010 and 2011. Speices included are Canada goose (*Branta canadensis*, CAGO) and mallard (*Anas platyrhynchos*, MALL). Mean occurrence and 95% credible intervals shown are estimated using a single-species hierarchical Bayes multi-scale occupancy model.

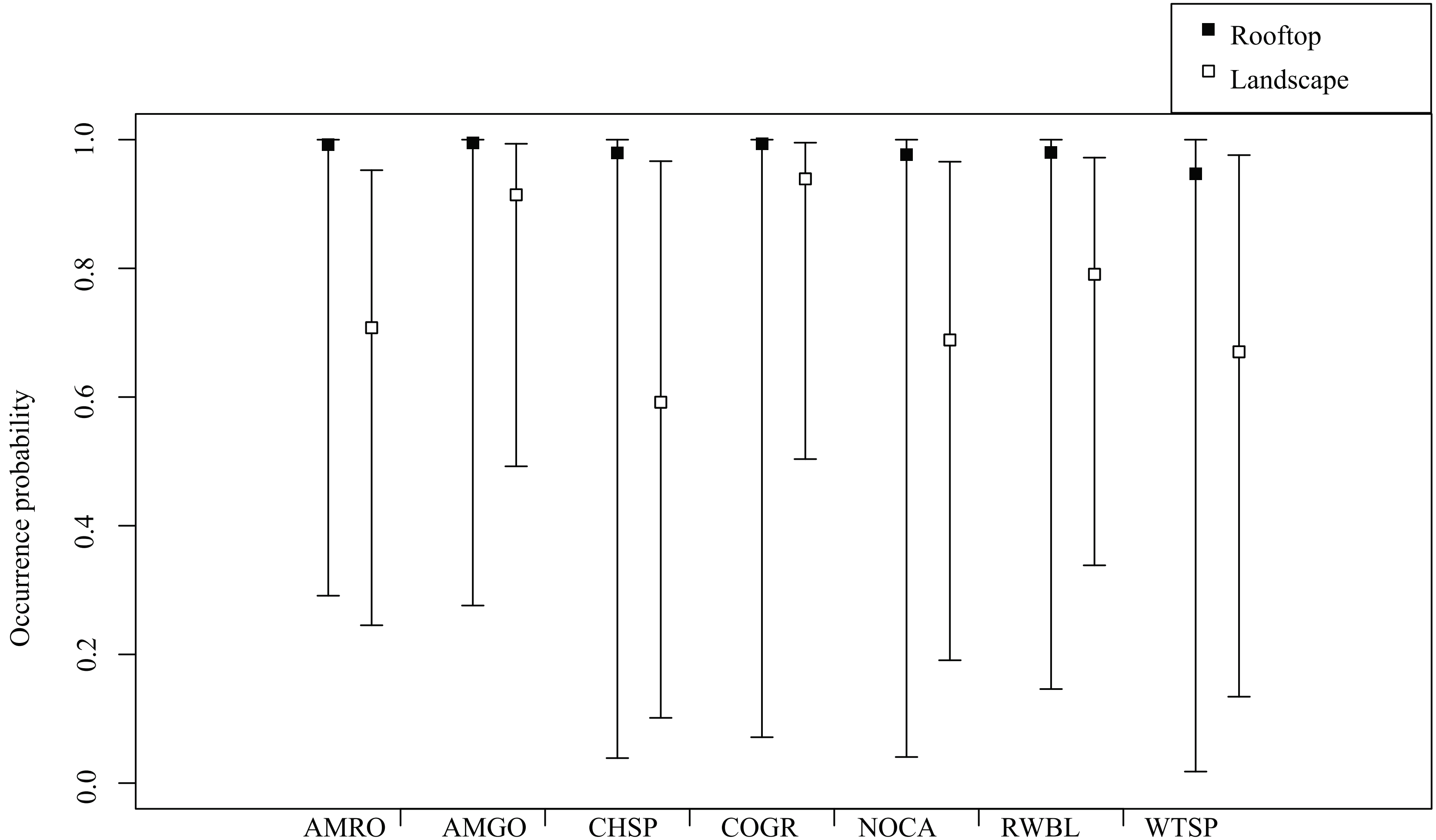

Figure 2.6. Occurance probabilities of native bird species, excluding urban-associated and waterfowl species, observed on 3 or more green roofs in Illinois and Michigan, U.S.A. during sampling in 2010 and 2011. Speices included are American robin (*Turdus migratorius*, AMRO), American goldfinch (*CardueFfigurelis tristis*, AMGO), chipping sparrow (*Spizella passerina*, CHSP), common grackle (*Quizcalus quizcula*, COGR), northern cardinal (*Cardinalis cardinalis*, NOCA), red-winged blackbird (*Agelaius phoeniceus*, RWBL), and white-throated sparrow (*Zonotrichia albicollis*, WTSP). Mean occurrence and 95% credible intervals shown are estimated using a multi-species hierarchical Bayes multi-scale model.

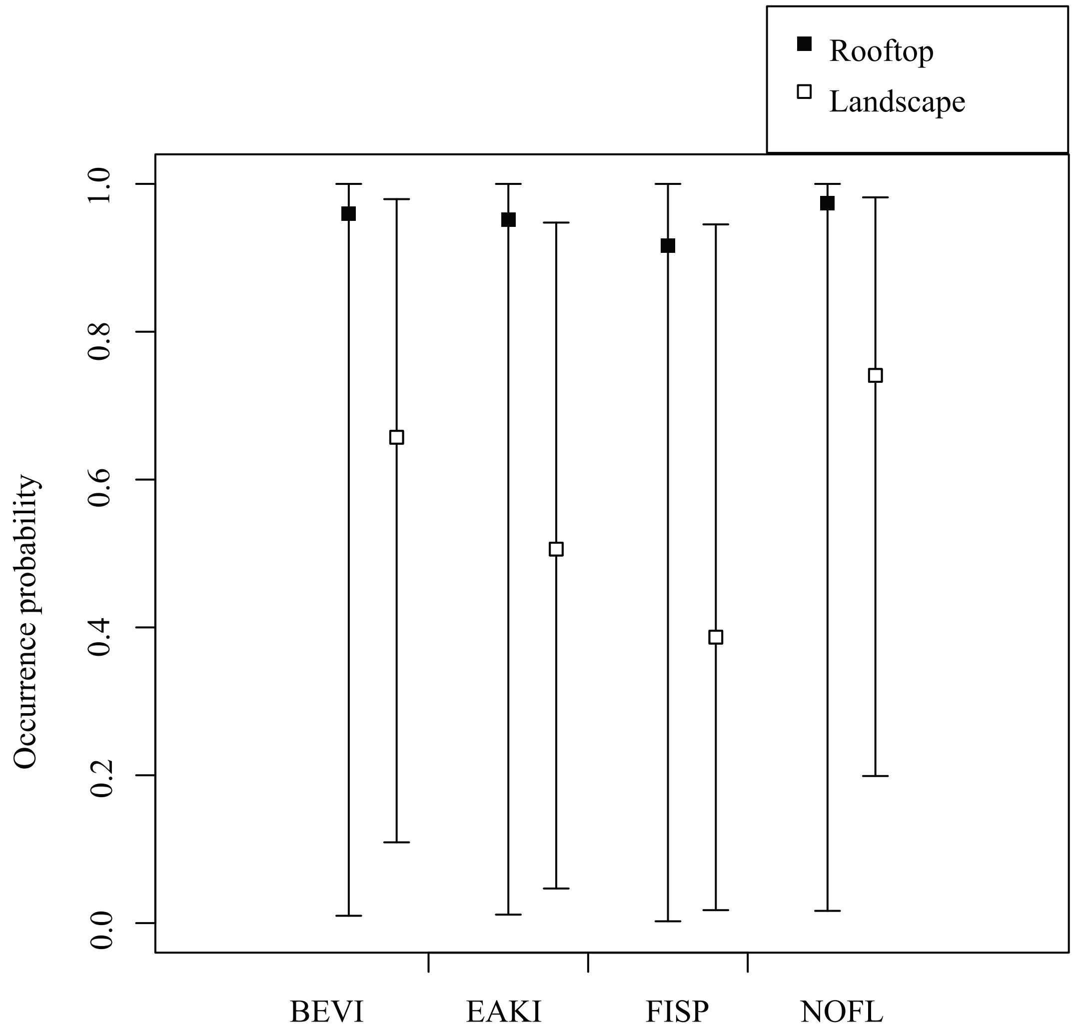

Figure 2.7. Occurence probabilities of declining native bird speciesobserved on green roofs in Illinois and Michigan, U.S.A. during sampling in 2010 and 2011. Speices included are Bell's vireo (*Vireo bellii*, BEVI), eastern kingbird (*Tyrannus tyrannus*, EAKI), field sparrow (*Spizella pusilla*, FISP), and northern flicker (*Colaptes auratus*, NOFL). Mean occurrence and 95% credible intervals shown are estimated using a multi-species hierarchical Bayes multi-scale model.

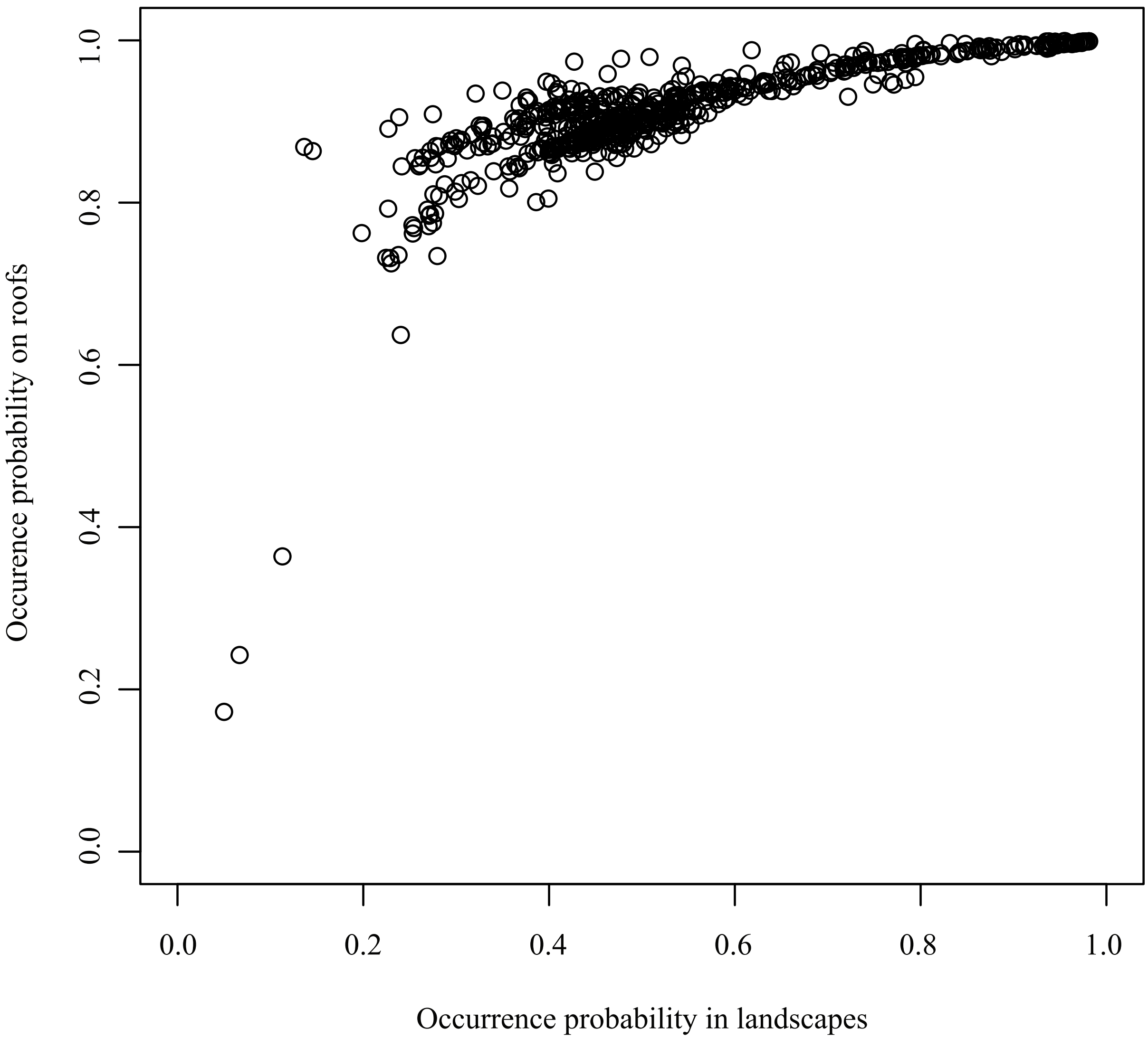

Figure 2.8. Mean occurrence probabilities on green roofs compared with mean occurrence probabilities in surrounding landscapes for all non-invasive, native bird species, excluding waterfowl and urban associated species, in Illinois and Michigan, U.S.A. during sampling in 2010 and 2011. Mean occurrence probabilities shown are estimated using a multi-species hierarchical Bayes multi-scale model.

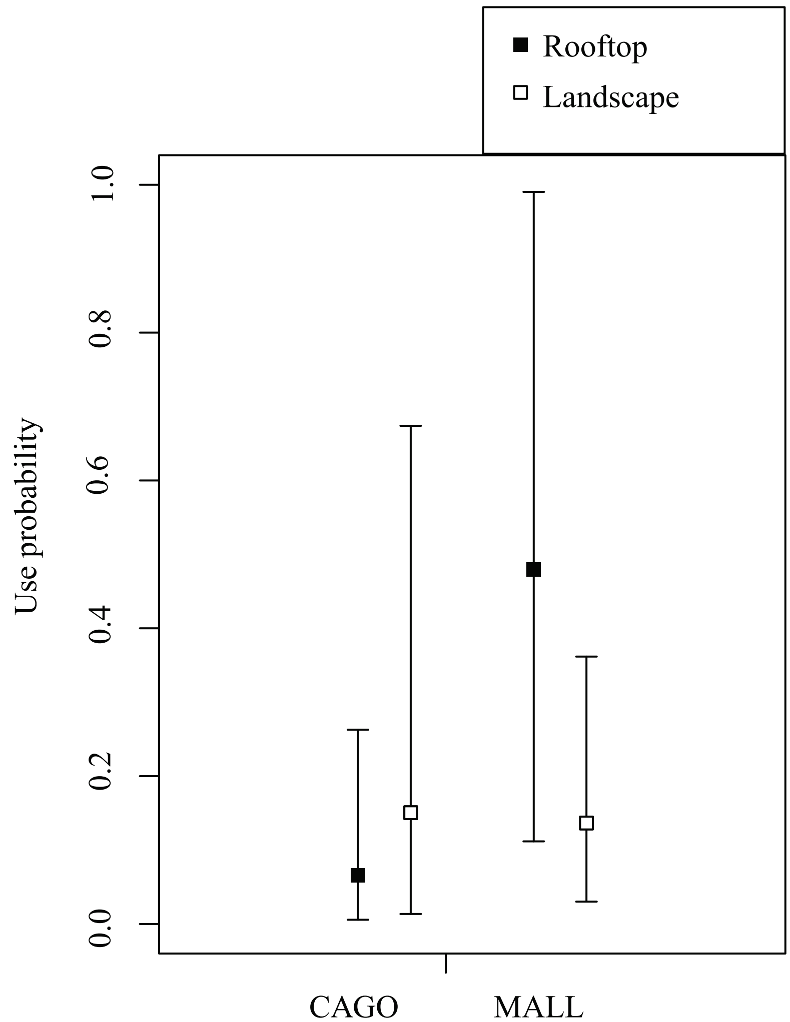

Figure 2.9. Use probabilities of native waterfowl bird species, excluding urban-associated species, observed on three or more green roofs in Illinois and Michigan, U.S.A. during sampling in 2010 and 2011. Speices included are Canada goose (*Branta canadensis*, CAGO) and mallard (*Anas platyrhynchos*, MALL). Mean use and 95% credible intervals shown are estimated using a single-species hierarchical Bayes multi-scale occupancy model.

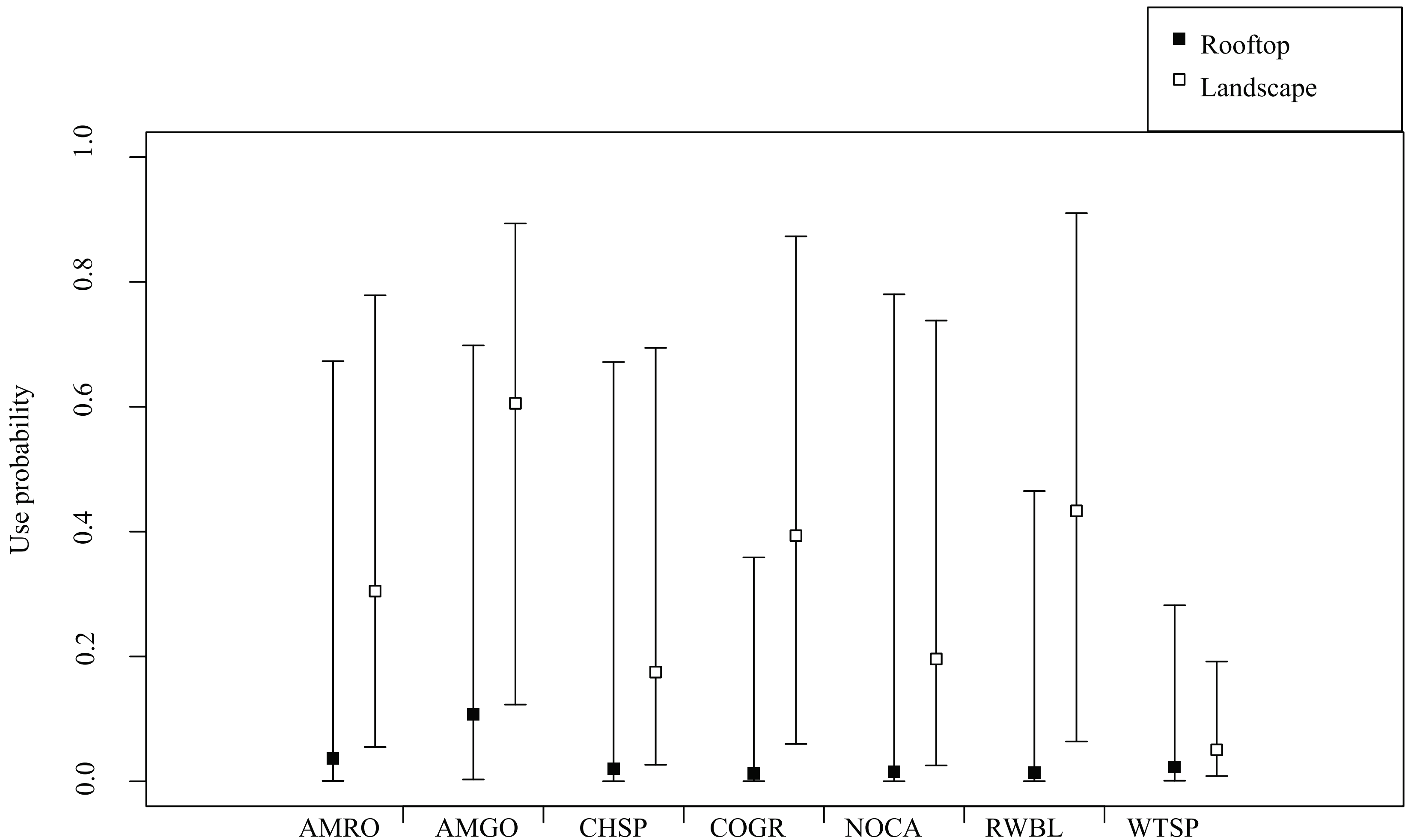

Figure 2.10. Use probabilities of native bird species, excluding urban-associated and waterfowl species, observed on 3 or more green roofs in Illinois and Michigan, U.S.A. during sampling in 2010 and 2011. Speices included are American robin (*Turdus migratorius*, AMRO), American goldfinch (*Carduelis tristis*, AMGO), chipping sparrow (*Spizella passerina*, CHSP), common grackle (*Quizcalus quizcula*, COGR), northern cardinal (*Cardinalis cardinalis*, NOCA), red-winged blackbird (*Agelaius phoeniceus*, RWBL), and white-throated sparrow (*Zonotrichia albicollis*, WTSP). Mean use and 95% credible intervals shown are estimated using a multi-species hierarchical Bayes multi-scale model.

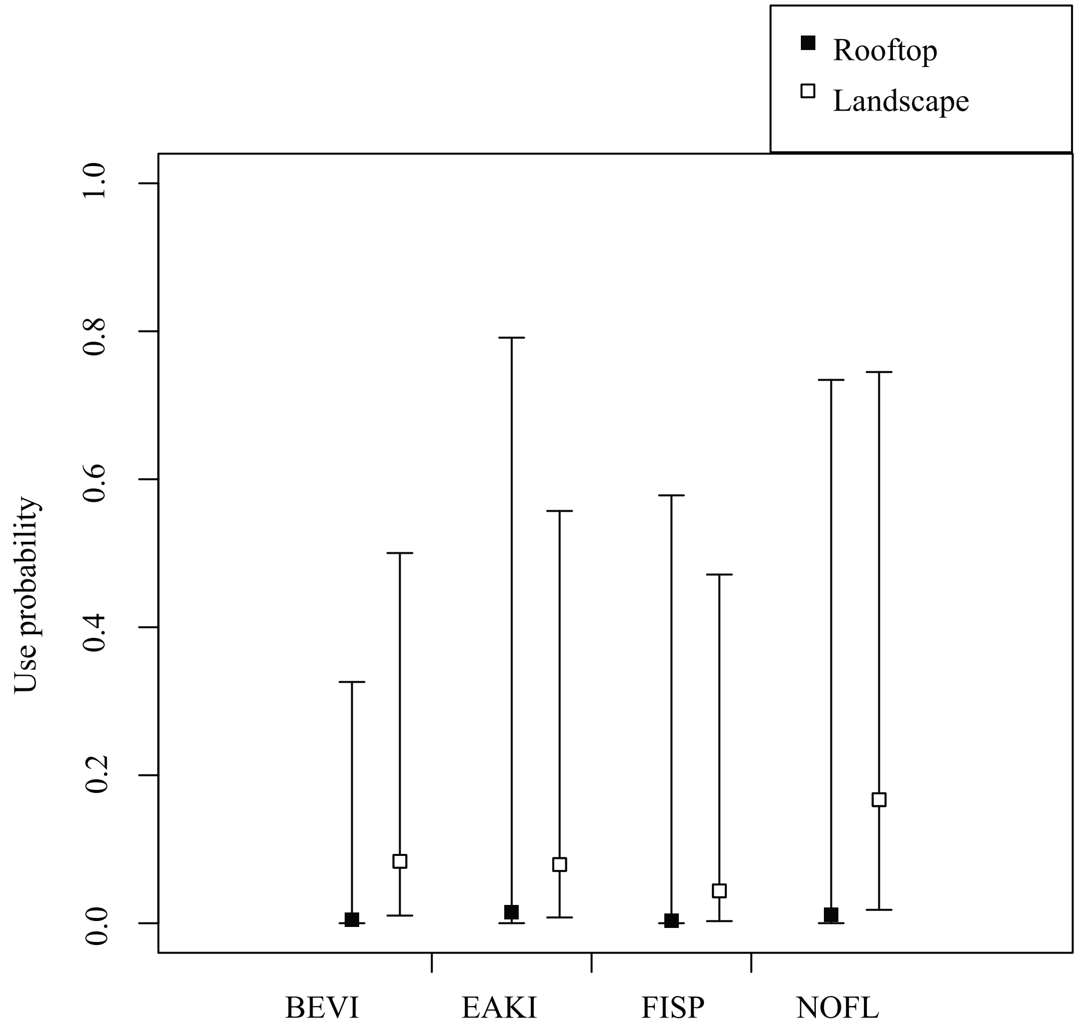

Figure 2.11. Use probabilities of declining native bird speciesobserved on green roofs in Illinois and Michigan, U.S.A. during sampling in 2010 and 2011. Speices included are Bell's vireo (*Vireo bellii*, BEVI), eastern kingbird (*Tyrannus tyrannus*, EAKI), field sparrow (*Spizella pusilla*, FISP), and northern flicker (*Colaptes auratus*, NOFL). Mean use and 95% credible intervals shown are estimated using a multi-species hierarchical Bayes multi-scale model.

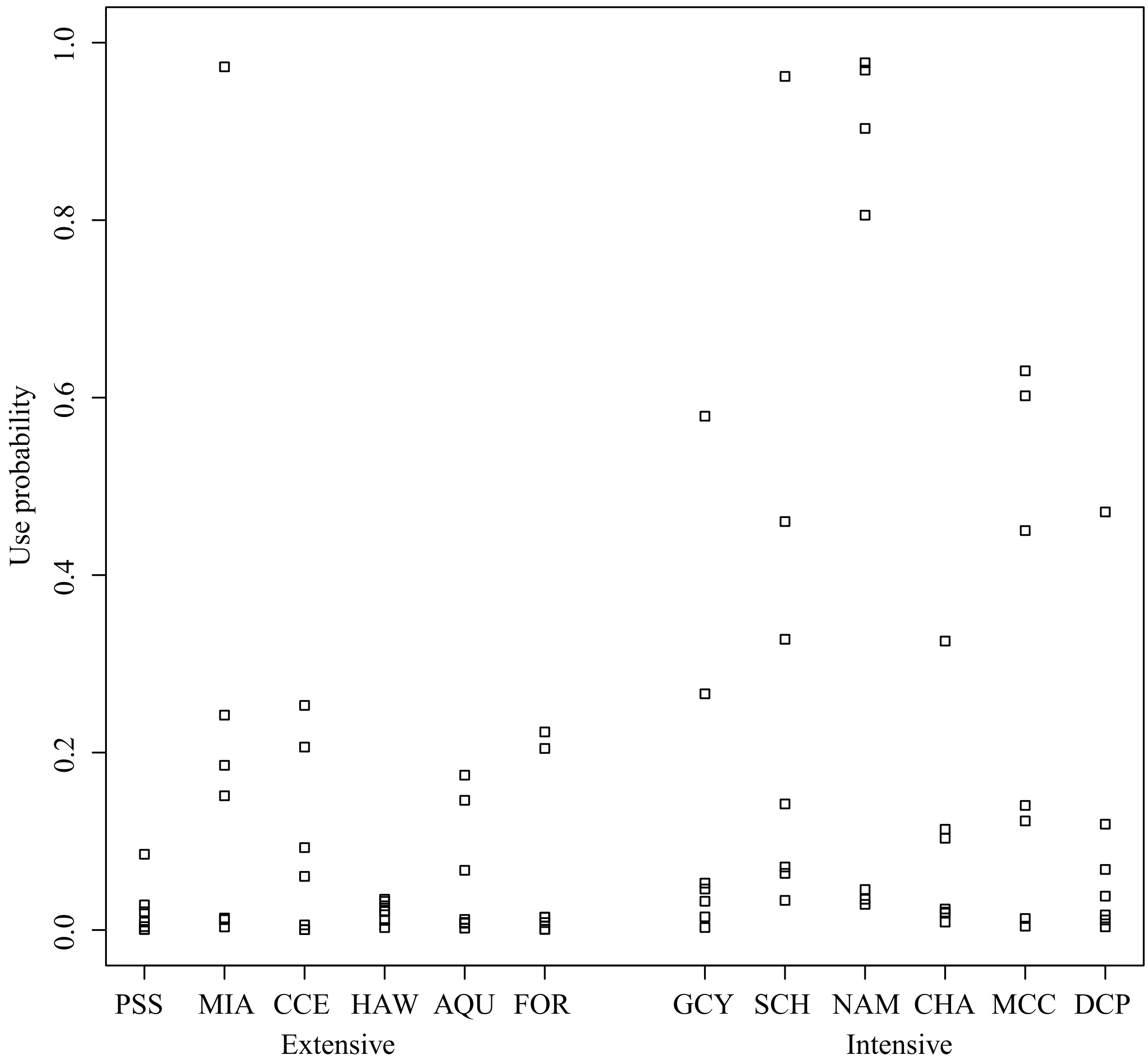

Figure 2.12. Mean use probabilities on extensive and intensive green roofs for non-invasive, native bird species, excluding waterfowl and urban associated species, that were observed on at least 25% of green roofs during sampling in Illinois and Michigan, U.S.A. in 2010 and 2011. Mean use probabilities shown are estimated using a multi-species hierarchical Bayes multi-scale model.

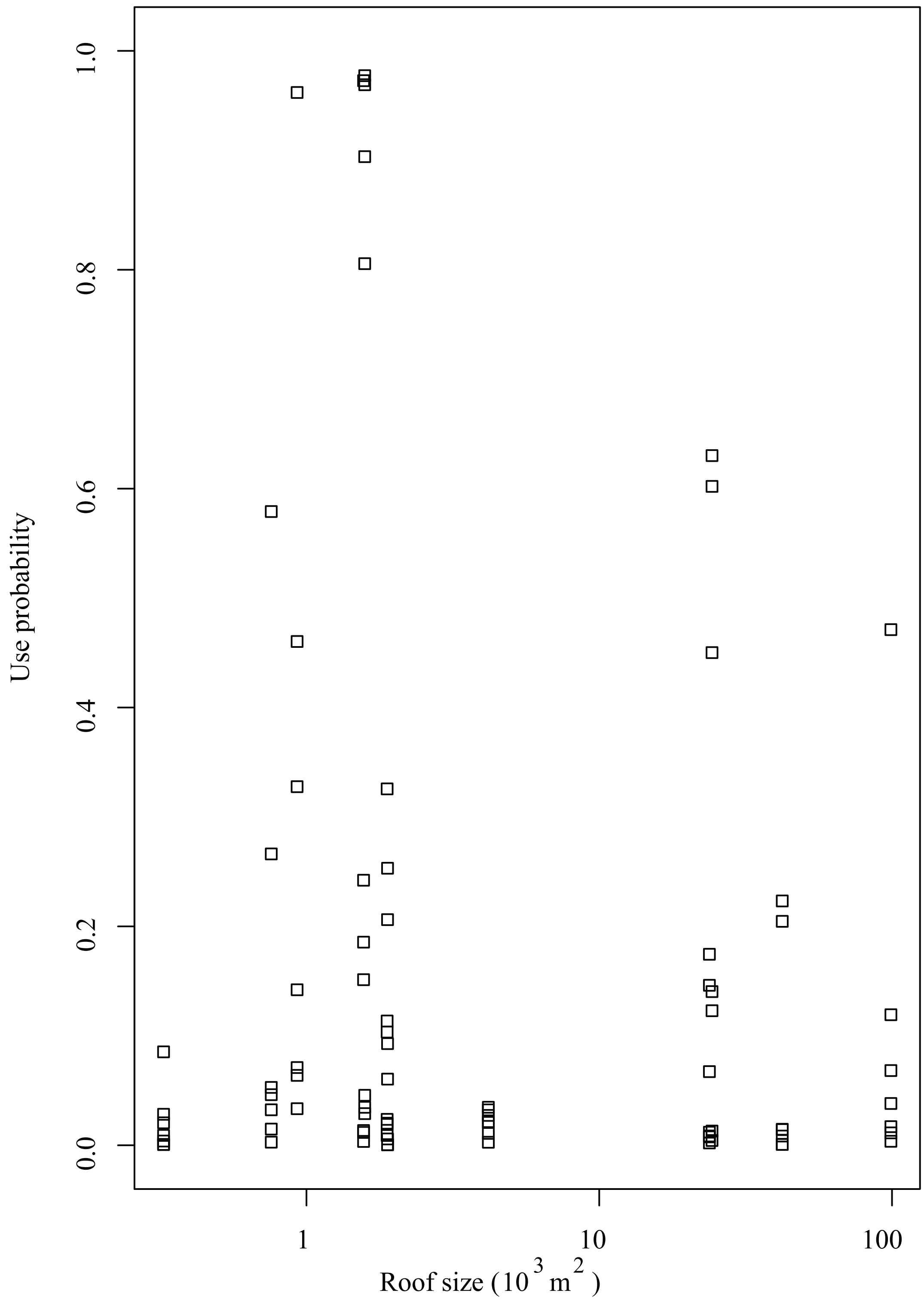

Figure 2.13. Mean use probabilities on green roofs organized by size for non-invasive, native bird species, excluding waterfowl and urban associated species, that were observed on at least 25% of green roofs during sampling in Illinois and Michigan, U.S.A. in 2010 and 2011. Mean use probabilities shown are estimated using a multi-species hierarchical Bayes multi-scale model.

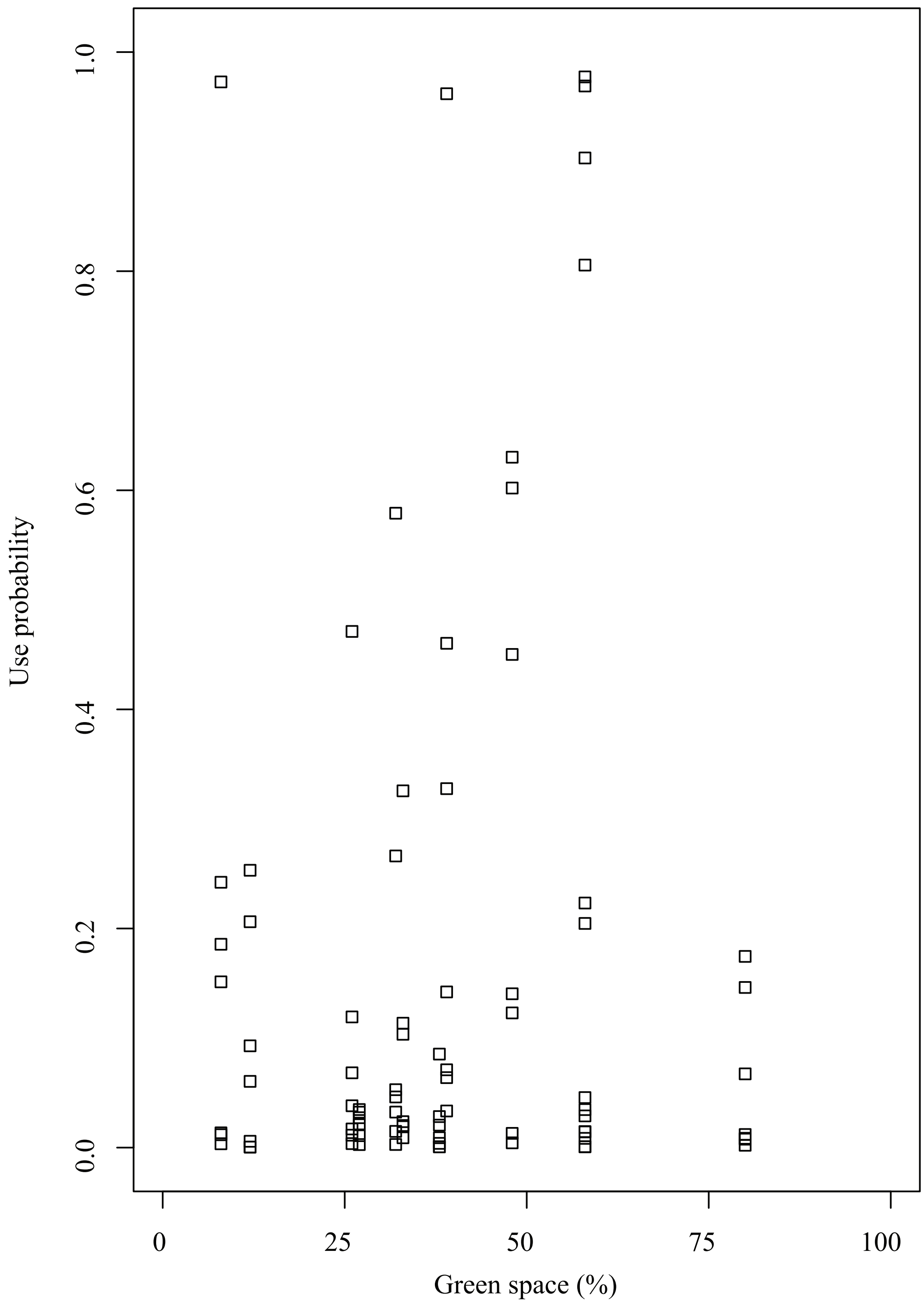

Figure 2.14. Mean use probabilities on green roofs organized by green space at study sites for non-invasive, native bird species, excluding waterfowl and urban associated species, that were observed on at least 25% of green roofs during sampling in Illinois and Michigan, U.S.A. in 2010 and 2011. Mean use probabilities shown are estimated using a multi-species hierarchical Bayes multi-scale model.

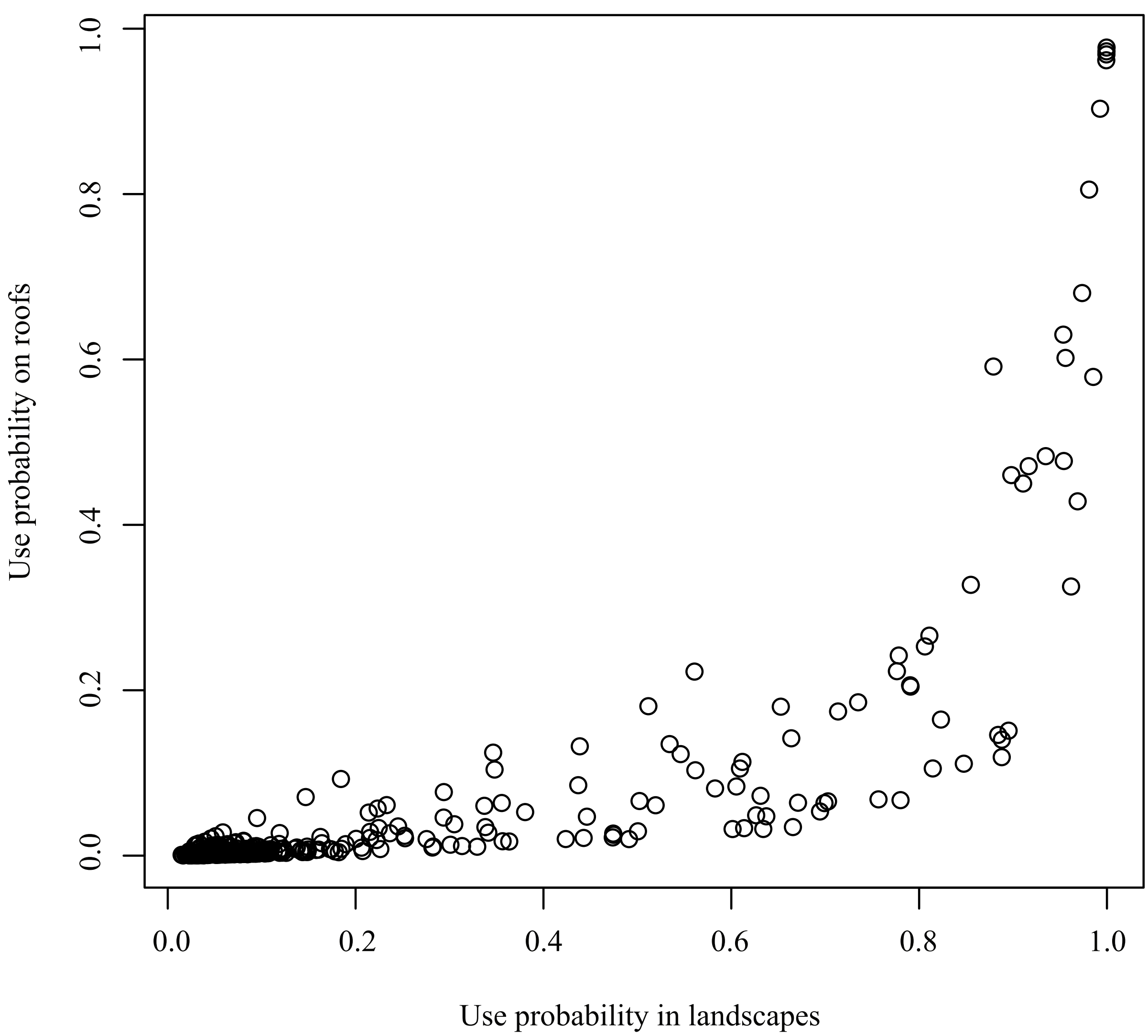

Figure 2.15. Mean use probabilities on green roofs compared with mean use probabilities in surrounding landscapes for all non-invasive, native bird species, excluding waterfowl and urban associated species, in Illinois and Michigan, U.S.A. during sampling in 2010 and 2011. Mean use probabilities shown are estimated using a multi-species hierarchical Bayes multi-scale model.

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CONCLUSIONS

This project evaluated if green roofs could contribute to bird conservation by providing additional green space in urban landscapes. Associated objectives were addressed by collection and analysis of data on vegetation characteristics and bird communities on and surrounding green roofs.

Analysis of vegetation on and surrounding green roofs demonstrated significant differences between intensive and extensive green roof vegetation characteristics. Intensive roofs had taller perennial and woody species, whereas extensive green roofs generally had low-growing, drought-tolerant perennial or shrubs species. Analyses of bird surveys demonstrated a tendency for birds to use intensive green roofs for more time than extensive roofs. In addition, intensive green roofs appear better suited to support a greater richness of bird species and successful nesting because of increased niche opportunities in vegetation. Ground foragers were observed on intensive and extensive roofs, and those in shrub and low canopy foraging and bark gleaning guilds (6 species) were only observed on intensive roofs with shrub and/or tree cover. However, successful nesting attempts have been observed on large extensive green roofs, indicating the ability of these roofs to also support nesting activities. Wildlife species that require shorter vegetation and less woody cover may be better supported on extensive roofs. Comparisons of vegetation characteristics provided on green roofs with those required for various native grassland bird species habitat requirements demonstrated the ability of green roofs to provide bird habitat.

Green roofs may be able to support native bird species due to the ability of green roof vegetation to fulfill grassland bird species habitat requirements. In addition, 25 non-invasive, native bird species were observed on green roofs, and nearly all bird species observed in landscapes and not on green roofs are estimated to have a > 70% probability to occur on green roofs. Among these bird species with high occurrence probabilities are those with populations in decline throughout the Midwest United States. These estimates coupled with the ability of vegetation on green roofs to support the habitat requirements of species in decline demonstrate the ability of green roofs to provide habitat for species of conservation concern.

Green roofs were estimated to have higher median bird species richness than in surrounding landscapes. However, comparatively low use probabilities on green roofs indicate that birds primarily use landscapes and green roofs may function as complimentary bird habitat. The high bird species richness and low use probability for green roofs also suggest that birds may use green roofs as stepping stones to traverse urban areas. Bird species present in landscapes directly surrounding green roofs appear to influence which bird species frequently use on green roofs, as those on green roofs are generally also observed in landscapes.

Future research is needed to examine the effect other green roof factors (roof height, human presence, non-native plant species, landscape matrix, lack of mesopredators) have on bird use and wildlife habitat connectivity. Green roofs with greater variability in roof size and vegetation structural diversity and/or roofs with similar structure could be studied to hone in on the bird community that uses a specific type of roof (e.g., intensive, native prairie vegetation with >60% cover, mean height of 1.1m) and the effect various green roof factors have on observed and predicted bird communities. Telemetry studies could be used to further understand how birds move through the landscape, when they are on green roofs, and where they are nesting. Pre- and post-construction bird surveys of green roofs would help explain how to achieve bird conservation goals (i.e., abundance, species richness, diversity).

Wildlife managers, land planners, environmental designers and policy makers who aim to improve ecosystem function and wildlife habitat quality in urban and developing landscapes may refer to this manuscript to better understand how wildlife communities may interact with green roofs, green roof vegetation, and surrounding landscapes. Presented information could be used to help select a wildlife group to target with conservation efforts through green roof installation. Results from our study could also demonstrate the ability of green roof installations to address conservation objectives at the landscape scale. Our research has demonstrated that green roofs have the ability to drastically increase (>300%) the amount of green space that may provide ecosystem functions (i.e., stormwater management, air pollution mitigation) and that is important for wildlife conservation. Wide-spread implementation of green roofs focused on creating bird habitat throughout urban areas could help minimize population declines of various grassland and neo-tropical migratory bird species, and promote biodiversity conservation in urban areas.