A comparison of arthropod abundance and arthropod mediated predation services in urban green spaces

ASHLEY B. BENNETT[1],* and SARAH T. LOVELL[1]   [1]Department of Crop Sciences, University of Illinois, Urbana, IL, USA and * Present address: Michigan State University, East Lansing, MI, USA

Abstract. 1. The need to conserve biodiversity and ecosystem services in urban landscapes is widely recognised, yet specific planning and design strategies that promote conservation in urban areas are limited. Little is known about the ability of different types of urban green spaces to support biodiversity and provide ecosystem services.

2. In this study, we compared the abundance of beneficial arthropods (predators and bees) and measured predation services in two different types of green space, areas of turf and prairies. Beneficial arthropods and predation services were measured three times during the 2011 field season in six Chicago (IL, USA) parks that contained both turf and prairie.

3. Using a repeated measures analysis, we found bee abundance was significantly higher in the prairie compared to turf by August, and predator abundance was higher in the prairie throughout the summer. While predation services were not significantly different between the turf and prairie in June, predation steadily increased in the prairie over the course of the summer with significantly higher rates of predation by August.

4. Of the predators measured, spiders were positively correlated with prairie habitat and negatively correlated with the survival of pest insects.

5. We found turf and prairie differentially supported beneficial arthropod abundance and ecosystem services, suggesting the type of green space incorporated into urban areas may be an integral component to expanding the conservation potential of urban landscapes.

Key words. Natural pest suppression, pollinator, prairie, predator, urbanization.

Introduction

More than half of the world's inhabitants now live in cities (UN Population Division, 2010), and the proportion of people living in cities is expected to increase as the population continues to grows. The influx of people into urban areas creates new demand for housing, transportation and commerce, causing urban development to expand into neighbouring undeveloped landscapes. One of the most significant consequences of urban development is degradation and loss of semi-natural and natural habitats.

Habitat loss resulting from urban development has contributed to declines in arthropods, birds, amphibians and mammals along gradients of urban intensification (Chace & Walsh, 2006; Pillsbury & Miller, 2008; Niemela & Kotze, 2009). Loss of biodiversity, however, does not have to be a consequence of urban development, if conservation strategies appropriate for the urban landscape can be identified and incorporated into the planning and design of urban areas.

The potential for biodiversity conservation in urban areas is gaining recognition, and advocates for urban conservation suggest urban green space can play an important role in supporting urban biodiversity (Goddard *et al.*, 2010). Urban green space is a broad term used to define both public and private spaces that often have multiple uses and contain one or more than one type of

Correspondence: Ashley B. Bennett, Department of Crop Sciences, University of Illinois, 1201 S. Dorner Dr., Urbana 61801, IL, USA. E-mail: abb@msu.edu

habitat (Gaston, 2010). Urban green space ranges from small neighbourhood parks with playgrounds to large natural areas that support multiple native plant communities such as woodlands, grasslands and wetlands. Urban green space also includes residential lawns and gardens, which can be important contributors to urban biodiversity (Davies *et al.*, 2009). Because urban green spaces are designed for different purposes, plant community composition, landscape management and level of human activity will vary depending on the functional purpose of the green space. Plant community composition and the level of human activity, for example, are factors known to affect the abundance and diversity of upper trophic levels such as insects and birds (Knops *et al.*, 1999; Evans *et al.*, 2009). While urban green spaces can contribute to biodiversity conservation in cities, more work is needed to quantify and optimise this contribution for different types of green space.

Arthropods, particularly beneficial arthropods (i.e. predators, pollinators and decomposers), are important components of urban landscapes because many perform valuable ecosystem services such as pollination, natural pest suppression and decomposition. Predators, for example, provide pest suppression to landscape plantings and woodlands, while pollinators support fruit and seed set in natural areas and gardens (Shrewsbury & Raupp, 2006; Ksiazek *et al.*, 2012). Decomposers play an important role in transforming organic matter and recycling nutrients (Swift *et al.*, 2004). Arthropod mediated ecosystem services such as these are becoming increasingly important for supporting urban agriculture systems (i.e. the production of food crops in and around cities) as demand for locally grown food continues to increase. In addition to providing important ecosystem services, the structure of arthropod communities can reflect the broader health of the ecosystem. In fact, invertebrates have been proposed as important bioindicators for urban landscapes because they reflect general biodiversity, have rapid generation times, and are easy to sample (Jones & Leather, 2012).

Because beneficial arthropods respond to changes in plant community composition and management practices (Wratten *et al.*, 2012), we might expect different types of green space to differentially support beneficial arthropods and arthropod-mediated ecosystem services. Arthropod abundance and diversity, for example, are positively correlated with increases in plant diversity and structural complexity (Landis *et al.*, 2005; Ebeling *et al.*, 2008; Bennett & Gratton, 2013). As arthropod abundance and diversity increase, research has found the provision of arthropod mediated ecosystem services such as predation also increase (Frank & Shrewsbury, 2004; Straub & Snyder, 2008; Shrewsbury & Leather, 2012). Management activities such as mowing, human treading and burning, on the other hand can be detrimental to arthropods (Morris, 2000; Swengel, 2001; Steffan-Dewenter & Leschke, 2003). In urban landscapes, for example, mowing as well as human treading have been shown to negatively impact the abundance and diversity of Coleoptera, especially predacious beetles, and Hemiptera (Morris & Rispin, 1987; Morris, 2000; Helden & Leather, 2004; Jones & Leather, 2012). Determining the potential for different types of green spaces to support beneficial arthropods will be an important step towards developing conservation strategies that maximize beneficial arthropods and the ecosystem services they provide to urban landscapes.

In this study, we investigated beneficial arthropod communities and associated ecosystem services in different types of green space in the greater Chicago, IL metropolitan area (Cook County, USA). The first objective of this study was to compare beneficial arthropods (bees and predators) in two different types of green space, turf and prairie. In this study, we investigated six parks, which included more than one type of habitat. For clarity, we will refer to the type of habitat, turf or prairie, sampled within the larger green space. Our second objective was to measure natural pest suppression provided by arthropod predators in turf and prairie habitats. We hypothesized that the abundance of bees and predators, as well as the predation services provided by the predators, would be higher in the prairie compared to turf habitats due to the presence of more floral resources and fewer management activities such as mowing.

Methods

Study area

This study focused on green space in Chicago, the third most populated city in the United States. Chicago covers a total land area of 606.1 km^2, at an elevation of 176 m above sea level and geographical centre at 41°50′ 26.43″N, 87°40′45.71″W. The city experiences a humid continental climate, with four distinct seasons, despite some moderation of temperatures provided by Lake Michigan. Average yearly temperatures are a high of 28.8 °C and a low of −4.2 °C with an average annual precipitation of 868 mm (Wilson & Weng, 2011). Within the boundaries of the Chicago municipal area, we identified six parks that contained both prairie and turf habitats (Fig. 1). The prairie habitats represented grassland communities native to the Midwestern USA that are composed of warm-season grasses and forbs. In general, prairie habitats are managed by burning or mowing every 3–5 years to control invasion of non-native plant species (Shirley, 1994). In this study, management of non-native species ranged from hand removal to mowing on a 3–5 years schedule due to the location of prairie habitats in urban areas. In contrast, the turf habitats were composed of cool-season grasses typical of residential lawns and recreational parks and management of these areas included regular mowing (e.g. every 1–2 weeks) to prevent the establishment and flowering of weeds. The prairies in this study consisted of plantings that ranged from 0.12 to 6.07 ha in size and 2–15 years in age, while areas of turf were 0.32–4.45 ha in size. Floral surveys were conducted in each prairie and
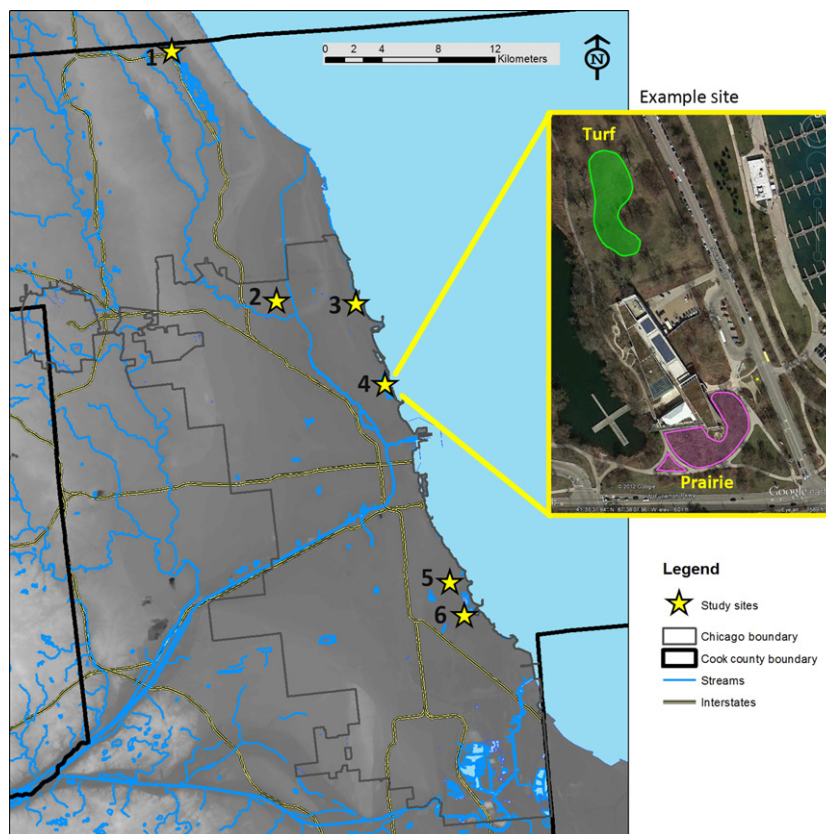
Fig. 1. The location of the six urban green spaces sampled across the metropolitan area of Chicago IL (Cook County, IL, USA). The inset highlights the turf and prairie habitats sampled for one site (see Supplementary Material E for the geographical coordinate of each green space habitat).

turf habitat once during the summer of 2011 to estimate the diversity of flowers at each site. Floral diversity was measured along two 50 m transects. Transects were established a minimum of 10 m from the edge of the planting and any paths running through the prairie or turf. All flowering plants within 1 m of each transect (0.5 m/side) were identified to species.

Arthropod sampling

Predator and bee abundances were measured the third week of each month from June to August, using pan traps filled with a soap solution (Droege *et al.*, 2010). Within each park ($n = 6$), we established four sampling stations in both the turf and prairie habitat. The four sampling stations were placed along a linear transect with a distance of 20 m between stations. One prairie was not large enough to accommodate a distance of 20 m between all stations, so a distance of 10 m was used to separate sampling stations. Each sampling station consisted of three pan traps (177 ml white plastic bowls; 4.5 cm in depth × 13 cm in diameter, SOLO® Cup Company PB6 0099, Solo Cup Company, Lake Forest, IL, USA), with one yellow, blue and white bowl, for a total of 12 pan traps per habitat (i.e. turf and prairie). Yellow and blue pan traps were painted on the inner surface with fluorescent yellow or blue paint (Ace® Glo Spray Fluorescent paint, Ace Hardware Corporation, Oak Brook, IL, USA). Pan traps were attached to bamboo stakes at a height of 1 m in both turf and prairie habitats. In prairie sites where vegetation exceeded 1 m by July and August, pan traps were adjusted to the height of the surrounding vegetation. All sampling stations were positioned 5 m from an edge or pedestrian walkway and in a sunny location outside the drip line of nearby trees. Turf and prairie habitats were sampled on the same dates with pan traps deployed for a 48 h period. Only spiders and insects that are predaceous as adults were counted as predators, since these would be the predators of sentinel eggs (see measuring predation services). Of the arthropods capable of providing pollination services, bees are the most effective pollinators of native plants and crops (Aizen & Feinsinger, 2003; Klein *et al.*, 2007; Winfree *et al.*, 2009). As a result, bees were the only group included in our calculation of pollinator abundance. In the laboratory, all predators and bees collected in pan traps were counted and identified to the family level, except for earwigs and spiders which were counted and identified to order. Predator and bee abundances are expressed as the mean number of individuals

caught per station each month during the 2011 field season for each turf and prairie habitat.

Measuring predation services

To determine how predation services differed with green space type, sentinel eggs were used to compare predation rates in turf and prairie habitats. Predation services were measured by comparing predation rates on covered (i.e. natural enemies excluded) and exposed sentinel eggs. Corn earworm, *Helicoverpa zea* (L.), eggs were the sentinel prey used in this study and were obtained from a commercial supplier (French Agricultural Research, MN). Approximately 48 h prior to being transported to the field, ~50 freeze-killed eggs were glued to a 0.1×0.1 m piece of card stock. Digital photographs were taken of each egg card, and the number of eggs on each card were counted using AutoCAD (AutoDesk 2010, Design and Engineering Software, Autodesk, Inc., San Rafael, CA, USA). Once in the field, egg clusters were randomly placed at two of the four sampling stations located within each turf and prairie habitat. Each sampling station received two egg cards that were attached to the underside of a Plexiglas platform (0.3×0.3 m), which was painted green (Krylon® Hunter Green, Krylon Products Group, Cleveland, OH, USA, Supplementary Material A, Fig. A1). The Plexiglas platform was attached to a bamboo stake and positioned at a height of 1 m. One egg card remained open, allowing predators access to the eggs (hereafter referred to as 'open'). The second egg card was placed in a disposable Petri dish glued to the underside of the platform and covered with a piece of white no-see-um netting (Quest Outfitters, Sarasota, FL, USA), which excluded predators and provided an estimate of egg removal in the absence of predators (hereafter referred to as 'closed'). Immediately prior to placing the egg cards in the field, eggs on each open and closed card were recounted to ensure no eggs had been lost in transport.

After 48 h, cards were collected from the field, and a digital photo was taken. Once in the laboratory, eggs were counted from the digital images using AutoCAD software, and counts were confirmed directly under a microscope. While the digital photograph documented missing eggs, which we attributed to chewing predators, predation by hemipterans, which have sucking mouthparts, was identified using a microscope. Thus, the number of eggs remaining after a 48 h period on open and closed cards included eggs lost to chewing and sucking predators. During the 2011 field season, we performed three natural pest suppression trials: one in June, July and August during the second week of each month.

Data analysis

To quantify sentinel egg predation, the proportion of eggs remaining at each station was calculated by dividing final by initial egg numbers on each open and closed card. This calculation adjusted for differences in initial egg densities on each card and allowed us to measure the relative change in egg numbers. The average number of remaining eggs, $RE_{avg,ij}$, was calculated for all $i = 6$ parks for each habitat ($j = 1,2$) by averaging across the $k = 2$ stations:

$$RE_{avg,ij} = \frac{\sum_K RE_{o,ijk}}{K} \Big/ \frac{\sum_K RE_{c,ijk}}{K}, \qquad (1)$$

where $RE_{o,ijk}$ is the proportion of eggs remaining at the Kth station from cards open to predation and $RE_{c,ijk}$ is the proportion of eggs remaining on closed egg cards. Values less than 1 indicate that the number of remaining eggs was lower on open cards (those exposed to natural enemies) than on closed cards (those protected from natural enemies), meaning greater predation as values approach 0. Values of 1 indicate no change in egg numbers between open and closed cards, suggesting no predation. Beneficial arthropod abundance (i.e. predators and bees) and predation services were analysed using a repeated measures ANOVA in PROC MIXED with an autoregressive covariance structure and date as the repeated measure. The response variables were predator abundance, bee abundance or the proportion of remaining eggs. Abundance data were square root transformed to account for heteroscedastic variances and to meet assumptions of normality. The fixed effects were date, habitat (turf or prairie), the interaction between date and habitat. The random effects included park (i.e. green space) and the interaction between park and habitat. Statistical analyses were performed in SAS 9.3 (SAS Institute, 2009). To identify potential associations among predators and predation services, Spearman rank correlations were calculated for each combination of predator, habitat and our index of predation, $RE_{avg,ij}$. Categorical variables (habitats) were encoded as binominal variables for analysis in R 3.0 statistical software package (R Core Team, 2013).

Results

Abundance of bees was numerically higher in the prairie compared to the turf; however, differences in abundance were not significant until August (Fig. 2a, $F_{1,5} = 21.72$, $P = 0.0055$). While bee abundance in the prairie increased over the summer, abundances did not change in the turf. Predator abundance remained consistent in both the turf and prairie throughout the summer, with higher abundances of predators in the prairie compared to the turf throughout the three-month sampling period (Fig. 2b, $F_{1,5} = 27.41$, $P = 0.0034$), although the difference in July was not significant. No significant interaction between habitat and date was found for either bee or predator abundance. Spearman rank correlations found the mean number of total predators in addition to sphecid wasps (Family Sphecidae), pompilid wasps (Family Pompilidae) and spiders (Order Araneae) were all positively correlated
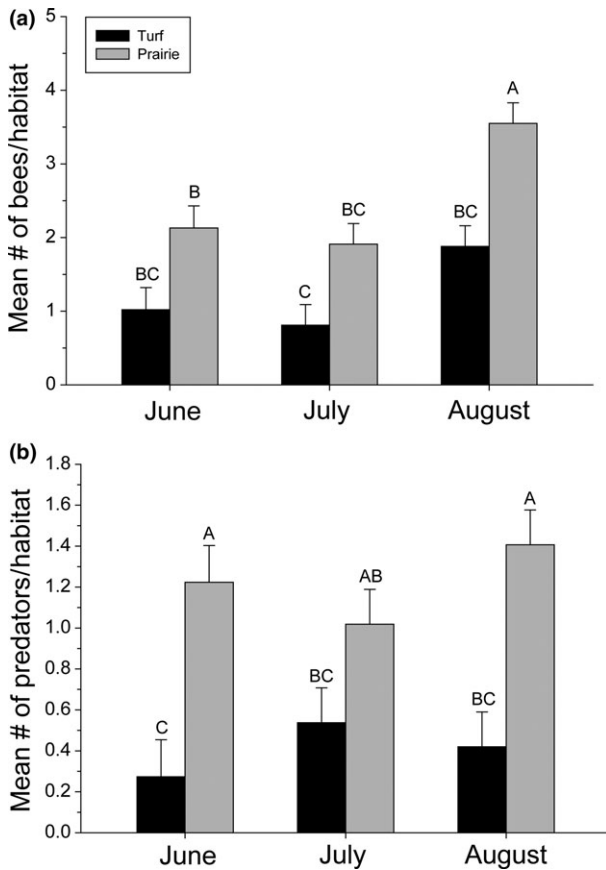
Fig. 2. The mean number of bees (±SEM) (a) and mean number of predators (b) sampled using pan traps during the 2011 field season in turf and prairie habitat. Bee and predator data were square root transformed. Significant differences ($P < 0.05$) are indicated by different letters.

with prairie habitat (Fig. 3, Supplementary Material B, Table B1), while spider abundance and the total number of predators were negatively correlated with the number of remaining eggs, our measure of predation (Fig. 3, Supplementary Material B, Table B1). A significant habitat and habitat by date interaction was found for predation (Fig. 4, $F_{1,5} = 28.44$, $P = 0.0031$, habitat; $F_{2,19} = 6.41$, $P = 0.0075$, interaction). Predation was not significantly different between the turf and prairie in June; however, we found predation increased over the course of the summer in prairies with significantly higher rates of predation by August (Fig. 4).

Discussion

Pollinators, bees in particular, rely on pollen and nectar for adult and larval food sources, and research has demonstrated pollinators positively respond to increases in the abundance and diversity of floral resources (Hennig & Ghazoul, 2012; Wratten *et al.*, 2012). In this study, the

sampled prairies supported a range of floral diversity, with 8–37 species depending on the planting (Supplementary Material C, Table C1). At the time of floral surveys, no flowering weed species were observed along transect surveys in the turf. Over the course of the field season, white clover (*Trifolium repens*) and dandelion (*Taraxacum officinale*) were, however, observed blooming at parks 2, 3 and 5 when mowing intervals permitted flowering (A. Bennett pers. observ.). The diversity of floral resources likely served as a reliable source of pollen and nectar and contributed to the overall higher number of bees collected in the prairie compared to the turf. One mechanism used to explain a higher abundance and diversity of arthropods in floristically diverse plantings is the interactive effects of overlapping flowering periods on neighbouring plants (Johnson *et al.*, 2006). When flower phenologies overlap, current visitors are retained by transitioning to recently opened flowers to forage while new visitors are recruited by the availability of additional resources. Although not directly tested in this study, positive interactions between the flowering periods of the plants in the prairie may have contributed to the increase in bee abundance from July to August (Moeller, 2004; Bluthgen & Klein, 2011).

In addition to requiring reliable food resources, bees also need to locate nesting sites. Soil and stem nesting bees may not find suitable nesting sites in all types of green space due to soil type, contamination, lack of appropriate stems or disturbances to vegetation from maintenance or visitor activities (McFrederick & LeBuhn, 2006; Goulson *et al.*, 2008; Murray *et al.*, 2009; Moron *et al.*, 2012). As a consequence, bees may nest in neighbouring natural areas, such as woodlands, and then disperse into prairie habitats once they emerge to forage for food resources. The relationship between nesting and foraging habitats is another factor that may have contributed to the increase in bee abundance we observed in the prairie over the course of the field season. Regardless of the mechanism, prairie habitat consistently supported more bees than the turf, suggesting that prairie habitat incorporated into urban landscapes may promote the conservation of bees.

While bee abundance in the prairie increased over the summer, predator abundance was higher in the prairie compared to the turf throughout the three-month sampling period, with differences significant in June and August. Some predators, like pollinators, feed on pollen and nectar to supplement their diet. Pollen and nectar feeding by predators can increase longevity and fecundity as well as serve as an alternative food source when prey are scarce (Lundgren *et al.*, 2005). The availability of pollen and nectar in the prairie may have supplemented the diet of predators, causing predator abundances to build early in the season and remain higher than the abundances observed in the turf. Prairie habitats may also benefit predators by supporting alternative sources of prey. Generalist predators, such as spiders, feed on multiple types of prey, and the presence of alternative sources of prey can support predators as prey populations fluctuate across the season (Shrewsbury & Raupp, 2006; Kuusk &
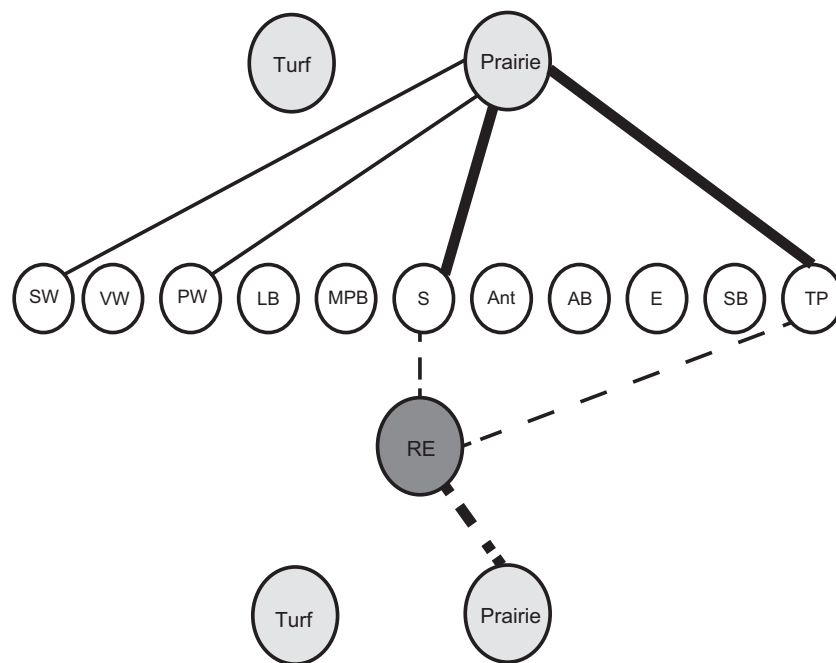
Fig. 3. Spearman rank correlations between green space habitats, predators, and remaining number of pest eggs. Solid lines indicate a positive correlation while dash lines show negative correlations between variables. Predator abbreviations include sphecid wasp (Family Sphecidea, SW), vespid wasp (Family Vespidae, VW), pompilid wasp (Family Pompilidae, PW), lady beetle (Family Coccinellidae, LB), minute pirate bug (Family Anthocoridae, MPB), spider (Order Araneae, S), ambush bug (Family Reduviidae, AB), earwig (Order Dermaptera, E), stilt bug (Family Berytidae, SB), total predators (TP) and the number of remaining eggs (RE). The thickness of the line indicates significant correlations with thin dashed and solid lines significant at $P = 0.05$–0.001 and thick dashed and solid lines significant at $P < 0.001$.
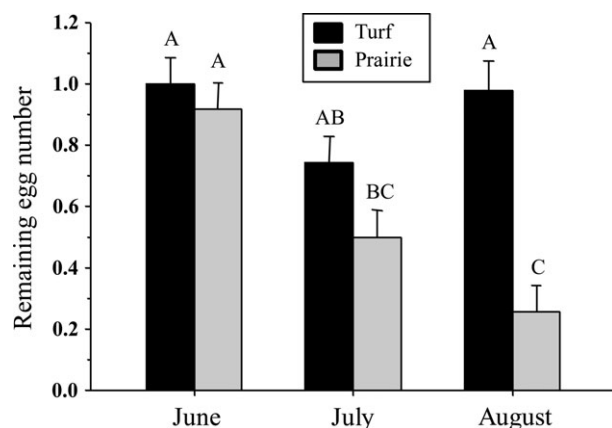
Fig. 4. The mean proportion of remaining eggs ($\pm$SEM) averaged across sampling stations ($n = 2$) for turf and prairie habitats. A decline in the proportion of remaining eggs indicates higher levels of predation. Significant differences ($P < 0.05$) are indicated by different letters.

Ekbom, 2010; Raupp *et al*., 2010). The availability of pollen and nectar in addition to alternative prey may have contributed to and sustained the higher abundance of predators we observed in the prairie.

Despite the fact predation was not significantly different between the turf and prairie in June or July, we found predation increased over the course of the summer with significantly higher rates of predation in the prairie by August. Several mechanisms may explain why higher predator abundances in the prairie did not translate into greater predation earlier in the season. While overall predator abundances did not change over the course of the summer in the prairie, individual predator abundances did vary between June and August. For example, minute pirate bugs (Family Anthocoridae) composed 37% of the predator community in June compared to 6.5% in August, while spiders increased from 29.7% in June to 34.8% in August (Supplementary Material D, Fig. D1). Spiders are known egg predators (Werling *et al*., 2012) and documented predators of corn earworm eggs (Pfannenstiel, 2008). In this study, we found spider abundance was negatively correlated with the number of remaining corn earworm eggs, our measure of predation services (Supplementary Material B, Table B1). Changes in predator abundance suggest certain predators, in particular spiders, were likely contributing to the increased predation over the course of the summer in the prairie habitat.

Conclusion

With the projected increase in the growth of urban areas, both ecologists and landscape planners have advocated

for the design of urban green spaces that have the capacity to support biodiversity and perform ecosystem services (Miller & Hobbs, 2002; Hunter & Hunter, 2008; Lovell & Johnston, 2009). While this area of research is growing, urban planners and land managers currently have few ecologically based strategies to guide the design and management of urban landscapes for biodiversity conservation and enhanced ecosystem functioning. The results from this study indicate that distinct habitats within larger green spaces can differentially support beneficial arthropods and ecosystem services. We found prairie habitat supported more predators and provided better predation services than areas of turf. Our results have important implications for urban planning, by suggesting the type of green space incorporated into urban landscapes can influence arthropod conservation, as well as the provision of ecosystem services. We expect the benefits of prairie habitat could be particularly important for urban food production systems, where crop yields rely on pollination and pest suppression. An important challenge for urban planners will be, however, developing planning strategies that use green space to not only attract beneficial arthropods but also facilitate their movement into areas targeted for enhanced provision of ecosystem services. Investigating the ability of additional types of urban green spaces such as ornamental gardens, green roofs and woodlands to support arthropods and other functionally important taxa will further expand our understanding of the role urban green spaces have in biodiversity conservation and the performance of multiple ecosystem services. Integrating ecological research into urban planning strategies will be a critical step towards understanding how to expand the conservation potential of urban landscapes.

Acknowledgements

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Supporting Information

Additional Supporting Information may be found in the online version of this article under the DOI reference: doi: 10.1111/icad.12062:

Figure S1. The experimental design used to measure predation services shows for one sampling station the open and closed egg cards attached to the underside of a Plexiglas platform.

Figure S2. The percent abundance each predator contributed to the predator community in the prairie during June and August 2011.

Table S1. Spearman's Rho between predators, green space habitats (turf or prairie), and the number of remaining eggs, our measure of predation services.

Table S2. List of the flower species identified in the six prairie green spaces during the 2011 field season. The flower phenology of each species was included to illustrate the availability of floral resources across the season.

Table S3. The geographic coordinates of the urban green space habitats sampled across the metropolitan area of Chicago (Cook County, IL., USA).