Title

Birds biodiversity in urban and periurban forests: environmental determinants at local and landscape scales

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Abstract

A significant decline in biodiversity is associated with the current and upcoming degree of urbanization. A challenging strategy to address this conflict is to make urban growth compatible with biodiversity protection and in this context urban parks can play a crucial role. Urban systems are highly dynamic and complex human-shaped ecosystems, where the relationship between species and environment may be altered and make the preservation of biodiversity within them a challenging goal. In this study, we analysed how different environmental features affect bird biodiversity in one of the most urbanized areas of Italy (the metropolitan area of Milan) at different spatial scales. Bird surveys were conducted in fifteen urban and peri-urban parks and environmental variables at landscape and local scale recorded. Results showed that a mixture of land covers and the presence of water bodies inside urban parks favoured species occurrence and abundance at

landscape scale, but a surrounding dense urban matrix deflated biodiversity. At local scale, woodland cover and presence of water bodies were key determinants in ensuring overall high biodiversity but local-specific vegetation management produced an unusual pattern for forests species. In particular, the maintenance of large trees may not result in biodiversity support for forest bird species if large trees are not located in woodland areas with a significant tree density. To understand biodiversity patterns and provide useful information for urban planning and design, we need to provide insights into species/environment relationships at multiple scales in the urban environment.

Keywords

Urban forests, birds' biodiversity, diameter at breast height, habitat provisioning

Introduction

Present-day trends draw attention to a significant decline in biodiversity associated with current and upcoming degrees of urbanization (Lerman et al., 2014; McDonald et al., 2008). Urbanization reduces the quantity of native vegetation and alters its local structure and regional spatial pattern (Donnelly and Marzluff, 2006) by inducing habitat fragmentation and favouring the invasion of exotic species (Qian and Ricklefs, 2006; Savard et al., 2000). Urbanization is also responsible of an increase in biotic homogenization (Alvey, 2006; McKinney and Lockwood, 1999) which leads "urban-adaptable" species to become increasingly widespread and locally abundant in cities across the planet (McKinney, 2006; Jokimäki and Kaisanlahti-Jokimäki, 2003), with a loss of less adaptable species. As a consequence, the urban avian community is often composed of few species that may dramatically differ from those of local natural environments (Chace and Walls, 2006; O'Connell et al., 2000). Despite these factors and although habitat loss, fragmentation, and human disturbances (i.e. pollution) associated with urbanization are among the major causes of biodiversity decline, urban areas can also be planned, designed and managed with the virtuous aim of increasing flora and fauna occurrence within them. However, cities are highly dynamic and complex human-shaped ecosystems that make the maintenance of high biodiversity levels within them a challenging goal to reach. A deeper understanding of what is required to maintain and enhance biodiversity in cities is of fundamental importance in planning effective conservation strategies aimed at reducing the ecological footprint and ecological debt of cities towards nature.

In this context, urban green area may play a major role in provide suitable habitat for biodiversity. Although their importance well-documented (Sanesi et al., 2011; Fernández-Juricic 2000; Gilbert 1989), their contribution is strongly influenced by different factors such as the intrinsic structure of green areas, as well the urban (or rural) landscape surrounding it (Sanesi et al., 2011). Profound differences in species richness or species diversity are detectable in intra-urban localities (Beninde et al., 2015), as confirmed by a large number of studies on the distribution of numerous taxonomic groups within cities globally (Goertzen and Suhling 2013; Lizee et al. 2012; Bates et al. 2011; Hobbs 1988). To understand what determines intra-urban variations in biodiversity in urban green spaces we need to quantify the individual factors that affect it in the study area of interest (Beninde et al., 2015). The maintenance of structural complexity of vegetation can ensure the within-stand variation in habitat conditions required by some taxa (a 'habitat heterogeneity' function, Lindenmayer et al., 2006; Sanesi et al., 2009; Savard et al., 2000) and the loss of structural complexity of vegetation in green areas has been demonstrated to have negative impacts on biodiversity (McKinney, 2006; Lindenmayer and Franklin, 2002). Structural complexity is related to attributes such as the presence of trees from multiple age cohorts within a stand, large living trees and snags, large-diameter logs on the forest floor and vertical heterogeneity created by multiple or continuous canopy layers, to mention but a few (Lindenmayer et al., 2006; Franklin and van Pelt, 2004; Hunter, 1999; Linder and Östlund, 1998, Berg et al., 1994).

The complexity of urban systems calls for an effort to understand the importance of other anthropogenic factors that act locally (Melles et al., 2003). Forest fragments of similar size and vegetative structure may not be ecologically equivalent because of differences in their surrounding landscapes (Friesen et al., 1995). The effects of fragmentation on local bird communities have been found to be context-dependent (Hedblom and Soderstorm, 2010) and some authors have emphasized the importance of including processes occurring in the peri-urban landscape in any attempt to study how birds in urban environments are affected by habitat loss (Hedblom and Soderstorm, 2010). In small habitat patches, ecosystem dynamics may be driven predominantly by external rather than internal forces (i.e. pollution from urban matrix surroundings, severe and frequent disturbances by humans) (Faeth et al., 2011; Saunders et al., 1991) and urbanization may represent detrimental influences (i.e. population decline of some species or deflation of the ecological value of forests patches) even when forest patches are maintained (Engels and Sexton, 1994; Herkert et al., 1993).

Besides the importance of the urban matrix (Snep et al., 2006; Watson et al., 2005), other studies have strengthened the notion that urban research also needs to incorporate effects on the studied taxon at different hierarchical levels (Clergeau et al., 2006). It should be considered that the influences of different environmental features on biodiversity also operate at different spatial scales. Such scales are not independent from one another but linked in a hierarchical way (Allen and Star, 1982): the effects of an action at a given scale must be considered on higher and lower scales (Savard, 1994). In urban areas, as in other complex systems of biotic organisation, there is a need to define several levels of ecological functioning (Allen and Star, 1982) such as the habitat (or local) level, which is defined by elements within the green space, its characteristics, and the landscape level, such as a district with its parks, houses and avenues, which may differ structurally from the centre and the edge of town (Clergeau et al., 2006; Donnelly and Marzluff, 2004). Similarly, urban forests can be managed in relation to their vertical structure (Rutten et al., 2015). In fact, many green infrastructure solutions that aims to reduce the ecological impact and to enhance habitat provision, developed on green roofs and walls because they represent an important surface to host vegetation in cities (Wong et al., 2010).

With this study we aimed to investigate: i) how environmental factors at landscape scale affect bird species' richness and abundance, ii) how the presence of 28 selected bird species are affected environmental variables at local scale by and iii) whether and how small and large trees affect the abundance of forest bird species.

Materials and Methods

Study area

The study area comprises the metropolitan area of Milan and surrounding municipalities. The city of Milan has a population of 1,345,851 (ISTAT, 2015) with a surrounding province of 3,208,509 (ISTAT, 2015). Compared to other Italian cities, Milan has a considerable amount of urban green spaces. However, the metropolitan area (in particular in the north) is one of the most urbanized areas in the country and Europe (Trono and Zerbi, 2002). Here, the urban development of the last decades has been characterized by sprawl and a high degree of landscape fragmentation (Canedoli et al., 2017; European Environment Agency EEA, 2006). Geographically, the metropolitan area of Milan extends between the alluvial plain of the Po River and the mountainous area of the Alps. The area has been subject to profound land use changes in the past decades, and urban expansion has led to the conversion of extended natural and semi-natural lands to newest anthropogenic land uses. Today, the area is mainly characterized by urban land uses surrounded by intensive agricultural lands, while semi-natural lands are fragmented and little represented.

For this study, we selected 15 urban and peri-urban parks that presented different characteristics and that are representative of the typologies of the parks in Milan (Figure 1, Table 1). The history of Milan's urban parks is closely related to that of the city itself (Mariani et al., 2016). These parks are mainly represented by new plantation derived from former agricultural or industrial areas. The oldest parks were established around the end of the 18th century (in 1784 Parco Indro Montanelli and in 1804 Parco di Monza). Parco Sempione, which is the main central park of Milan, was constructed at the end of the 19th century on a military area. In the 20th century, many urban and peri-urban parks were further established: Parco Ravizza (1902) was established during the urban expansion of the city into the agricultural lands surrounding the city, and is nowadays close to the city centre; Parco Don Giussani and Parco Guido Vergani are central parks that were constructed respectively in the 1930s and 1960s on areas formerly occupied by the railway station of the Scalo Sempione (Mariani et al., 2016); Montestella (1950s) represent a singularity in origins and design because it is an artificial hill created after World War II bombings using the remnants of the buildings destroyed and the demolished ancient Spanish walls of the city; Parco Trotter derives from the renewal (around 1920) of the area of the historical Trotter hippodrome (which was created in the year 1800); Parco Lambro is the oldest peri-urban park of the city (established in 1936) and was designed to re-create the traditional rural landscape of the region with a natural river (Lambro River), groves, rolling hills, and farmsteads; Boscoincittà, Parco Trenno and Parco Forlanini are large peri-urban parks built in the 1970s on previously agricultural lands and were designed to recreate the typical rural landscapes; Parco Nord (1983) and Parco delle Cave (1990) are recently established peri-urban parks developed respectively from a former military airport and the Breda factory brownfield areas (Marziliano et al., 2001; Sanesi et al., 2017) and an agricultural area with sand pits.

Bird surveys

Bird surveys were carried out using repeated point-counts (Ralph et al., 1998) at 93 sampling points randomly distributed in a balanced design regarding the size of the park (the number of point-counts in each park was proportional to the park area). Minimum distance between two points was set to at least 200 meters to prevent overlapping observations (Sandström et al., 2006). Surveys were conducted during the breeding season (from April to June 2014) in the early morning (from sunrise until around 4-5 hours later) when birds' singing activities are at a peak. Each point-count was surveyed twice in days with no adverse meteorological conditions (no rain, no heavy wind). Counts were carried out using a standardized quantitative methodology where a skilled observer (in this study a professional ornithologist) recorded both occurrence and number of individuals for each bird species detected at each point and distinguished between birds contacted (seen or heard) within and beyond the point area (a circular buffer of 100 m of radius around the point) (Blondel et al., 1981). Overall data were used to estimate species richness for the whole park, while data referring to birds detected within the point area were used for presence and abundance at local scale.

Data on species traits (Hedblom and Soderstorm, 2010) were taken from the literature (BirdLife International, 2017; del Hoyo et al., 2014; Bani et al., 2008) (Table 2). Traits for each bird species included: (1) main habitat (coniferous forest, deciduous forest, farmland–forest edge, farmland, mixed deciduous–coniferous forest, synanthropic, wetlands, mountains); (2) nesting site (cavity, ground, house, shrub, tree, wetland vegetation); (3) migration strategy in Italy (resident or trans-Saharan migrant); (4) diet (carnivore, insectivore, herbivore, insectivore–herbivore, insectivore–herbivore–carnivore).

Environmental features: landscape, habitat (local) and vegetation structure

Previously utilised approximations of the complexity of the urban fabric (such as the urban–rural gradient) may be implemented by individually quantified habitat features and often distinguish precisely between different aspects of urban features, such as patch area, vegetation variables, or others (Hamer and McDonnell 2008; Chace and Walsh 2006). Data on environmental features were recorded directly during the field surveys or derived from a Geographic Information System (land cover) (using ArcMap 10.2.2) or combining either methodologies when needed to validate the GIS information. Here, landscape scale refers to the whole park, while local scale refers to a circular area of a 100-metre radius.

The following landscape variables were recorded in each park: area of park (m^2), minimum distance from downtown (m), distance from the nearest park (m), park surface covered by woodlands (m^2), park surface covered by grassland (m^2), unvegetated park coverings (represented by paving or buildings) (m^2), presence of water bodies (canals, rivers or small lakes), age of the park (estimated as years from park establishment, amount of green areas in a buffer of 1 km surrounding the park (m^2), amount of built area in a buffer of 1 km surrounding the park (m^2).

Local habitat variables were recorded for each bird point-count (a circular area of 3.14 hectares), and were: surface covered by trees (% of the total area), surface covered by grassland (% of the total area), other type of land covers (paving or buildings) (% of the total area), presence of water bodies, distance from the nearest park border (m).

To account for vegetation structure, we recorded the trees Diameter at Breast Height (DBH - taken at 1.3 m above the ground) in each point count (Sreekar, 2016; Sanesi et al., 2009; Berg, 1997). The structural heterogeneity of forest trees within greenspaces expressed by the DBH is a fundamental aspect supporting bird species abundance (Sanesi et al., 2009; Diaz et al., 2005; McBride, 2000; Willson et al., 1994). The number of trees measured was proportional to the amount of surface covered by trees in the point: a maximum of 100 trees were randomly measured at a point occurring in woodlands where the tree cover was 100% and no trees were measured in grassland sites.

Data analysis

Detectability and abundance of birds

Detection of animals is rarely perfect or constant for many reasons such as observer errors, species rarity or because detection varies with confounding variables such as environmental conditions (Kellner and Swihart, 2014). Failure to correct for imperfect detection may result in bias in estimating relationships with ecological covariates (Zipkin et al., 2010; Gu and Swihart, 2004) among other things. To account for this, we assessed the probability of occupancy (psi) of the sampling points for every bird species recorded using PRESENCE 11.2 (Hines, 2006). PRESENCE describes the probability of detecting a species using a probabilistic argument to describe the observed detection history for a site over a series of surveys (MacKenzie et al., 2002). This method estimates the probability of site occupancy in situations where a species is not guaranteed to be detected even when it is present, thus reducing the risk of underestimating occupancy. On the basis of occupancy results for every species we calculated the misdetection rate as the percentage difference between observed occupancy and the occupancy estimated by PRESENCE. We then selected only the species observed at least in the 10% (n = 28) of the point-counts surveyed. The probability of occupancy of each point (conditional psi) was used to assess the relationships between the 28 bird species that occurred and the environmental features at site-scale. For the species with a low misdetection rate, we also took into account the maximum number of individuals recorded for each point between the two sampling sessions performed to assess the relationships between the abundance of single species and some of the environmental features recorded.

Relationships between species richness and abundance at landscape scale

To extricate the importance of landscape variables on bird species richness and abundance, we performed a series of constrained redundancy analyses (RDA) using as endogenous dataset the total number of species recorded and the maximum number of individuals recorded, and as the exogenous dataset the environmental variables. The RDA is a canonical analysis that combines the proprieties of regression and ordination techniques and that evaluates how much of the variation of the structure of one dataset (e.g., community composition in a forest, endogenous dataset) is explained by the independent variables (e.g., habitat features, exogenous datasets) (Borcard et al., 2011). With RDA analysis the overall variance is partitioned into constrained and unconstrained fractions. To assess the significance of the explained variance by the RDAs and avoid type-I error; we performed ANOVA-like permutation tests (10,000 permutations). Prior to RDA analyses, we used variance inflation factors (VIF) to identify collinearity among explanatory variables. We calculated the VIF values for all explanatory variables, removed the variable with the highest value, and repeated the procedure until all VIF values were < 10 (Zuur et al., 2010).

Relationships between species occurrence and abundance at local scale

To understand which (and how) local features of the parks determined the presence of different bird species, RDA analyses were performed on a subset of 28 bird species observed in at least 10% of the sampling plots. The probability of occupancy (psi) at a given sector as estimated by PRESENCE was assumed for each species (endogenous dataset). The environmental variables of the sites were the exogenous dataset. Explanatory variables were checked for collinearity using VIF scores. As for previous analyses, ANOVA-like permutation tests (10,000 permutations) were performed to assess the significance of explained variance by RDA.

As the structural complexity of vegetation can provide the habitat conditions required by some birds and these requirements may vary among different species, we analysed the response of forest birds to different vegetation structures. We tested the presence of linearity in the relationship with mean DBH and the birds' abundance. The maximum number of individuals during all counts was used as an index of species abundance, which is a minimal estimate of the actual population (Johnson, 2008). For this analysis, seven forest birds with a misdetection rate ≤ 0.05 were selected: the Eurasian blackcap (*Sylvia atricapilla*), the great tit (*Parus major*), the common chaffinch (*Fringilla coelebs*), the common blackbird (*Turdus merula*), the great spotted woodpecker (*Picoides major*), the Eurasian blue tit (*Parus caeruleus*) and the European green woodpecker (*Picus viridis*). We used Generalized Additive Models (GAMs) assuming the park as a random factor and a Poisson error distribution. As dependent variable we used the log transformed mean number of individuals recorded during surveys. In GAMs, increasing values for the effective degrees of freedom (edf) indicate an increased complexity and non-linearity of the response curve (Wood, 2006); we therefore considered an edf of 1 as evidence of a linear relationship, while values higher than 1 indicated a non-linearity (Digiovinazzo et al., 2010). All the analyses were performed with R version 3.3.1 using the packages HH, vegan, car and gam.

Results

Bird surveys

A total of 63 species of birds were detected in the study area and, among these, 18 are listed in a protection list (Table 2). In total, 3343 individuals in the first survey and 3541 in the second were observed (Fig. 2). Most of the bird species contacted were resident in the study area, and less than a third were trans-Saharan migrants. Birds detected comprised species commonly observed in urban environment, but also elusive species, wetland birds or birds usually associated with agricultural environments; non-native species detected were 4.

The bird communities of urban parks of small dimension (less than 19 hectares) or closer to downtown (less than 5 km) were characterized by a similar species composition with the dominance of 12 species (Table 3). This bird community featured synanthropic species or species associated with mixed deciduous-coniferous forests or forests edges. They were mainly residential, cavity- or shrub-nesting birds. The twelve most common species for the smallest and central parks were also commonly observed in larger peripheral parks, except for the Italian sparrow (*Passer italiae*) and the European greenfinch (*Carduelis chloris*) which were observed less frequently.

In addition to these species, the bird community of large peri-urban parks commonly comprised eight other species (Table 3). In contrast to small central parks, large peri-urban parks showed a more heterogeneous bird community, with birds associated with deciduous, mixed deciduous-coniferous forests, farmland–forest edge or wetlands, and ground and house nesters. Interestingly, birds of prey were observed only in these typologies of parks.

Relationships between species richness and abundance at landscape scale

One goal of this study was to establish how landscape environmental features affected the number of species and the abundance of birds (maximum number of individuals). Some of the recorded environmental variables presented correlations. After variable selection using VIF scores, we obtained a significant redundancy analysis ($P<0.001$) that expressed a high degree of variation (91.1 %) (Table 4). The first RDA component (RDA1) expressed 89% of the variance described by the RDA. RDA1 was essentially represented by parks with scarce grass cover and without wetlands, while RDA2 by peripheral younger parks (the scores of variables are shown in Table 4). Both species richness and abundance showed a negative relationship with component RDA1, while only bird abundance presented a negative relationship with RDA2 (Fig. 3).

Relationships between species occurrence at local scale and effect of vegetation structure

Considering the relationships between 28 bird species present and environmental features at local scale, 14% of variation in species presence is explained by the variables considered ($P<0.001$) (Fig. 4, Table 5). The first component of the analysis ($RDA_{bird}1$) is mostly represented by surface covered by trees (Table 6) and explains 48% of variance described by RDA. The second component ($RDA_{bird}2$) is mostly represented by presence of water bodies and explains 26% of variance described by RDA.

The dominant tree species in the study area were: *Robinia pseudoacacia L, Quercus robur L., Quercus rubra L., Acer campestre L.,* gen. *Tilia (Tilia platyphyllos Scop., Tilia cordata, Tilia x vulgaris), Carpinus betulus L., Celtis australis,* gen. *Ulmus,* gen. *Fraxinus, and* gen. *Acer*. The GAMs analysis revealed that two forest bird species, the Eurasian blackcap (*Sylvia atricapilla*) and the Great tit (*Parus major*) presented a significant linear relationship with mean DBH in urban parks (respectively, $P < 0.001$ and $P<0.01$). In particular, the maximum number of individuals decreased with the increase in mean tree diameter.

Older and larger trees (> 20 cm DBH) were generally distributed with low densities in areas with open views of the park, while woodland patches with high tree densities usually presented few large trees but many medium and small trees (respectively > 3 cm and <= 20 cm DBH and <= 3 cm DBH) (see Fig. 5). To explain this relationship we performed an ANOVA analysis followed by a post-hoc Tukey test to assess differences in tree composition in forested (woodlands patches with high densities of trees) and open areas on the basis of DBH values. In forested areas there was a significant difference in density between small, medium, and large trees ($F_{2,39} = 6,55$; $P < 0.01$). In particular, small trees were significantly more abundant than large ($P < 0.01$) and medium ($P = 0.01$) ones. In open areas there was also a significant difference in tree composition ($F_{2,234} = 25.98$; $P < 0.001$). In particular, large trees were predominant with respect to medium and small trees ($P < 0.001$).

Discussion

A mix of land covers and the presence of water bodies favoured birds biodiversity at landscape scale, but a surrounding dense urban matrix may deflated it

Birds provide a suitable method for exploring urban effects and responses to different urban designs (Sanesi et al., 2009; Chace and Walsh, 2006). An essential first step in more effective management of urban environments is a fuller understanding of the interplay between landscape (matrix effects) and local factors (patch effects) that affect urban biodiversity (Angold et al., 2006). While local factors determine habitat suitability (in terms of species survival), landscape factors define the permeability of the surrounding landscape for species dispersal (Beninde et al., 2015; Melles et al., 2003). In this work, we tested factors that have been put forward as key determinants in explaining intra-urban variation in biodiversity (Beninde et al., 2015; Cushman 2006; Drinnan 2005; Faeth and Kane 1978) by studying the case of the metropolitan area of Milan.

The composition of the bird communities in the parks investigated is of particular interest because it showed some common patterns in terms of composition of bird communities for different kinds of parks and can tell us which bird species can be supported according to environmental specifics at landscape scale. The bird community observed was clearly affected by environmental variables considered at different scales of analysis. It is known that park surface is one of the features that mostly affect species abundance and richness: the bigger the park, the higher the number of individuals it can contain (Beninde et al., 2015; Alvey, 2006; Cornelis and Hermy, 2004; Godefroid and Koedam, 2003). However, it is not always feasible to establish large parks (i.e. in high-density urban contexts) or expand already existing green areas. Our results show that park area was closely correlated with all the other explanatory variables recorded at the landscape scale. Only by removing it from the analysis was it possible to extricate the role played by the other variables considered. This means that in other studies in which park area played a major role, this fact may have masked the importance of other environmental features. In particular, we found that the occurrence of water bodies (small artificial lakes or rivers) in urban parks is a fundamental feature for biodiversity, both at landscape and local scale. Water elements favoured the presence of wetland, but also of non-wetland, species (Fig. 4, Table 5).

The presence of buildings inside the parks was also positively related to bird biodiversity. Human structures may represent suitable nesting sites for different species, such as cavity or building nesters. Moreover, they are also related to trophic supply sources owing to a concentration of human activities, such as cafés or picnic areas that attract synanthropic species. In the urban parks surveyed, the typologies of buildings occurring were small buildings for recreational (cafès, eateries) or cultural activities, historical buildings (villas, museums) or schools. In the literature, the role that these structures play in urban park biodiversity is apparently not mentioned. Our results suggest that the presence of buildings in urban parks may have a positive role by favouring a higher habitat heterogeneity for the local fauna.

At the same time, our study confirmed the importance of the urban matrix around parks, as parks surrounded by dense urban surroundings hosted a lower number of bird species and less numerous populations. The urban tissue represents a low-permeable matrix characterized by open spaces and barriers scattered in the landscape, that affect the movements of animals. In this context, urban parks represent islands where animals can find suitable habitats and resources. The landscape surrounding the parks may influence the capacity of dispersal of individuals (i.e. concrete surfaces or roadways) as well as disturbance from human activities (i.e. noise from human activities, air pollution from automobiles and industry, large amounts of artificial and polarized light) (Faeth et al., 2011). Biodiversity inside urban parks is favoured when the urban surroundings present open-areas or other green infrastructures (i.e. street trees, private gardens) that may work as functional corridors or stepping-stones to the colonization and maintenance of species inside urban parks. Moreover, to maintain populations of specialized forests birds within cities, the importance of the urban matrix may be especially important for the (southern and western) European cities that experience urban sprawl and that are located in farmland landscapes with few peri-urban woodlands (Hedblom and Söderström, 2010), as is the city of Milan. Where the surrounding matrix is composed of dense built-up areas, the effect on the park may be a reduction in biodiversity levels and this was particularly evident in the parks we studied. Thus, to successfully conserve birds in cities we should take the surrounding landscape composition into account (Hedblom and Söderström, 2010).

The age of the park negatively influenced bird communities in our study area. Age is partially correlated with park dimension and position: centre city parks were usually older than peripheral and more extended parks. Alongside this, the oldest parks were created following the standards of the time and consequently show a different urban design compared to more recent parks (Madanipour, 2013): they were designed with attention to recreate beautiful gardens and less attention was placed on recreating natural settlements.

Woodlands and water bodies are key determinants for bird biodiversity at local scale, but urban vegetation management may lead to unusual patterns for forests species

By analysing the effects of environmental variables at local scale, woodlands and water bodies were found to be of great importance for the overall avian community investigated. Moreover, the presence of grassland land cover and the distance from the park border positively influenced the presence of birds within the study area (Table 6). Other features (such as the presence of buildings or paving cover; "Other land cover" in Table 6) were less represented, meaning that the role in explaining the variance in species present is negligible at this scale. As the presence of buildings was highly influential at landscape scale, we can argue that the high incidence of human-made surfaces at local scale (around 3 hectares) cannot support high biodiversity levels, but on the contrary can support high densities of a few synanthropic (i.e. building nesting) species (Figure 4).

The correlation between bird species richness and the presence of water, woodlands and grasslands emphasised the importance of urban green spaces containing heterogeneous elements capable of providing suitable habitats for a large number of species with different ecological requirements and the mixing of different land covers appeared to be important at landscape as well as local scale. Among the species observed, a considerable portion (30%) appears in some protection list and this makes their presence of particular conservation interest. This result emphasizes the importance of the role that green urban spaces can play in supporting wildlife conservation by harbouring not only common and synantrophic but also rare or endangered species.

It is known that the maintenance of stand structural complexity is critical for forest conservation of biodiversity (Sanesi et al., 2009; Lindenmayer et al., 2006). Old trees have been shown to be of great importance for some species and for biodiversity in general (Andersson and Östlund, 2004; Cowie and Hinsley, 1988). In this study, we tested whether the abundance of forest species increased with the presence of large trees (high mean DBH). Only two species out of seven investigated presented a significant relationship (the Eurasian blackcap, *Sylvia atricapilla* and the Great tit, *Parus major*): the number of individuals observed decreased with the increase in mean tree diameter, thus suggesting an opposite trend compared to what appears in the literature. However, the vegetation structure of the urban parks studied presented some peculiarities owing to management of local vegetation, which differed from natural forest stands. The results of the distribution of trees of different diameter suggested that the presence of old trees in isolated exemplary or very low-density stands may not be sufficient to promote biodiversity by itself because of difficult exploitation by forest bird species. In fact, in the study area forested patches were composed mainly of dense small trees, and not large trees. These patterns are likely to occur in novel ecosystems that are ecologically different from natural ones, and where as a consequence the species-environment relationships may result altered. However, considering the importance of old trees demonstrated in previous studies (Stagoll et al., 2012; Sanesi et al., 2009; Andersson and Östlund, 2004; Wells et al., 1998; Berg et al., 1994), their presence in the forested patches studied would probably further increase species presence and should therefore be promoted.

Conclusions

Urban green areas can be actively managed by foresters and city planners to preserve the biological diversity that they harbour (Hostetler et al., 2011). In general, this study shows that the presence of water bodies, a mixture of land covers (including buildings) and the distance from the city centre (which is positively correlated with park areas) help to enhance biodiversity at landscape scale for the parks of Milan. At local scale, water bodies and woodlands had the strongest positive effect on biodiversity and specialized forest species occurred in forested patches characterized by small and medium trees, while contrary to other studies larger trees did not have a positive effect. This study indicates that there is a need to differentiate the cover types within urban parks by creating the coexistence of both woodlands, grasslands (and other open habitats, including sufficient space for ecotones), but also some buildings and importantly with wetlands. While generally speaking the importance played by large trees in natural environments has been extensively studied (Stagoll et al., 2012), our study shows how specific human practices in the management of urban vegetation can lead to unexpected patterns for specialised forest species.

However, as postulated by Beninde et al. (2015), only when the conservation objective is clearly defined is it possible to determine thresholds for environmental features (such as tree diameters or extension of woodlands). For example, the conservation goal may be to minimise the loss of urban-adapted species (Drinnan, 2005) or to conserve urban-avoiding species. In either case, conservation strategies adopted would change depending on the predetermined goals. The concerted efforts made to preserve or enhance biodiversity in urban areas at various scales can produce the best results (Goddar et al., 2010; Savard et al., 2000; Poiani et al., 2000) and conservation actions that neglect the interplay between landscape and local features may fail, or produce powerless effects on biodiversity conservation (Savard et al., 2000).

Acknowledgments

This work was supported by the Ministry of Education, Universities and Research within the program PRIN 2012 (project name "Innovative models for the analysis of ecosystem services of forests in urban and periurban context", grant number 2012K3A2HJ). We are grateful to G. F. Ficetola for precious suggestions on data analyses. We also thank two anonymous reviewers and the journal editors for constructive comments.

Conflict of Interest: The authors declare that they have no conflict of interest.

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TABLES

Table 1

Parks selected for this study. Area = area of the park, Distance = distance from city centre.

	Park	Typology	Area (hectares)	Distance (km)
1	Parco di Monza	Peri-urban	688.0	17.91
2	Parco Nord	Peri-urban	596.5	7.78
3	Parco delle Cave	Peri-urban	122.9	7.11
4	Boscoincittà	Peri-urban	91.9	8.17
5	Parco Lambro	Peri-urban	71.7	5.70
6	Parco di Trenno	Peri-urban	61.0	6.90
7	Parco Forlanini	Peri-urban	59.7	5.55
8	Parco Sempione	Urban	51.2	1.55
9	Bosco delle Querce	Peri-urban	42.8	20.50
10	Monte Stella	Urban	38.6	5.24
11	Parco Montanelli	Urban	19.4	1.44
12	Parco Trotter	Urban	13.1	4.30
13	Parco Ravizza	Urban	8.0	1.85
14	Parco Guido Vergani	Urban	6.3	2.37
15	Parco Solari	Urban	5.6	1.95

Table 2. List of bird species observed in the study area. Conservation status: V - listed in Annex V of Birds and Habitats Directive, VU - vulnerable (IUCN), NT - near threatened (IUCN), S - SPEC3 (BirdLife International); Main habitat: Co - coniferous forest, De - deciduous forest, Ed – farmland/forest edge, Fa - farmland, Mi - mixed deciduous/coniferous forest, Sy - synanthropic, We - wetlands, Mo - mountains; Nesting site: C - cavity, G - ground, H - house, S - shrub, T - tree, W - wetland vegetation; Migration strategy in Italy: Re – resident, Sh - trans-Saharan migrant; Diet: C - carnivore, I - insectivore, H - herbivore, IH – insectivore/herbivore, IHC – insectivore/herbivore/carnivore).

Latin name	**English name**	**Cons. stat.**	**Main habitat**	**Nesting site**	**Migration strategy**	**Diet**
Accipiter nisus	Eurasian sparrowhawk		Co	T	Re	T
Acrocephalus arundinaceus	Great reed warbler	NT	We	W	Sh	I
Acrocephalus scirpaceus	Eurasian reed warbler		We	W	Sh	I
Aegithalos caudatus	Long-tailed tit		Ed	S	Re	I
Aix sponsa	Wood duck		We	G	Re	IHC
Alauda arvensis	Eurasian skylark	VU	Fa	G	Re	IH
Alcedo atthis	Common kingfisher	V	We	G	Re	C
Anas platyrhynchos	Mallard		We	G	Re	H
Apus apus	Common swift		Sy	C	Sh	I
Ardea cinerea	Grey heron	V	We	T	Re	IHC
Buteo buteo	Common buzzard		Ed	T	Re	C
Carduelis carduelis	European goldfinch	NT	Ed	T	Re	H
Carduelis chloris	European greenfinch	NT	Ed	S	Re	IH
Certhia brachydactyla	Short-toed treecreeper		Mi	C	Re	I
Columba livia	Rock dove		Sy	H	Re	IH
Columba palumbus	Common wood pigeon		Mi	T	Re	IH
Corvus cornix	Hooded crow		Sy	T	Re	IHC
Corvus monedula	Western jackdaw		Fa	C	Re	IHC
Cuculus canorus	Common cuckoo		Ed	T	Sh	IHC
Delichon urbicum	Common house martin	NT, S	Sy	H	Sh	I
Dendrocopos major	Great spotted woodpecker		Mi	C	Re	I
Erithacus rubecula	European robin		Mi	S	Re	I
Falco subbuteo	Eurasian hobby		Ed	T	Sh	C
Falco tinnunculus	Common kestrel	S	Fa	T	Re	C
Ficedula hypoleuca	European pied flycatcher		De	C	Sh	I
Fringilla coelebs	Common chaffinch		Mi	S	Re	I
Fulica atra	Eurasian coot	V	We	G	Re	IHC
Gallinula chloropus	Common moorhen		We	G	Re	IHC
Hippolais polyglotta	Melodious warbler		Ed	S	Re	I
Hirundo rustica	Barn swallow	NT, S	Fa	H	Sh	I
Ixobrychus minutus	Little bittern	V, VU	We	W	Sh	C

Lanius collurio	Red-backed shrike	VU	Ed	S	Sh	C
Luscinia megarhynchos	Common nightingale		De	G	Sh	I
Melopsittacus undulatus	Budgerigar		Sy	C	Re	H
Motacilla cinerea	Grey wagtail		We	C	Re	I
Muscicapa striata	Spotted flycatcher		Ed	T	Sh	I
Oriolus oriolus	Eurasian golden oriole		Mi	T	Sh	IHC
Parus caeruleus	Eurasian blue tit		De	C	Re	I
Parus major	Great tit		Mi	C	Re	I
Parus palustris	Marsh tit		De	C	Re	I
Passer italiae	Italian sparrow	VU	Sy	C	Re	H
Passer montanus	Eurasian tree sparrow	VU	Sy	C	Re	IH
Phalacrocorax carbo	Great cormorant		We	G	Re	C
Phasianus colchicus	Common pheasant		Fa	G	Re	IH
Phoenicurus ochruros	Black redstart		Mo	C	Re	I
Phoenicurus phoenicurus	Common redstart		Ed	C	Sh	H
Phylloscopus bonelli	Western Bonelli's warbler		Mi	G	Sh	I
Phylloscopus trochilus	Willow warbler		Mi	G	Sh	I
Pica pica	Eurasian magpie		Sy	T	Re	IHC
Picus viridis	European green woodpecker		De	C	Re	I
Podiceps cristatus	Great crested grebe	V	We	W	Re	C
Psittacula krameri	Rose-ringed parakeet		Sy	C	Re	H
Regulus ignicapillus	Common firecrest		Co	T	Re	I
Serinus serinus	European serin		Ed	G	Re	IH
Sitta europaea	Eurasian nuthatch		De	C	Re	I
Streptopelia decaocto	Eurasian collared dove		Sy	H	Re	IH
Streptopelia turtur	European turtle dove	S	Sy	T, S	Sh	IH
Sturnus vulgaris	Common starling	S	Ed	C	Re	I
Sylvia atricapilla	Eurasian blackcap		Mi	S	Re	I
Tachybaptus ruficollis	Little grebe	V	We	W	Re	I
Tachymarptis melba	Alpine swift		Mo	C	Sh	I
Troglodytes troglodytes	Eurasian wren		Mi	S	Re	I
Turdus merula	Common blackbird		Mi	S	Re	I

Table 3. Bird communities in urban parks. The table distinguishes between larger and more peripheral parks (larger than 19 hectares or distant of more than 5 km to downtown) on the left and smaller and more central parks on the right. PM = Parco di Monza, PN = Parco Nord, CV = Parco delle Cave, BO = Boscoincittà, LA = Parco Lambro, TN = Parco di Trenno, FO = Parco Forlanini, SE = Bosco delle Querce di Seveso, ST = Monte Stella; SM = Parco Sempione, MO = Parco Montanelli, TT = Parco Trotter, RV = Parco Ravizza, VE = Parco Guido Vergani SO = Parco Solari.

Latin name	**English name**	**PM**	**PN**	**CV**	**BO**	**LA**	**TN**	**FO**	**SE**	**ST**	**SM**	**MO**	**TT**	**RV**	**VE**	**SO**
Turdus merula	Common blackbird	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*
Fringilla coelebs	Common chaffinch	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*
Parus major	Great tit	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*
Corvus cornix	Hooded crow	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*
Sylvia atricapilla	Eurasian blackcap	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*
Sturnus vulgaris	Common starling	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*
Apus apus	Common swift	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*
Columba palumbus	Common wood pigeon	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*		*x*
Columba livia	Rock dove	*x*	*x*	*x*	*x*	*x*	*x*	*x*		*x*	*x*	*x*	*x*		*x*	*x*
Dendrocopos major	Great spotted woodpecker	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*		*x*	
Aegithalos caudatus	Long-tailed tit	*x*	*x*	*x*	*x*	*x*		*x*	*x*	*x*	*x*	*x*	*x*	*x*		*x*
Passer italiae	Italian sparrow	*x*	*x*	*x*	*x*		*x*				*x*	*x*	*x*	*x*	*x*	*x*
Erithacus rubecula	European robin	*x*	*x*			*x*	*x*	*x*	*x*		*x*				*x*	*x*
Parus caeruleus	Eurasian blue tit	*x*	*x*	*x*		*x*	*x*			*x*		*x*	*x*	*x*		
Luscinia megarhynchos	Common nightingale	*x*	*x*	*x*	*x*		*x*	*x*		*x*						
Hirundo rustica	Barn swallow	*x*	*x*	*x*	*x*		*x*	*x*					*x*			
Picus viridis	European green woodpecker	*x*	*x*	*x*	*x*			*x*	*x*				*x*			
Corvus monedula	Western jackdaw	*x*	*x*		*x*	*x*		*x*	*x*	*x*						
Anas platyrhynchos	Mallard	*x*	*x*	*x*	*x*	*x*			*x*		*x*					
Delichon urbicum	Common house martin	*x*	*x*	*x*	*x*	*x*			*x*							
Gallinula chloropus	Common moorhen	*x*	*x*	*x*	*x*	*x*					*x*					
Phoenicurus phoenicurus	Common redstart	*x*	*x*	*x*		*x*		*x*					*x*			
Serinus serinus	European serin		*x*	*x*			*x*	*x*					*x*		*x*	
Falco tinnunculus	Common kestrel	*x*	*x*	*x*			*x*	*x*								
Passer montanus	Eurasian tree sparrow	*x*	*x*		*x*		*x*	*x*								
Ardea cinerea	Grey heron		*x*	*x*	*x*		*x*	*x*								
Muscicapa striata	Spotted flycatcher					*x*	*x*				*x*			*x*	*x*	
Carduelis chloris	European greenfinch									*x*	*x*		*x*	*x*		*x*
Streptopelia decaocto	Eurasian collared dove	*x*	*x*	*x*	*x*											
Psittacula krameri	Rose-ringed parakeet		*x*			*x*	*x*	*x*								
Accipiter nisus	Eurasian sparrowhawk	*x*	*x*				*x*		*x*							
Troglodytes troglodytes	Eurasian wren	*x*	*x*						*x*							
Carduelis carduelis	European goldfinch		*x*				*x*	*x*								
Phasianus colchicus	Common pheasant			*x*			*x*	*x*								
Phylloscopus bonelli	Western Bonelli's warbler										*x*	*x*				*x*
Hippolais polyglotta	Melodious warbler	*x*	*x*													
Cuculus canorus	Common cuckoo	*x*	*x*													
Sitta europaea	Eurasian nuthatch	*x*				*x*										
Oriolus oriolus	Eurasian golden oriole	*x*								*x*						
Alauda arvensis	Eurasian skylark		*x*	*x*												
Alcedo atthis	Common kingfisher			*x*	*x*											
Phalacrocorax carbo	Great cormorant			*x*		*x*										
Pica pica	Eurasian magpie					*x*			*x*							
Certhia brachydactyla	Short-toed treecreeper	*x*														
Aix sponsa	Wood duck	*x*														
Parus palustris	Marsh tit	*x*														

Regulus ignicapillus	Common firecrest	*x*														
Ficedula hypoleuca	European pied flycatcher		*x*													
Motacilla cinerea	Grey wagtail		*x*													
Phoenicurus ochruros	Black redstart		*x*													
Phylloscopus trochilus	Willow warbler		*x*													
Tachymarptis melba	Alpine swift		*x*													
Acrocephalus arundinaceus	Great reed warbler			*x*												
Fulica atra	Eurasian coot			*x*												
Lanius collurio	Red-backed shrike			*x*												
Acrocephalus scirpaceus	Eurasian reed warbler			*x*												
Falco subbuteo	Eurasian hobby			*x*												
Ixobrychus minutus	Little bittern			*x*												
Tachybaptus ruficollis	Little grebe			*x*												
Podiceps cristatus	Great crested grebe			*x*												
Buteo buteo	Common buzzard				*x*											
Streptopelia turtur	European turtle dove						*x*									
Melopsittacus undulatus	Budgerigar														*x*	

Table 4. Coefficients of environmental variables represented in RDA analysis of the relationships between birds occurrence and environmental features at the landscape scale. Grasslands habitat, buildings (‘Other land covers’) and presence of water bodies have the strongest influence on the first component of RDA, while the variable distance from the center and the age of the park mainly explain the second RDA component. Grassland = surface covered by grassland (Log); Other land covers = surface covered by paving or buildings (Log); Water = presence of water bodies; Age = years from the establishment of the park; Distance downtown = distance from downtown; Distance other park = distance from the nearest urban park; Built surrounding = built surface in a buffer of 1 km surrounding the park.

Variable	**RDA1**	**RDA2**
Built surrounding	0.34	-0.42
Distance downtown	-0.35	**0.68**
Distance other park	-0.36	-0.38
Age	0.21	**-0.56**
Water	**-0.72**	0.13
Grassland	**-0.87**	0.22
Other land covers	**-0.94**	0.13

Table 5. Species correlations with the RDA scores extracted by the RDA analysis on the relationships between bird species presence and environmental features at local scale.

Species	**$RDA_{bird}1$**	**$RDA_{bird}2$**	**Species**	**$RDA_{bird}1$**	**$RDA_{bird}2$**
Ardea cinerea	0.08	0.12	*Psittacula krameri*	0.08	0.01
Delichon urbica	-0.00	0.01	*Passer italiae*	0.38	-0.21
Sylvia atricapilla	-0.17	0.31	*Erithacus rubecula*	-0.12	0.03
Parus major	-0.12	-0.09	*Sitta europaea*	-0.26	-0.00
Parus caeruleus	-0.22	-0.03	*Dendrocopos major*	-0.23	0.00
Aegithalos caudatus	-0.04	0.02	*Picus viridis*	-0.19	-0.04
Phoenicurus phoenicurus	0.00	-0.04	*Columba livia*	0.24	-0.06
Columba palumbus	0.01	0.08	*Hirundo rustica*	0.49	0.04
Erithacus rubecula	-0.07	-0.10	*Apus apus*	0.12	0.02
Fringilla coelebs	-0.02	0.01	*Sturnus vulgaris*	0.42	0.06
Gallinula chloropus	0.06	0.40	*Corvus monedula*	0.02	0.01
Anas platyrhynchos	0.10	0.33	*Streptopelia decaocto*	0.05	-0.01
Falco tinnunculus	0.01	-0.02	*Luscinia megarhynchos*	0.02	0.25
Turdus merula	-0.06	0.08	*Serinus serinus*	0.15	-0.01

Table 6. Coefficients of environmental variables represented in RDA analysis of the relationships between bird presence and environmental features at local scale. Woodland cover = surface covered by trees; Grassland cover = surface covered by grassland; Other land covers = surface covered by paving or buildings; Water = presence of water bodies; Age = years from the establishment of the park; Border distance = minimum distance from the park border.

Variable	**$RDA_{bird}1$**	**$RDA_{bird}2$**
Woodland cover	**-0.89**	0.19
Grassland cover	0.61	-0.05
Other land covers	0.31	-0.18
Water	0.19	**0.87**
Border distance	-0.40	-0.06

FIGURES

Figure 1. Study area.

Figure 2. Frequencies of observation of the most common species (shown here are the species detected in more than 20% of the sampling points considering both surveys) and total number of individuals observed (above the columns is the sum of the individuals observed in the first and second surveys).

Figure 3. Constrained redundancy analysis showing the relationship between bird species richness and abundance and the environmental variables tested. Constraining variables are represented by black arrows. Richness = number of bird species; Abundance = number of individuals; Log grassland = surface covered by grassland (Log); Log other coverings = surface covered by paving or buildings (Log); Water = presence of water bodies; Age = years from the establishment of the park; Distance downtown = distance from downtown; Distance other park = distance from the nearest urban park; Built surrounding = built surface in a buffer of 1 km surrounding the park.

Figure 4. Constrained redundancy analysis showing the relationship between 28 species and environmental variables tested. Constraining variables are represented by blue arrows. Woodland cover = surface covered by trees; Grassland cover = surface covered by grassland; Other land covers = surface covered by paving or buildings; Water = presence of water bodies; Border distance = distance from the park border. Constraining variables are represented by blue arrows. Group C* = central group composed of the following species: *S. serinus, S. decaocto, A. caudatus, E. rubecula, A. apus* , *F. coelebs*, *C. monedula*, *P. krameri*, *D. urbica* and F. *tinnunculus.*

Figure 5. Pictures taken from two different types of parks in our study area: (a) a typical forested environment in a peri-urban park (Parco Nord) and (b) large isolated trees in a central park (Parco Solari).