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Primary productivity in cities and their influence over subtropical bird assemblages

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ABSTRACT

Changes in ecosystem structure caused by urbanization produce a reduction in photosynthetic productivity, which can lead to reductions in resource availability for birds. Here, we analyzed the relation between photosynthetic productivity and bird assemblages in a subtropical urban ecosystem, in North-Western Argentina. We used Generalized Linear Models to assess the responses of bird abundance, richness and diversity to photosynthetic productivity, vegetation cover and distance to main natural forest. We found higher bird richness and diversity with increasing photosynthetic productivity and vegetation cover, and with decreasing distance to forests; while total bird abundance was positively related to vegetation cover. When we classified bird species in different groups, based on their use of the environment, we found that species adapted to urban environments were more dependent on photosynthetic productivity, while species related to native forests were more dependent on the distance to source forests. Understanding the factors that affect bird assemblages in cities is important for the development of strategies for urban planning and conservation.

1. Introduction

Urban areas have significantly expanded in the last decades, becoming one of the most important and permanent components of global land cover change (Hepinstall et al., 2008; Pickett et al., 2011; Wu 2014). Even though cities occupy less than 3% of the land area (Alberti 2010; Fengsong et al., 2013) more than 50% of human population is currently concentrated in cities (Wu 2014) and this proportion is expected to increase in the future. This implies a strong pressure over natural resources, which affects ecosystems and biodiversity (Croci et al., 2008; Vitousek et al., 2008). The expansion and densification of urban areas involve the replacement of natural and semi-natural areas (e.g., agriculture) by impervious surfaces (roads, buildings; Alberti, 2008). As a result, the main patches of vegetation are clumped in green areas surrounded by a human built matrix and minor vegetation components are interspersed in this matrix (Marzluff and Ewing, 2001). These spatial structure of vegetation affect the functioning and provision of its ecological services, with significant consequences for both, local biodiversity and human well-being (Alberti et al., 2008; Vitousek et al., 2008; Niemela et al., 2010; Wu 2013; Alberti 2015).

One of the main effects of urban expansion over ecosystems is the modification of spatial and temporal patterns of net primary productivity (from now on, productivity; Gallo et al., 1993; Figueirola and Mazzeo, 1998; White et al., 2002; Imhoff et al., 2004; Zhang et al., 2004; Faeth et al., 2005; Shochat et al., 2006; Buyantuyev and Wu 2009; Fengsong et al., 2013; Wu 2013). Since productivity is directly linked to photosynthetic activity, it is a good indicator of ecosystem functioning, and it plays an important role as resource supply (i.e. habitat and food) for different animal groups (Loreau et al., 2001; Hawkins et al., 2003; Morales-Castilla et al., 2012; Alberti 2015). Even though urban ecology studies increased significantly during the last decades in Latin America (Faggi and Perepelizin, 2006; et al., 2010; Villegas and Garitano-Zavala, 2010; Bellocq et al., 2011; Ortega-Álvarez and MacGregor-Fors, 2011; Leveau and Leveau, 2012; Reis et al., 2012), the relation between productivity and other organisms in urban settlements is unclear. Birds are sensitive species which respond to environmental shifts by moving rapidly to adequate sites so they constitute a good indicator of the functioning and ecological conditions of the environment (Jokimaki and Fernández-Juricic, 2001; Croci et al., 2008). Moreover, human beings appraise the presence of birds in urban areas due to their cultural, emotional and recreational values, (among other ecological services that they provide; Sekercioglu 2006; Whelan et al., 2008; Dearborn and Kark 2009; Belaire et al., 2015; Tryjanowski et al., 2015). Since bird species depend on vegetation for food and shelter supply (Reis et al., 2012), they are an appropriate group for

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assessing interactions with productivity as a surrogate of resource availability associated to vegetation.

The spatial arrangement of vegetation-related resources in urban landscapes is determined by human activity (Faeth et al., 2005; Alberti 2015). Assessing the spatial association between vegetation productivity and bird biodiversity will permit understanding the functioning of urban ecosystems, and it can inform urban planning strategies. Despite the negative effects of urban expansion over biodiversity, particularly for birds (i.e. reduction of biodiversity, homogenization; Blair and Johnson, 2008; Marzluff, 2008; Vitousek et al., 2008; Morelli et al., 2016) some species or ecological groups tolerate and adapt or even thrive in these environments (Shochat et al., 2006; Williams et al., 2009). While certain bird species may become threatened, others may benefit from urbanization processes, when some habitat conditions are preserved or new ones are created (Alberti et al., 2008; Hepinstall et al., 2008; Haedo et al., 2010; Bellocq et al., 2011; Reis et al., 2012). As a consequence, species assemblages in urban settlements may be composed by a mixture of native species which remain from the original landscape (specialists or avoiders); species which expand their distribution area, favoured by the environmental modifications (generalists or tolerant species), and new exotic species which thrive in urban systems (Donnelly and Marzluff, 2006; Alberti et al., 2008; Minor and Urban, 2010).

The main objective of this study is to assess the responses of bird assemblages to spatial patterns of urban vegetation productivity and to assess the effect of different environmental variables of urban structures which might influence bird assemblages. In order to achieve this, we analysed whether productivity, urban cover (percentage of built-up area), vegetation cover and distance to native forest explained the abundance, richness and diversity of avian assemblages. We also examined the responses of three ecological groups of birds (classified according to their use of the environment in: birds of modified landscapes ML; birds of edges and secondary forests ESF; and birds of native Yungas mature forests YMF) to the same set of variables. Given the particular characteristics of these ecological groups, their use can provide information to understand varying responses to urban environmental changes, which would remain hidden if birds were considered as a single homogeneous group.

We expect a positive association between productivity (i.e. indicator of resource availability) and the number of individuals (abundance), species richness and diversity. We expect to find a similar association with vegetation cover, but a negative association with urban cover. Finally, distance to native forest might negatively relate to species richness and diversity, due to a source-sink effect. At the level of ecological groups, we expect that abundance and richness of ML and ESF birds will be positively associated with productivity and vegetation cover, since these groups prioritize sites with high food abundance, nesting and protection sites within the urban matrix. Birds of YMF will respond to vegetation cover and to the distance to native forests, due to their high dependence on the environmental characteristics provided by native vegetation. To assess these predictions, we 1) reconstructed the primary productivity of the system, and determined the percentage of urban/vegetation cover and distance to the main native forest; 2) estimated the abundance, richness and diversity of bird species; classifying bird species in the three ecological groups mentioned before (ML, ESF and YMF); and 3) tested different models to analyse the relationship between environmental variables and bird assemblages.

2. Methods

2.1. Study area

We carried out this study in a metropolitan area of South America: Gran San Miguel de Tucumán (GSMT) 26°49′ S and 65°13′ W (Fig. 1 A), in Tucumán province. This area constitutes the major urban ecosystem of NW Argentina, with more than 1.4 million people living in the foothills of sub-Andean mountains. The two main cities, San Miguel de Tucumán (SMT) and Yerba Buena (YB) represent an east-west urbanization gradient, with the Salí river towards the east end, and Sierra de San Javier (SSJ) mountains at the west (Fig. 1 B −C). SSJ is a natural reserve of about 14000 has of well conserved Yungas forest. Rises in human population and rapid urban growth have promoted the expansion of the urban matrix (3400 ha between 1986 and 2006; Gutiérrez Angonese 2010), exerting strong pressure towards natural areas such as the foothills of the Yungas forests mountain. This configuration is representative of urban and peri-urban landscapes of other foothill cities of Latin America, such as NW Argentina (i.e. Salta and Jujuy) Bolivia, Colombia and Mexico (Grau, 2010; Parés-Ramos et al., 2013; Gioia et al., 2014; Angonese and Grau, 2014). Climate is subtropical with a marked seasonality (hot-wet summers and cool-dry winters), with an annual mean temperature of 18 °C and 1000 mm of annual precipitation, mainly concentrated in summer (December-March; Brown et al., 2005). Natural vegetation corresponds to Yungas phytogeographic province (Cabrera, 1976). In peri-urban areas, Yungas forests in the lowlands have been totally replaced by agriculture and urbanization, while forests located at the mountainous area of SSJ are well preserved (Grau et al., 2010).

2.1.1. Bird surveys

To quantify the abundance, richness and diversity of bird assemblages, we performed point-count surveys (Ralph et al., 1995). Surveys took place from October to December of two consecutive years (2010 and 2011). These months correspond to austral spring, when breeding activity of most species in the region occur (Auer et al., 2007; Lomáscolo et al., 2010; Blendinger et al., 2015). We traced a regular grid of 50 sites, placed 750 m from each other (Fig. 1C). In each site, we performed two bird surveys per year separated from each other by 250 m. Each survey consisted in recording all species seen or heard from a fixed point during 8 min (making a total of 16 min in each sampling site). We used 8 min per survey point instead of the 5 min suggested by Ralph et al., (1995) to increase the probability of capturing infrequently encountered species in highly disturbed areas (e.g. traffic, pedestrians). However, most bird species were detected within five-minute point counts (Lynch 1995). Although some distant individuals were recorded, only those detected at less than 50 m from the survey point were considered in the analyses to reduce the differential detectability due to the spatial structure of plants and buildings associated to urban gradients. All bird surveys were conducted by one single observer (HJ) between 6 and 9 am (the time of highest bird activity) on non-rainy and windless days (Ralph et al., 1995). Birds flying were not recorded except those that made use of airspace for food, such as insectivorous species. In each case, the cumulative data was used for each counting site.

Bird species were classified in three ecological groups according to the use of Yungas forest and associated transformed environments following the classification of Blendinger and Álvarez (Blendinger and Álvarez, 2009). However, given that this classification takes into account only Yungas native birds, we adapted it to an urban context by including two synanthropic species (see below). Species were classified in the following groups: species of Yungas mature forest (YMF), which occupy forests with a complex structure; edge and secondary forest species (ESF), which inhabit edges and young or secondary Yungas forests; and modified landscape species (ML), which inhabit highly modified and disturbed landscapes, such as urban settlements, generally avoiding mature forests. Two exotic species frequently observed in cities (*Passer domesticus* and *Columba livia*), were added to this group, since they exhibit higher affinity to these landscapes. In each site we estimated abundance and species richness for the entire bird assemblage by direct counting and we estimated its biodiversity using the Shannon-Wiener diversity index (H'). We also estimated the species richness and abundance for each of the ecological groups.