Chapter 5
‘Green’ or ‘Gray’? Infrastructure and Bird Ecology in Urban Latin America

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Abstract Urban systems are highly complex and heterogeneous, comprised basically by two types of infrastructure. On the one hand, ‘gray’ infrastructure includes all artificial structures and buildings, often impervious, and their components. On the other hand, ‘green’ infrastructure is conformed by all remaining and planted vegetation within an urban center. In this chapter, we reviewed the global response of birds to these two main types of urban infrastructures, and then focus on urban Latin America. Few studies have focused on urban ‘gray’ infrastructure, with many of them biased toward its close relationships with exotic, invasive, and/or generalist bird species. On the contrary, many studies have been performed focusing on the ‘green’ infrastructure of cities. Due to the amount of knowledge regarding ‘green’ infrastructure, we approached it considering greenspace location, size, heterogeneity, vegetation traits, management, and human activities. Our review shows that there is a pressing need for studies that consider ‘gray’ comparison baselines when assessing the effect of urbanization on birds. Also, studies need to focus on the ‘gray’ matrix in which urban greenspaces are embedded, as we have little to null information regarding it, and it is essential to plan healthier and sustainable cities. Another important gap that needs to be bridged is the role that exotic plants have not only on bird ecology, but also on the ecology of cities. Finally, we suggest to include other conditions that, although are not as representative in all urban centers, are highly important for birds and other wildlife groups. Specifically, we consider it

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crucial to join efforts on studying water bodies ('blue' infrastructure) and wastelands ('brown' infrastructure) to increase our understanding of the role that these urban components play on bird conservation in urban Latin America.

Keywords Citywide • Gray infrastructure • Green infrastructure • Streetscapes • Urban ecology

5.1 Urban Infrastructure

Urban centers are unique systems within landscapes, characterized by high densities of built-up and hard relatively impervious surfaces (Eldredge and Horenstein 2014). Throughout their territory, cities are comprised by complex components pertaining to different land-uses, creating highly heterogeneous systems (Alberti 2005). In terms of infrastructure, urban centers are mainly comprised by built-up surfaces (referred to as 'gray' infrastructure hereafter) and areas with vegetation (referred to as 'green' infrastructure hereafter). The former includes buildings, thoroughfares, and other types of constructions and related components (e.g., poles, cables, antennas, rods, air-conditioning units). The latter includes the sum of all vegetation components within urban settlements, ranging from large native vegetation patches or remnants to isolated street trees (e.g., parks, private gardens, cemeteries, median-strip trees, agricultural fields; Chamberlain et al. 2004; Andersson et al. 2007; Carbó-Ramírez and Zuria 2011; Strohbach et al. 2013). In this chapter, we first summarize our knowledge on the general relationships between 'gray' and 'green' infrastructures with birds, then focus on the literature for Latin America, and conclude highlighting research gaps and future directions.

5.2 Global Role of 'Gray' and 'Green' Infrastructure on Birds

'Gray' infrastructure is highly diverse and complex, reflecting the history and ongoing cultural and economic processes of a city (Seto et al. 2011). This type of infrastructure can be categorized in low, medium, and high densities in a variety of land-uses (e.g., residential, commercial, industrial; MacGregor-Fors 2011). The proportion of 'gray' infrastructure has been commonly used as a proxy to describe the degree of urban development in urban ecology studies (McDonnell et al. 1997; McKinney 2008; Aronson et al. 2014). In fact, an important number of avian ecology studies in urban areas have focused on urbanization intensity gradients (also referred to as urban–rural, urban–wildland, urban–ex-urban gradients; McDonnell and Hahs 2008).

'Gray' infrastructure generally represents a limitation for birds. As reviewed and discussed by Delgado-V and Santiago-Alarcon (Chap. 7), there are numerous urban-

related threats to birds, among which several are related to the built-up structures and their components (e.g., collisions with windows and power lines). Yet, previous literature reviews have shown the complexity of the response of birds throughout urbanization gradients, often driving depauperated communities toward the more urban end, mainly comprised by a set of bird species able to dwell, and even thrive, in urban areas (Croci et al. 2008; McDonnell and Hahs 2008; McKinney 2008; Puga-Caballero et al. 2014). Given the nature of urban areas, with high extensions of impervious surfaces and a different array of components, resources, and hazards, birds have shown important acclimation and adaptive responses in these systems (Emlen 1974; McDonnell and Hahs 2015; Chap. 6). Many examples have been recorded in the literature, such as raptors using artificial substrates for nesting (e.g., buildings, bridges, power lines, transmission and communication towers; Chace and Walsh 2006), hummingbirds nesting on open-sky cables (Escobar-Ibáñez and MacGregor-Fors 2015), and parakeets nesting in air-conditioning units (Souza 2016; Chap. 8).

Several studies have shown how urban birds are related with urban 'gray' infrastructure. In a pioneer study, Emlen (1974) underlined the role of house tops and their components (e.g., air-conditioning systems, antennas) as attractive resting and perching sites. The style, density, height, and heterogeneity of buildings have also been shown to be relevant factors for urban birds, with 'ornate older buildings' providing potential nesting and roosting sites, and dense tall buildings related to higher bird abundances, mainly driven by generalist 'urban-dwelling' species (also referred in the literature as 'urban-exploiters'; DeGraaf and Wentworh 1986; Sacchi et al. 2002; MacGregor-Fors et al. 2012; Pellissier et al. 2012).

Although some bird species can benefit from urban 'gray' infrastructure, the 'green' component is crucial for the establishment and permanence of native bird communities in urban systems due to the wide range of resources they provide (Hadidian et al. 1997; Tratalos et al. 2007; MacGregor-Fors and Schondube 2011). Urban 'green' infrastructure is often embedded within the 'gray' one, being isolated at different spatial scales (Davies and Glick 1978; Fernández-Juricic and Jokimäki 2001). When major greenspaces are not connected among them, there are important components of the urban 'green' infrastructure that play crucial roles as ecological connectors (Sodhi et al. 1999; Sandstrom et al. 2006; Evans et al. 2009; MacGregor-Fors et al. 2009).

Urban 'green' infrastructure is mainly determined by human decisions and includes a wide range of different components, such as urban parks, plazas, gardens, lawns, agricultural space, tree-lined avenues and leafy boulevards, natural ecosystem remnants, nature reserves, and cemeteries (Forrest and Konijnendijk 2005; Nowak and Greenfield 2012; Escobedo et al. 2015; Konijnendijk 2016). With urbanization, preexistent conditions are replaced by artificial structures and a mix of native and exotic vegetation, mainly ornamental, which have great adaptability to urban conditions. Many plant species that grow in reference vegetation communities do not look 'attractive' for people and are often perceived to be associated with disservices (e.g., accidents, damages on the 'gray' infrastructure; Gómez-Baggethun and Barton 2013). In urban Latin America, the main factor determining the distribution of urban vegetation seems to be related with socioeconomic level, being scarcer

in the low-income sectors incurring in environmental justice issues (Pedlowski et al. 2002; Escobedo et al. 2006; Vázques-Fuentes 2008).

Several traits of the urban 'green' infrastructure have been related with bird diversity, often focused on greenspaces, although few studies focus on street trees (e.g., Donovan and Butry 2010; Carbó-Ramírez and Zuria 2011; Avolio et al. 2015). Despite the findings of different studies are diverse in the type, strength, and direction of such relationships, many vegetation traits have been shown to drive the diversity and composition of urban birds, among which greenspace size, vegetation complexity, and species origin head the list (Nuorteva 1971; DeGraaf and Wentworth 1986; Thompson 1993; Jokimäki et al. 1996; Jokimäki and Suhonen 1998; Fernández-Juricic and Jokimäki 2001; Chamberlain et al. 2007; Jim and Chen 2008, 2009; Ortega-Álvarez and MacGregor-Fors 2009; Caula et al. 2010, 2013).

5.3 Role of 'Gray' and 'Green' Infrastructure on Birds in Latin America

In this section, we review a substantial sample of the literature focused on the documented relationships between both 'gray' and 'green' infrastructures and birds in urban Latin America. For this, we performed an intensive search for published studies in Web of Science platform (www.webofknowledge.com), several other databases (i.e., Google Scholar, Scopus, Science Direct, PubMed), as well as regional journals and theses, using the following keywords: 'urban', 'bird', and 'ecology' in both Spanish and English. Additionally, we searched for publications in the references of the retrieved publications, especially literature reviews. As a result of our search, we gathered a total of 90 studies conducted in 14 Latin American countries.

It is noteworthy that both 'gray' and 'green' infrastructures in urban Latin America are the products of a transcultural process highly influenced by Western colonization, excluding preexisting natural landscapes and focused on European traditions (Faggi and Ignatieva 2009). Currently, Latin American cities are compact, with high population densities and highly unequal socioeconomically and environmentally (Ingram and Carroll 1981; Psacharopoulos et al. 1995; Pauchard and Barbosa 2013; Escobedo et al. 2015). The latter shows the complexity of the context in which urban ecology is done in the region, with both 'gray' and 'green' infrastructures often separated from each other, with the latter mostly focused on human use, rather than to safeguard ecological processes or provide habitat for wildlife species.

5.3.1 'Gray' Infrastructure

Despite the fact that an important proportion of studies focused on the drivers of avian assemblage in urban Latin America has studied vegetation traits, few have addressed the 'gray' components of cities. Some of them have focused on

bird communities and others on particular species that are, in general, positively related to 'gray' components. Regarding the community level, several studies have found relationships between urbanization intensity and bird species richness and abundance (see Chap. 3 for a thorough review and analysis), with highly urbanized sites sheltering less bird species but a higher number of individuals of a few urban-dwelling species (also known as 'urban exploiters'; see Blair 1996 and Fischer et al. 2015; Fig. 5.1). Some of these studies have related buildings (and their traits; e.g., height), as well as built cover, as some of the predictor variables of such decreases (Leveau and Leveau 2004; Rivera-Gutierrez 2006; Torres Pinheiro et al. 2008; Villegas and Garitano-Zavala 2010; MacGregor-Fors and Schondube 2011; Reis et al. 2012; Toledo et al. 2012; Sanz and Caula 2015). Another topic that has not received enough attention is the role of specific variables related to the urban 'gray' infrastructure. One example of such types of studies is that of MacGregor-Fors and Schondube (2011) evaluated the relationship between bird richness and abundance with 33 variables in Morelia (Mexico), of which 14 described the 'gray' infrastructure (i.e., built cover, number of electric and telephone poles, cables, lamp poles, niches, balconies, lightning rods, antennas, exposed construction rods, maximum and minimum building heights, number of windows, number of street doors). Results of this study show that highly abundant bird species (i.e., House Sparrow—*Passer domesticus*, Barn Swallow—*Hirundo rustica*, Rock Pigeon—*Columba livia*, Inca Dove—*Columbina inca*, Great-tailed Grackle—*Quiscalus mexicanus*) were positively related with cables and lightning rods, while their richness was positively

Fig. 5.1 Rock Pigeon (*Columba livia*), one of the most representative urban-related species across the globe (Photo: Ian MacGregor-Fors)

associated with building height. On the other hand, the number of moderately abundant species was negatively related with built cover, and number of electric and telephone poles. Finally, rare bird species richness was positively linked to number of electric and telephone poles, while their abundances were negatively related to the number of lamp poles. This does not only show the complexity of the relationships between bird assemblage and the 'gray' infrastructure of cities, but also shows that several specific variables are of importance for birds.

In relation to the few urban 'dwelling', often exploiter, species that are mostly generalist and/or exotic, studies have shown that their numbers increase importantly in urban scenarios, both in large urban centers (e.g., Mexico City, Buenos Aires, Bogotá, São Paulo, Rio de Janeiro, Valencia–Chile) and smaller ones (Morelia, Mar del Plata, Pelotas, Taubaté) (Ruszczyk et al. 1987; Leveau and Leveau 2004; Faggi and Perepelezin 2006; Ortega-Álvarez and MacGregor-Fors 2009; Perepelizin and Faggi 2009; MacGregor-Fors et al. 2010; Fontana et al. 2011; Toledo et al. 2012; Sacco et al. 2013; Fig. 5.2). Two widely distributed examples of the latter are the Rock Pigeon and House Sparrow (Aronson et al. 2014; Figs. 5.1 and 5.3). These species, native to Eurasia and northern Africa, are both frequent and often hyperabundant in many Latin American cities (e.g., Carbó-Ramírez and Zuria 2011; Fontana et al. 2011; Leveau 2013). Novel sites, such as derelict and abandoned buildings, are used by these species and other generalist urban 'dwellers' for perch-

Fig. 5.2 Food provisioning to Rock Pigeons (*Columba livia*) by people in Heredia (Costa Rica) (Photo: Ian MacGregor-Fors)

Fig. 5.3 House Sparrow (*Passer domesticus*) perched on a house fence in Ajijic, Jalisco (Mexico) (Photo: Juan F. Escobar-Ibáñez)

ing, roosting, and even nesting (MacGregor-Fors et al. 2010; Perepelizin et al. 2014; Villalba-Sánchez et al. 2015). Their presence and numbers are often used as indicators of highly urbanized and busy areas (de Vasconcelos 1999; Amâncio et al. 2008; Perepelizin and Faggi 2009; Hernández et al. 2010; MacGregor-Fors and Schondube 2011; Londoño-Betancourth 2013). Additionally, there is evidence that some of these species can have detrimental ecological effects, as well as human health issues, with the House Sparrow being related to declines in native bird species richness (MacGregor-Fors et al. 2010; Ortega-Álvarez and MacGregor-Fors 2010) and Rock Pigeons being related with diseases and vectors (de Sousa et al. 2010; Ortiz et al. 2015; Pérez-García et al. 2015).

5.3.2 'Green' Infrastructure

Although many urban greenspaces are mostly determined by human decisions, their presence and traits have been shown to drive the avian species that they can shelter (Leveau and Leveau 2004; Faggi and Perepelizin 2006; Caula et al. 2010; Sanz and Caula 2015). In agreement with studies from other regions across the globe, results show that Latin American urban greenspaces shelter a higher number of bird species when compared with more urbanized sites. Yet, the mere existence of urban greenspaces does not necessarily ensure potential habitats for birds with regional conditions often playing a crucial role. Below, we summarize the results of studies focused on the relationship between greenspace traits (i.e., location, size, heterogeneity, vegetation characteristics, management, and disturbances) and bird ecology in urban Latin America.

5.3.2.1 Greenspace Location

The location of greenspaces within Latin American cities has been identified as one of the main drivers of bird community diversity (Galina and Gimenes 2006). Although the effect of location of greenspaces greatly depends on the size of cities, the semipermeability process that occurs in peri-urban areas, representing an important ecological interaction zone that differs greatly from 'intra-urban' areas, limits the presence of some species that are able to dwell under given urban conditions, including greenspaces (Garaffa et al. 2009; MacGregor-Fors 2010; MacGregor-Fors and Ortega-Álvarez 2011; Puga-Caballero et al. 2014).

In southwestern Mexico City, MacGregor-Fors and Ortega-Álvarez (2011) showed that bird species richness decreased with increasing distance from a preserve located in the boundary of the city in greenspaces of similar size. Contrarily, bird densities increased, with a dramatic peak in the farthest greenspace from the border of the city. Also, taxonomic similarity decreased almost linearly in relation to the assemblage from the reference preserve. Accordingly, Urquiza and Mella (2002) recorded a higher number of bird species in greenspaces of Santiago (Chile), as the distance to the premountain Andes decreased.

A recent study performed in Xalapa, a small-sized Mexican city, showed that when comparing greenspaces of different sizes and locations within the same urban continuum, bird species richness was highest in the largest and outermost greenspace, followed by an array of medium-sized to small-sized greenspaces with different disturbance rates, and least richness in a small highly disturbed greenspace (MacGregor-Fors et al. 2016). Regarding species composition, this study shows that vegetation structure plays a more important role than size does (Chap. 3). The latter agrees with the findings of previous studies that have addressed the value of small urban greenspaces for birds. For example, Carbó-Ramírez and Zuria (2011), based on their study performed in Pachuca, a medium-sized city located in a Mexican arid-scrub region, highlight the importance of small greenspaces and the need to expand their vegetation cover to favor both resident and migrant bird species. Also, studies from Brazil and Costa Rica (Stiles 1990; Mendonça-Lima and Fontana 2000; Guix 2007) have suggested that small-to-medium-sized greenspaces, such as neighborhood parks and private gardens, can play an important role as 'habitat islands' for birds to breed or use as stopover sites during migration.

5.3.2.2 Greenspace Size and Heterogeneity

As occurs worldwide, studies focused on the relationship between urban birds and greenspace size are common in Latin America (see Chace and Walsh 2006; Evans et al. 2009; MacGregor-Fors et al. 2009; Marzluff 2016 and references therein). In general, results of these studies reinforce the existence of positive species–area relationships, suggesting that larger areas have conditions that can support more avian species, as described in the island biogeography theory (MacArthur and Wilson 1967; Urquiza and Mella 2002; Garitano-Zavala and Gismondi 2003; Faggi and

Perepelizin 2006; Carbó-Ramírez and Zuria 2011). Yet, large greenspaces with higher bird diversity are often related with heterogeneous environmental conditions, involving plant diversity and physiognomic complexity, low human disturbance rates, and management regimes, among others (MacGregor-Fors et al. 2016). However, some studies performed in Latin America have not found positive species–area relationships in urban greenspaces. For example, Malagamba-Rubio et al. (2013) did not find statistical differences in bird species richness between small (0.27–3.85 ha), medium (8.63–12 ha), and large (22.04 ha) greenspaces of Querétaro, a semi-arid Mexican city. This suggests that greenspace size per se does not necessarily determine the number of bird species that can dwell within a given urban greenspace. Due to the unfavorable conditions that highly urbanized sites often pose to many bird species, small parks, squares, private gardens, median strips, and even isolated street trees may play crucial roles for birds able to use their resources and survive their hazards (Pineda-López et al. 2010; Carbó-Ramírez and Zuria 2011); however, these spaces do not necessarily ensure the maintenance of viable populations (González-Oreja et al. 2007).

Regarding greenspace heterogeneity, several studies have shown that, regardless of bird species richness, species composition can differ in contrasting conditions of vegetation heterogeneity (Manhães and Loures-Ribeiro 2005; Gómez 2006; Lopes and Anjos 2006; Caula et al. 2010). The latter does not only apply for single greenspaces, but also for urban greenspace networks, where the contribution to the total diversity increases when the array of greenspaces is diverse in terms of size, heterogeneity, vegetation traits, management, and human disturbances (Faggi and Perepelizin 2006; Cursach and Rau 2008; MacGregor-Fors et al. 2016). Caula et al. (2010), in Valencia City (Venezuela), compared two close areas of the same size embedded within the same urban matrix, but differing in complexity: the first area was highly heterogeneous, while the second one was simplified by human management. Results of this study show that bird richness was two times higher in the first area, sheltering species considered as urban 'avoiders' (e.g., Red Rumped Woodpecker—*Veniliornis kirkii*, Lineated Woodpecker—*Dryocopus lineatus*, Boat-billed Heron—*Cochlearius cochlearius,* Green Kingfisher—*Chloroceryle americana*). This study highlights the importance of native remnant areas that preserved vegetation heterogeneity for urban bird conservation. Similar findings have been reported comparing municipal greenspaces maintained for recreational purposes with unmaintained greenspaces in the city of Valdivia, in Southern Chile (Silva et al. 2015).

5.3.2.3 Greenspace Vegetation Traits

Greenspaces in urban Latin America are highly diverse in origin, type, and traits. A first classification of such diversity has to do with their use. Commonly, urban greenspaces are categorized as conservation remnants, parks, university campuses, sports fields, gardens, median strips, among others. Although many urban bird ecological studies have been carried out in urban parks, the amount of studies

developed in university campuses is noteworthy (e.g., Escobar and Salomón 1983; MacGregor-Fors 2008; Pozo and Cisneros 2014). Although greenspace type can be a proxy of human use and management, studies have focused on addressing the role that specific greenspace variables have on urban bird communities.

Vegetation traits have been identified as the local-scale greenspace variables that drive urban bird communities. Among plants, trees have also shown to play crucial roles for bird diversity in greenspaces, and among tree traits, their cover, diversity, and size (measured as height and/or diameter at breast height) have shown to be positively related with bird diversity (e.g., Naranjo and Estela 1999; Garitano-Zavala and Gismondi 2003; MacGregor-Fors 2008). Such local-scale vegetation variables have often shown to override the importance of greenspace size and location—mainly isolation from the city border—in urban Latin America (Urquiza and Mella 2002; Toledo et al. 2012). Yet, there is an important bias toward urban tree planting, rather than including native vegetation components to their greenspaces. A study performed by Leveau and Leveau (2004) shows that regions whose original systems lack trees (e.g., Argentinean Pampas) are mainly comprised by shrub and grass-related birds. Including urban greenspaces that differ from the original ecosystems, such as tree-based ones in arid regions, can attract different species to those present in the immediate species pool. The latter was recorded in the city of Pachuca, where eight species that had not been recorded in several years in arid tropical scrubs in and around the city were recorded in tree-based greenspaces (Carbó-Ramírez and Zuria 2011).

Another vegetation trait that has been controversial in urban Latin America is the role of species origin (namely native and exotic) on bird diversity (Fig. 5.4). Particularly for exotic vegetation, studies have shown both positive and negative relationships with bird diversity. For example, Noguera Chacón (2012) compared two greenspaces differing in size and vegetation origin in Quito (Ecuador), finding that the smaller one with native vegetation remnants had more than twice bird species richness than the larger one, which was mainly covered by gum and pine trees. In contrast, a larger number of birds were recorded in mixed native–exotic woodland of an heterogeneous greenspace of Mendoza (Argentina) when compared with a native scrubland (Gómez 2006). Other studies have shown scenarios under which exotic plants can attract bird species, most of which have been related with food provisioning. For instance, some exotic trees in Argentina (e.g., *Fraxinus* spp., *Liquidambar styraciflua, Ulmus procera, Ligustrum lucidum*) produce abundant seeds that attract native birds to cities. This is the case of the Green Ash (*Fraxinus pennsylvanica*), which has been related with the arrival and fairly commonness of the Hooded Siskin (*Spinus magellanicus*) in Buenos Aires, Argentina (Montaldo and Roitman 2000).

Exotic trees with nectar-rich flowers, such as Australian Silk Oaks (*Grevillea robusta*) in Guadalajara (Mexico), have also been found to attract both breeding and wintering bird species (MacGregor-Fors 2008). Fruit trees have also been recorded to attract birds in urban Latin America, which are widespread through cities and its greenspaces and provide important ecoservices (Dobbs et al. in rev). A study focused on fruit-eating birds in 11 large and medium-sized Brazilian cities found that many of the migratory species feed on exotic urban trees, mainly during winter, while others suggest that exotic trees represent year-round food resources for birds

Fig. 5.4 Greenspace located in peri-urban Bogotá (Colombia) with a sign promoting the protection of native vegetation (Photo: Juan F. Escobar-Ibáñez)

(Santos and Ragusa-Netto 2013; Oliveira et al. 2013). Although this could be considered as positive for birds, it is tricky (as generally occurs with exotic, potentially invasive, and invasive plant species; Vitousek et al. 1997; Corlett 2005). Birds could be important dispersers of nonnative plants in other human-modified systems, as well as native ecosystems, posing a potential ecological threat at different scales (Guix 1996, 2007; Montaldo and Roitman 2000). Also, a recently published study from São Carlos (Brazil) showed exotic tree abundance to be positively related with bird richness in its university campus, but note that native tree species were clearly underrepresented in the area (Lessi et al. 2016).

5.3.2.4 Greenspace Management and Human Activities

The way in which urban spaces are designed and managed can influence the birds that can inhabit them (Evans et al. 2009). In particular, vegetation management through mowing and pruning, among other human activities (e.g., path clearing, leaf sweeping, passing pedestrians, picnicking), can play crucial roles on the bird

diversity that urban greenspaces can shelter. Vegetation management practices regularly alter vegetation physiognomy, often decreasing its structural complexity and limiting the presence of specialist bird species (Leveau and Leveau 2004; Filloy et al. 2015). As noted earlier, Caula et al. (2003) compared two similar-sized greenspaces: a native vegetation remnant and a managed park, finding that bird species richness was twofold in the native remnant with many urban avoider species. However, open and disturbed areas in greenspaces do create novel areas of which some bird species take advantage. As outlined in two regional reviews that include Latin American cities, open-space insectivores and granivores have been highly successful in urban Latin America, often representing the predominant groups within its cities (Ortega-Álvarez and MacGregor-Fors 2011a, b).

Regarding human activities, several studies have negatively related recreational activities and disturbances, caused by pedestrians and vehicles, with avian diversity in Latin American cities. In the city of Valdivia (Chile), Silva et al. (2015) found that greenspaces with recreational purposes shelter less bird diversity than nonmanaged ones. Also, studies performed in two Mexican cities (i.e., Morelia, Mexico City) show negative relationships between passing cars and bird species richness (Ortega-Álvarez and MacGregor-Fors 2009; MacGregor-Fors et al. 2010, 2011). Moreover, passing pedestrians were identified as a predictor variable related to decreases in the abundance of several bird species in greenspaces of Mexico City (e.g., House Finch––*Haemorhous mexicanus*, Rufous-backed Robin—*Turdus rufopalliatus*). Leveau (2008) assessed the spatial and temporal variations of nectar feeding in Krantz Aloe (*Aloe arborescens*) by House Sparrows in a public garden and a recreational area along the coast of Mar del Plata (Argentina), finding that vehicle and pedestrian traffic were negatively related with sparrow visitation rates during weekends.

5.4 Opportunities and Future Research Needs

Research developed in urban Latin America has shown that birds respond to the urbanization process both similarly and differently to the patterns reported for other regions. Due to its high biodiversity and urbanization rates, Latin America is a clear target for conservation, for which evidence-based information of the effect of urbanization on birds is crucial (Ortega-Álvarez and MacGregor-Fors 2011a, b). One main gap regarding urban infrastructure, basically given by a greenspace survey bias, has to do with our knowledge of the ecological patterns and processes occurring in highly developed urbanized systems. In general, studies lack comparisons with the 'urban matrix', failing to set a baseline of its effect assessed through paired comparisons (see MacGregor-Fors and Schondube 2011; MacGregor-Fors et al. 2015, 2016). Such contrasts could shed important light on many ecological topics, ranging from community diversity drivers, to ethological, physiological, health, and even genetic assessments of the ways in which birds respond to urbanization, allowing to make the leap toward more mechanistic urban ecology studies (as suggested by Shochat et al. 2006 and McDonnell and Hahs 2013).

Also regarding the 'gray' infrastructure, there is an urgent need to understand the role of socioeconomics, as well as the types and intensities of 'gray' urban infrastructure (e.g., industrial, residential, commercial), with all its physical, ecological, and social components, not only as comparison standpoints for greenspaces, but also as the constant matrix of urban landscapes. Studies from across the globe, including Latin America (e.g., MacGregor-Fors and Shondube 2011; Reis et al. 2012; Chávez-Zichinelli et al. 2013; Silva et al. 2015), have shown that these variables may play imperative roles in determining the response of birds in urban systems. There are other variables of the 'gray' infrastructure that represent important threats to bird diversity, such as window strikes (see Chap. 7 for a thorough review on the topic); yet, our understanding of their effects in the region is woefully limited.

Although urban 'green' infrastructure has been widely studied in Latin America, there are important areas within the region for which we remain to ignore basic ecological information of cities. Thus, we urge ecologists to study their cities, including both 'gray' and 'green' infrastructures in the best of cases, and moving forward with the rest of well-studied regions to improve our understanding on their role as avian drivers in urban Latin America. Long-term studies considering the wide array of 'greenspaces' (including some widely ignored ones, such as abandoned lots) will allow the generated knowledge translate to action. One urgent topic regarding 'green' infrastructure has to do with the origin of the used plants within and across streetscapes. Although in some cases exotic plants have been shown to play a positive role for birds, there is evidence of contrasting results that have highlighted the potential threats of using them to populate urban areas. Thus, a major discussion must be established between ecologists, botanists, landscape architects, and local governments, to say the least, to tackle this highly complex issue.

Undoubtedly, studies have focused on the most conspicuous infrastructure of cities, namely the 'gray' and the 'green' ones, failing to include other conditions that have been widely ignored. For instance, water bodies ('blue' infrastructure) have been shown to be highly relevant bird diversity in urban Latin America (e.g., Bryce and Hughes 2002; Lugo 2002; Rosselli and Stiles 2012a, b; Pineda-López 2011; Lobo et al. 2015). Furthermore, there are other types of urban conditions that need to be cautiously analyzed if we aim to understand cities as systems, such as wastelands (e.g., deposits, treatment ponds). Due to their physical, ecological, and social relevance, as well as the uniqueness of their role in food provisioning and relationship with urban 'dweller' wildlife species, these sites, which we suggest to name 'brown' infrastructure, are interesting to be assessed using birds as bioindicators at many scales (Yorio and Giaccardi 2002; Novaes and Cintra 2015; Ortiz et al. 2015).

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