# Bird use of living walls in the city of Bogotá, Colombia

E. I. BOLHUIS[1]

[1]Facultad de Ciencias Ambientales, Universidad de Ciencias Aplicadas y Ambientales U.D.C.A., Campus Universitario Norte, Calle 222 No. 55 - 37, Bogotá, Colombia.

## ABSTRACT

A novel trend consisting in the installation of living walls can be evidenced in Bogotá, Colombia, a city characterized by its considerable avian diversity. Living walls have been recognized as a habitat improvement technique that may be valuable in the framework of reconciliation ecology, but very little is known about the habitat provision potential of living walls. Between 2013 and 2014, I studied bird use of living walls in the city of Bogotá. I selected a total of 13 living walls and described them in terms of height, area, and number of plant genera. At each of the sampling sites I performed a spatial analysis using GIS and measured the distance to the nearest park, forest reserve, ecological waterway corridor, and ecological road corridor; I also measured tree cover area within a 100 m radius. I recorded nesting activity in each of the living walls and carried out regular surveys on nine of these. My results indicate that only a few common urban species use living walls, mostly for foraging. A single species, the Rufous-collared Sparrow (*Zonotrichia capensis*), nested in living walls, discriminating in favor of the taller walls. I found a differential use of living walls, by bird species, in terms of wall zones used and activities performed in the walls. I found that plant composition is an important attribute of living walls as various plant genera provide feeding resources for hummingbirds. I also found a positive relationship between living wall area and sightings of the Great Thrush (*Turdus fuscater*), as well as a negative relationship between distance to ecological waterway corridors and hummingbird sightings. I conclude that living walls are of value to birds in Bogotá because they provide resources such as food, nesting sites and perching elements, and that living walls can indeed satisfy the conditions of reconciliation ecology. I also make a number of suggestions for generating value-added living walls for urban avifauna.

**Key words:** Andes, avifauna, birds, green walls, urban landscape, conservation, reconciliation ecology

## RESUMEN

Una novedosa tendencia que consiste en la instalación de muros vivos se evidencia en Bogotá, Colombia, ciudad caracterizada por albergar una considerable diversidad de aves. Los muros vivos han sido reconocidos como una técnica de mejoramiento del hábitat que podría tener valor en el marco de la ecología de la reconciliación. Sin embargo, muy poco se conoce sobre su potencial para incrementar oferta de hábitat. Entre 2013 y 2014 estudié el uso de muros vivos por parte de la avifauna en la ciudad de Bogotá. Seleccioné un total de 13 muros vivos y los describí de acuerdo a su altura, área, y número de géneros vegetales. En cada sitio de muestreo realicé un análisis espacial usando SIG y medí la distancia hasta el parque, la reserva forestal, el corredor ecológico de ronda y el corredor ecológico vial más cercano; también medí el área de la cobertura arbórea en un radio de 100 m. En cada uno de los muros vivos registré la actividad de anidación de aves y en nueve de éstos realicé muestreos regulares. Mis resultados indican que unas pocas especies urbanas comunes utilizan los muros vivos, principalmente para forrajear. El copetón (*Zonotrichia capensis*) fue la única especie que anidó en los muros vivos y ésta discriminó a favor de los muros más altos. Encontré un uso diferencial de los muros vivos, por especies, con respecto a las zonas de los muros usadas y las actividades realizadas en los muros. Encontré que la composición vegetal es un atributo importante de los muros vivos ya que varios géneros de plantas proporcionan recursos de alimentación a los colibríes. También encontré una correlación positiva entre el área de los muros vivos y los avistamientos del Mirlo grande (*Turdus fuscater*), así como una correlación negativa entre la distancia a corredores ecológicos de ronda y los avistamientos de colibríes. Concluyo que los muros vivos tienen valor para las aves porque proporcionan recursos como alimento, sitios de anidación y elementos de percha, y que los muros vivos efectivamente pueden satisfacer las condiciones de la ecología de la reconciliación. También hago algunas recomendaciones para generar muros vivos con valor agregado para la avifauna urbana.

**Palabras clave:** Andes, avifauna, aves, muros verdes, paisaje urbano, conservación, reconciliación ecológica

## 1. Introduction

According to the United Nations Program for Human Settlements (2012), Latin-America is the world's most urbanized developing region; almost 80% of the population lives in urban areas and it is estimated that by the year 2030 the figure will reach 85%. Among the main effects associated with urban growth are the destruction and fragmentation of natural ecosystems and changes in plant cover that favor non-native ornamental species (Pauchard et al. 2006). As a result, there is an impact on biodiversity consisting of changes in species richness and composition along the urban-rural gradient (McKinney 2002). Regarding avifauna, there is a trend in species richness loss with increasing urbanization; more specifically, a decrease in species that are sensitive to human disturbance in the initial stages of suburban encroachment and a marked increase in the proportion of non-native species toward urban centers (Marzluff 2001; Chace and Walsh 2004). Also of concern is avian community homogenization as specialist species become locally extinct and are replaced by a few generalist species (Devictor et al. 2007). The prospects for urban expansion (ONU-HABITAT 2012) and avian species losses to rapid landscape change (Hepinstall et al. 2008) emphasize the pressing need for the development and implementation of effective conservation strategies aimed at avian diversity. Traditionally, the prevailing conservation approach has been the preservation of as many natural habitat remnants as possible, yet where landscapes are already fragmented, restoring the ecological function to fragments is the ideal approach (Marzluff and Ewing 2001). However, if we are to conserve biodiversity in highly transformed places where preservation and restoration may not be viable, another strategy must be considered. Reconciliation ecology is a novel approach to conservation developed by Michael L. Rosenzweig (2003) that seeks to reconcile the needs of both humans and wild, native species in habitats that have been highly intervened for human use. The purpose of reconciliation ecology is to establish and maintain new habitat to conserve the diversity of species in the places where people live, work and play. For this purpose it is essential to establish the needs of those species target of conservation and then diversify the habitats that are being created so that these will be able to support their populations (Rosenzweig 2003).

Francis and Lorimer (2011) point out two habitat improvement techniques with great potential for reconciliation ecology in urban areas: green roofs (planted living roofs) and green walls. In doing so, they distinguish two types of green walls: green façades, which are covered by climbing vegetation that is rooted to a substrate at the base of the wall, and living walls, which are covered by vegetation that grows inside modules located on the surface of the wall but separated from it by an impermeable membrane. Although several of the ecosystem services of both green roofs and green walls have been studied (e.g., Oberndorfer et al. 2007; Alexandri and Jones 2008; Yang et al. 2008; Cameron et al. 2014), including green roof habitat provision for invertebrates (Kadas 2006; Colla et al. 2009; Tonietto et al. 2011) and birds (Baumann 2006), little is known about the habitat provision potential of green walls in general. Chiquet et al. (2012) found that some bird species in the city of Staffordshire (UK), including species of conservation concern, use green façades, presumably for nesting, food and shelter. Birds also exploited the green façade depending on the season and whether the vegetation was evergreen or deciduous.

During the last few years there has been a growing trend in green infrastructure in Bogotá, Colombia, and several companies that offer the installation of living walls have emerged. Considering that the city and its surroundings contain a large diversity of bird species, almost 200 overall (ABO 2000), the current trend in living walls offers an opportunity to study their use by birds in the city. I did a thorough literature search and found no previous studies that examine green wall use by Neotropical birds. My objectives, therefore, are to assess bird use of living walls in the city of Bogotá, Colombia, and examine which attributes of living walls and their surrounding landscape have an effect on this use. I also wish to establish whether living walls represent a habitat improvement for birds, and whether they have value within the reconciliation ecology framework. Considering that many of the city's bird species are associated with green areas (Berget 2006; Agudelo-Álvarez 2007; Peraza 2011), I expect to find that bird activity in living walls will be negatively correlated to the distance to certain landscape features, such as parks and ecological corridors. I also expect that bird activity in living walls will be positively correlated to the dimensions and plant composition of living walls.

## 2. Materials and methods

### *2.1. Study site*

Bogotá, Colombia's capital, extends over an area of 1776 $km^2$ (EIU 2010) and is home to nearly eight million people (DANE 2009). The city is located on the country's Eastern Andes Mountain Range, on a plateau known as the 'Sabana de Bogotá', with most of the city located between 2550 m and 2620 m above sea level. The climate in Bogotá is cold, sub-humid with an arid trend toward the south and southwest areas of the city (DAMA 2003). Mean multiannual temperature is 13.5 °C, and precipitation follows a bimodal regime with highest values between mid-March and mid-June, and later on between mid-September and mid-December (IDEAM-FOPAE 2007).

The city of Bogotá possesses a variety of ecosystems including native forest, native shrub, lower paramo, exotic forest and shrub, semi-arid areas, wetlands, and large urban parks and green spaces that offer refuge to avifauna within a highly transformed matrix (ABO 2000; Berget 2006).

Toward the east, an extensive mountainous area known as 'Cerros Orientales' (eastern ridges) functions as a natural boundary to the city and stands as a conservation area of national order designated as 'Bosque Oriental de Bogotá Protective Forest Reserve'. It covers some 14 000 ha (CAR 2006) and is a main component of the city's 'Main Ecological Structure'—a network of spaces and corridors expected to sustain biodiversity and also to provide environmental and ecosystem services. As many as 95 bird species have been reported inhabiting the Reserve (Peraza 2011) accounting for a large portion of the roughly 200 species reported for the entire Sabana de Bogotá, which is recognized as an area of endemism (BirdLife International 2015; Fjeldsa 1985) and an important stopover for boreal and austral migrants (ABO 2000).

*2.2. Living walls selection and description*

Searching for living walls by foot, I inspected a 10.7 $km^2$ transect of urban land in a northeastern area of the city. This transect was approximately 8.9 km long and ran parallel to the 'Bosque Oriental de Bogotá Protective Forest Reserve'. This land was under residential, commercial/services and non-residential uses. I proceeded to make an inventory wherein I classified all the living walls I found by type of module used: pocket, plant pot, or hollow brick. To remove variability that could result from different living wall designs, I selected 13 living walls consisting of pocket type modules; the most frequent living wall design I found. I procured authorization to perform regular surveys on nine living walls only, but was able to obtain relevant data for the remaining four. These 13 sampling sites were located along the transect at a distance no greater than 1651 m in relation to the 'Bosque Oriental de Bogotá Protective Forest Reserve' and separated by no less than 239 m between them.

These living walls were erected either on building façades or on boundary walls which separated two distinct properties (Fig. 1). In each one of them I measured the following attributes: a) height, b) area, and c) number of plant genera. At each of the 13 sites I performed a spatial analysis and measured: d) distance to nearest park, e) distance to nearest forested area of the 'Bosque Oriental de Bogotá Protective Forest Reserve', f) distance to nearest ecological waterway corridor, g) distance to nearest ecological road corridor, and h) tree cover area within a 100 m radius around the sampling site. Considering a medium-sized park where I typically observe numerous birds of different species, I defined park as an open green space with a minimum area of 5000 $m^2$, fully or partially covered with grass and with scattered trees. I also defined ecological waterway corridor as a zone of vegetation running alongside an urban waterway; and ecological road corridor as a zone of vegetation running between opposing lanes of traffic on a main divided roadway. I did the spatial analysis using Google Earth Pro, with an image dated Feb.13.2014.

*2.3. Bird survey*

I counted the species and number of birds visiting the living walls between October the 7$^{th}$ 2013 and July the 25$^{th}$ 2014, covering most of the boreal and austral migratory seasons. I identified birds using ABO (2000), and had previous training in local bird identification during the preceding six months. I recorded bird sightings when an individual was present on any of four living wall zones: a) vegetation, b) upper edge, c) lower edge, and d) any other structure integrated into the vertical surface including window ledges, irrigation tubes or lighting structures (Fig. 1.). Whenever I observed a single individual visiting a living wall multiple times during a survey, I accordingly recorded those multiple sightings. When birds were in sight, I recorded their activities in the living wall and classified those considering behaviors and activities previously reported for birds on green roofs, as reviewed by Fernandez-Canero and Gonzales-Redondo (2010). I classified the activities observed into six categories: a) using the living wall's upper edge as a stepping stone between two spots, b) perching, c) sunbathing or grooming, d) calling, e) foraging or obtaining nest materials, and f) feeding chicks or checking on chicks.

On nine of the 13 living walls I did 136 surveys, each of which lasted 20 min. I did 15 surveys on each sampling site, except for one where I did 16 surveys, therefore completing 5 h to 5.3 h of observations on each site. With similar efforts in the morning and afternoon periods I completed at least one survey within every 1-hour time period between 07:00 h and 17:00 h. I established an orderly route and started each series of surveys on a randomly selected sampling site and then proceeded to the next sampling sites on the route. I also recorded the occurrence of nests in the 13 living wall sample, and then confirmed and complemented my observations with those of maintenance personnel employed in the companies that installed the living walls.

*2.4. Statistical analyses*

In order to establish which attributes have an effect on bird nesting on living walls, I used a logistic binary regression (Zar 2010) using data of presence/absence of nesting on living walls as the dependent variable and, as the independent variables, height; area; number of plant genera; distance to nearest park; distance to nearest forested area of the 'Bosque Oriental de Bogotá Protective Forest Reserve'; distance to nearest ecological waterway corridor; distance to nearest ecological road corridor; and tree cover area within a 100 m radius. I further examined the nesting data in relation to wall height categories (2 m – 3 m and ≥ 4 m) using Fisher's Exact Test (Zar 2010). I also used Fisher's Exact Tests to analyze a possible association between bird species and bird activity in living walls, and between bird species and living wall zones respectively. In order to establish which living wall attributes have an effect on mean sightings per species per hour, I did Spearman's Rank-Order Correlations. I did all statistical analyses using PASW Statistics 18 and used $\alpha$=0.05 as significance level.

## 3. Results

In all living walls the vegetation was exclusively made up of ornamental plants with *Duranta*, *Bergenia*, *Tradescantia*, *Begonia, Chlorophytum* and *Vinca* as the most frequent genera (Table 1). The mean number of plant genera was 11 (range 5 – 18), the mean area was 138.2 $m^2$ (range 17.22 $m^2$ – 570 $m^2$), and the mean height was 5.9 m (range 2.2 m –26.4 m). Five living walls faced east; three faced west; two faced north; two faced south; and one, which was made of two opposing panels, faced both north and south.

In total, I recorded 126 bird sightings in living walls: 110 corresponding to six species, plus 16 sightings of unidentified species which likely correspond to the former identified species. Mean sightings per hour was 2.78 ± 4.16. The most frequent species was the Rufous-collared Sparrow (*Zonotrichia capensis*), followed by the Eared Dove (*Zenaida auriculata*) and hummingbirds (Table 2). I observed more birds in the living walls during the morning hours than in the afternoon, but single species activity peaked at different times of day. The Rufous-collared Sparrow was the only species that I observed in all 1-hour time periods surveyed, and it displayed two activity peaks, one in the early morning and one around midday. Hummingbird activity also peaked in the early morning; the only time when I observed all species (Fig. 2).

I documented six nesting events within the living wall sample, three of which I confirmed as belonging to the Rufous-collared Sparrow. I found no significant relationships when running a binary logistic regression analysis between occurrence of nesting and the attributes of the living walls and their surroundings. However, I found a higher proportion of nesting events occurring on walls with heights ≥ 4 m than on walls with heights between 2 m – 3 m (Fisher's Exact Test P = 0.025; Fig. 3). I also received additional information from maintenance staff regarding two nests in two other livings walls not included here because, either the pocket type was different, or I lacked data on their attributes. According to their accounts, these two nesting events were unsuccessful due to direct human tampering.

I found a differential use of living wall zones by bird species (Fisher's Exact Test P<0.01; Fig. 4). I observed both the Rufous-collared Sparrow and the Great Thrush (*Turdus fuscater*) on all living wall zones, and at least half of these sightings were on the vegetation. I always observed hummingbirds on the vegetation but, in contrast, I never observed the Eared Dove interacting with the vegetation, but rather with the upper and lower edges and other structures integrated into the living walls. The Rufous-collared Sparrow was considerably more active in the upper edges rather than the lower edges where the Eared Dove and the Great Thrush were more active. A differential use of living walls in terms of activities carried out by bird species was also established at a significant level (Fisher's Exact Test P<0.01); Fig. 5). Foraging was the most frequent activity by hummingbirds, the Great Thrush and the Rufous-collared Sparrow. I observed hummingbirds foraging on flowering plants, and once observed the Rufous-collared Sparrow foraging directly on a plant of the *Sedum* genus (Table 1). Other recorded instances of foraging by the Rufous-collared Sparrow where typified by pecking on horizontal surfaces on the living walls (wall edges and window ledges), but not on plants directly. The Rufous-collared Sparrow was the only species that

I recorded carrying out reproductive activities, including feeding chicks and checking on chicks, and was also the only species that I observed performing all established activity categories.

Spearman's Correlations indicate a significant negative relationship (ρ= -0.733, P<0.025) between hummingbird sightings per hour and distance to waterway corridors, and a significant positive relationship (ρ= 0.707, P<0.033) between Great Thrush sightings and the area of the vegetation ($m^2$) (Table 3).

**4. Discussion**

The living walls I studied offered resources to only a few bird species. These species are, with the exception of the Green-tailed Trainbearer (*Lesbia nuna*), common urban species in Bogotá (ABO 2000; Berget 2006). I only spotted the Green-tailed Trainbearer in one living wall which was adjacent to forest edge habitat where this species is fairly common (ABO 2000; Peraza 2011). The presence of the Shiny Cowbird, a brood parasite that uses the Rufous-collared Sparrow as host (Redondo 1993), may have been associated with the Sparrow's reproductive activities in the living walls, considering that I exclusively observed female individuals of the brood parasite prowling about the wall vegetation. I observed no migratory species, endemic species, nor species considered as threatened. My counts may have underestimated the number of birds in living walls as it is likely that a small number remained undetected under the vegetation while I conducted the surveys.

The Rufous-collared Sparrow was the most active species in the living walls. The presence of its nests and the numerous sightings of the species in the vegetation suggest that the vertical plant cover is an attractive resource for the species. This also appears to be the case with hummingbirds, which I typically observed foraging on flowers found in most of the living walls surveyed. The opposite was true for the Eared Dove which I never found in direct association with the vegetation but was always perching on the lower or upper edge of the living walls or on other living wall structures. These observations are in agreement with the results of Chiquet et al. (2012) who found that some bird species are associated with the entire green façade, whereas others only with its upper edge. I also found a differential use of living walls by species in terms of activities: foraging was the main purpose for which hummingbirds, the Rufous-collared Sparrow and the Great Thrush used the living walls; whereas perching was the main use given by the Eared Dove. The Rufous-collared Sparrow was the only species that carried out all the activities recorded in the living walls, including reproductive activities.

My results highlight the importance of various living wall attributes including height, area, plant composition, living wall zones, and distance to landscape features. The Rufous-collared Sparrow favored taller walls for nesting, which suggests that this species perceives a reduced risk of predation at higher altitudes. Human disturbance may very well represent the nesting pressure this species is responding to (Knight and Fitzner 1985; Beale and Monaghan 2004; Smith-Castro and Rodewald 2010). This view is supported by the fact that two nesting events failed as a result of direct human tampering. Another form of human disturbance such as living wall maintenance, which may involve the use of harmful pesticides, could also affect reproductive success as a result of nest abandonment or pesticide toxicity (Burn 1999), and this aspect should be examined in the near future. The area of the vegetation is of importance to the Great Thrush, the largest bird that I observed in the living walls. Its presence in the larger living walls may respond to a greater availability of insects and other feeding resources, considering that foraging was its main activity in the walls. The number of plant genera does not appear to be of relevance; what is rather important is the presence of suitable plants that offer feeding resources for birds. The availability of feeding resources could also affect bird activity in living walls along the day, particularly if considering hummingbirds, seeing as the nectar availability of some flowering plant species may decline along the day in relation to their foraging activity (Mendonça and dos Anjos 2006). Also of importance are living wall zones; all living walls bear a vertical plant cover, but those that have an upper edge, a lower edge, or other structures such as lamps and irrigation tubes, essentially offer more landing and perching possibilities for birds. The lower edge, where water from irrigation is collected and re-circulated, also offers a readily available source of water for drinking or bathing. In terms of the attributes of the surrounding landscape that have an effect on bird use of living walls, the distance to waterway corridors is of importance to hummingbirds. The fact that the Sparkling Violetear (*Colibri coruscans*) has been found to be one of the most abundant species along a waterway corridor included in this study (Agudelo-Álvarez 2007) supports my results.

In my own exploration into living wall companies operating in Bogotá, I found some overstated claims regarding living walls and biodiversity, for example: "[living walls] are an excellent habitat for animal species…such as birds and insects" (NaturalBOX 2012) and "[living walls] restore biodiversity in cities" (Ecotelhado 2013). My results, nonetheless, demonstrate that living walls are of value to urban birds in Bogotá, especially for the Sparkling Violetear and the Rufous-collared Sparrow. By providing resources such as food, nesting sites and perching elements, living walls increase habitat availability for some species. Living walls can therefore represent a habitat improvement for birds. They may also be of value to invertebrates, but this remains to be studied.

Living walls can indeed satisfy the conditions established by reconciliation ecology. Given that living walls and built areas are not mutually exclusive, living walls can offer greenery where otherwise there would be a bare concrete wall. This greenery enhances the spaces used by people, and it can simultaneously offer resources to some avian species. In such cases it means that humans do not have to stop using the land for their own benefit; they can share it. Secondly, the establishment of living walls has the potential to generate novel habitats by altering the urban landscape composition and configuration (Pellissier et al. 2012) which birds are sensitive to. A collection of dispersed living walls within the landscape may not be of much value for conservation strategies, but creating a network of living walls, with the involvement of landowners and local government, could be a step in the right direction. The companies that install living walls would be crucial in informing about the success of such conservation strategies, as they could more easily collect valuable data. As urban development increases in Bogotá and other cities of the world, green walls in general may become more valuable to urban wildlife as backyard gardens are inevitably replaced by built areas. However, one major aspect to consider is the steep price of living walls, which may be an obstacle to their implementation and hence discourage their use as habitat improvement techniques and biodiversity conservation strategies. A major challenge for green infrastructure companies will be to make their products more accessible to low-income communities.

To conclude, additional efforts are needed to improve living walls to allow uncommon species to use them. Height, plant composition and wall zones appear as important attributes that ought to be considered for generating value-added living walls that can enhance not only our habitat but also that of urban avifauna. Plant species selection for living wall design is usually based on plant endurance and client expectations, but the use of nectar-producing flowers such as *Begonia*, *Fuchsia*, *Nematanthus* and *Tulbaghia* may attract nectar-feeding birds and also satisfy people's aesthetic and emotional needs (Todorova et al. 2004; Haviland-Jones et al. 2005. The use of plant species with seeds and juicy fruits typically consumed by birds can also enhance living walls, as well as integrating feeders, perches and even birdhouses (Vogelbescherming Nederland 2012), all of which should ideally be placed at heights above 3 m in order to reduce human disturbance and risk of predation. Perches, nonetheless, could in principle be placed anywhere on the living wall as long as they can be used by birds only (and not household predators) and allow them to move upward to escape from any perceived threats. Designing living walls with the benefit of birds in mind will need to be worked out case by case, taking into consideration how birds may be affected by the immediate surroundings and the typical forms of disturbance at a chosen location.


**Fig. 1** Living wall zones: a) vegetation, b) upper edge, c) lower edge, and d) any other structure integrated into the vertical surface including window ledges, irrigation tubes or lighting structures. Pictures a) and b) respectively show a living wall incorporated into a building façade and bearing no upper edge, and a living wall incorporated into a boundary wall bearing a distinct upper edge. Picture c) shows a living wall's lower edge where water from irrigation is collected and re-circulated.

**Table 1** Plant composition in the 13 living wall sample. The number of living walls where the genus is found is shown to the right. The number of genera found in each living wall is shown at the bottom.

| Family | Genus | Living walls | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | |
| Acanthaceae | *Acanthus* | | | | x | x | | | | | | | | | 2 |
| Acanthaceae | *Aphelandra* | | | | | | | x | | | | x | x | | 3 |
| Amaryllidaceae | *Tulbaghia* | | | | x | x | | x | | x | | x | | | 5 |
| Apocynaceae | *Vinca* | x | x | x | x | | | x | | x | x | | x | | 8 |
| Araceae | *Monstera* | x | | | | | | | | | | | | x | 2 |
| Araceae | *Syngonium* | | | | | | | | | | | | | x | 1 |
| Araliaceae | *Schefflera* | x | | | | | | | | | | | | x | 2 |
| Asparagaceae | *Asparagus* | x | x | | x | | | x | x | | | | | | 5 |
| Asparagaceae | *Liriope* | x | | | | | | x | x | x | | | | | 4 |
| Asparagaceae | *Chlorophytum* | | x | | x | x | | x | x | | x | x | | x | 8 |
| Asteraceae | *Leucophyta* | | | x | | | | | | | | | | | 1 |
| Begoniaceae | *Begonia* | x | x | | x | x | | x | | | | x | x | x | 8 |
| Caryophyllaceae | *Dianthus* | | | | | | x | | | | | x | | | 2 |
| Commelinaceae | *Tradescantia* | x | | x | | | x | x | x | x | x | x | x | | 9 |
| Crassulaceae | *Crassula* | x | | | | | | | | | | | | | 1 |
| Crassulaceae | *Kalanchoe* | x | | | x | | x | x | | | x | x | | | 6 |
| Crassulaceae | *Sedum* | | | x | | | | | x | | | | | | 2 |
| Davalliaceae | *Davallia* | | | | | | | | | | | | x | | 1 |
| Geraniaceae | *Pelargonium* | | x | | | | | | | | | | | | 1 |
| Gesneriaceae | *Nematanthus* | x | x | | | | x | | | | | x | x | | 5 |
| Lamiaceae | *Lavandula* | x | | | x | | | | | | | | | | 2 |
| Lamiaceae | *Plectranthus* | x | x | | | | x | | x | | x | | | | 5 |
| Lamiaceae | *Stachys* | | | | | | x | | | | | | | | 1 |
| Loganiaceae | *Buddleja* | x | | | x | x | | x | | | | | | | 4 |
| Lomariopsidaceae | *Nephrolepis* | | | | | | | x | | | | x | x | | 3 |
| Lythraceae | *Cuphea* | x | | | | | | | | | | | | | 1 |
| Melastomataceae | *Centradenia* | | x | x | | | x | | x | x | | | x | x | 7 |
| Moraceae | *Ficus* | | | | x | | | | | | x | | | | 2 |
| Onagraceae | *Fuchsia* | | | | | x | | | | | x | | | | 2 |
| Oxalidaceae | *Oxalis* | | | | | | x | | | | | | | | 1 |
| Plantaginaceae | *Hebe* | | | | x | x | | x | | x | x | x | | x | 7 |
| Poaceae | *Festuca* | | x | | | | | | | | | | | | 1 |
| Poaceae | *Pennisetum* | | | | | x | | | | | | | | | 1 |
| Polypodiaceae | *Phlebodium* | | | | | | | x | | | | | | | 1 |
| Rosaceae | *Rosa* | | | | | x | | | | | | | | | 1 |
| Saxifragaceae | *Bergenia* | x | x | | x | x | | x | | x | x | x | | x | 9 |
| Saxifragaceae | *Tolmiea* | | | | | | x | | x | | | | | | 2 |
| Selaginellaceae | *Selaginella* | x | | | | | | | | | | | | | 1 |
| Urticaceae | *Soleirolia* | x | | | x | | | x | | | x | x | | | 5 |
| Verbenaceae | *Duranta* | x | x | | x | x | x | x | | x | x | x | x | x | 11 |
| | | 18 | 11 | 5 | 14 | 11 | 10 | 16 | 8 | 8 | 11 | 13 | 9 | 9 | |

**Table 2** Mean sightings per species per hour in living walls between October 2013 and July 2014. Sightings under the unidentified class most likely correspond to *Zonotrichia capensis*, but they were observed high up in the tallest living wall (~26 m tall) and could not be identified with certainty. Some hummingbirds merely offered a glimpse, also making their identification impossible. For each species I indicate any of four living wall zones used, as well as the plant genera individuals foraged on. I completed 45.3 h of surveys. Overall bird sightings (n=126) averaged 2.78 (*s*= 4.16) per hour.

| Order | Family | Species | Common name | Mean sightings per hour | Zone used | Plant genera foraged on (family) |
|---|---|---|---|---|---|---|
| Apodiformes | Trochilidae | *Colibri coruscans* | Sparkling Violetear | 0.15 | Vegetation | *Begonia* (Begoniaceae)<br>*Fuchsia* (Onagraceae)<br>*Nematanthus* (Gesneriaceae)<br>*Tulbaghia* (Amaryllidaceae) |
| | | *Lesbia nuna* | Green-tailed Trainbearer | 0.04 | Vegetation | |
| | | Unidentified | — | 0.11 | Vegetation | |
| Columbiformes | Columbidae | *Zenaida auriculata* | Eared Dove | 0.38 | Upper edge, lower edge, others | |
| Passeriformes | Emberizidae | *Zonotrichia capensis* | Rufous-collared Sparrow | 1.59 | Vegetation, upper edge, lower edge, others | *Sedum* (Crassulaceae) |
| | Icteridae | *Molothrus bonariensis* | Shiny Cowbird | 0.13 | Vegetation | |
| | Turdidae | *Turdus fuscater* | Great Thrush | 0.13 | Vegetation, upper edge, lower edge, others | |
| Unidentified | Unidentified | Unidentified | — | 0.24 | Vegetation, lower edge, others | |

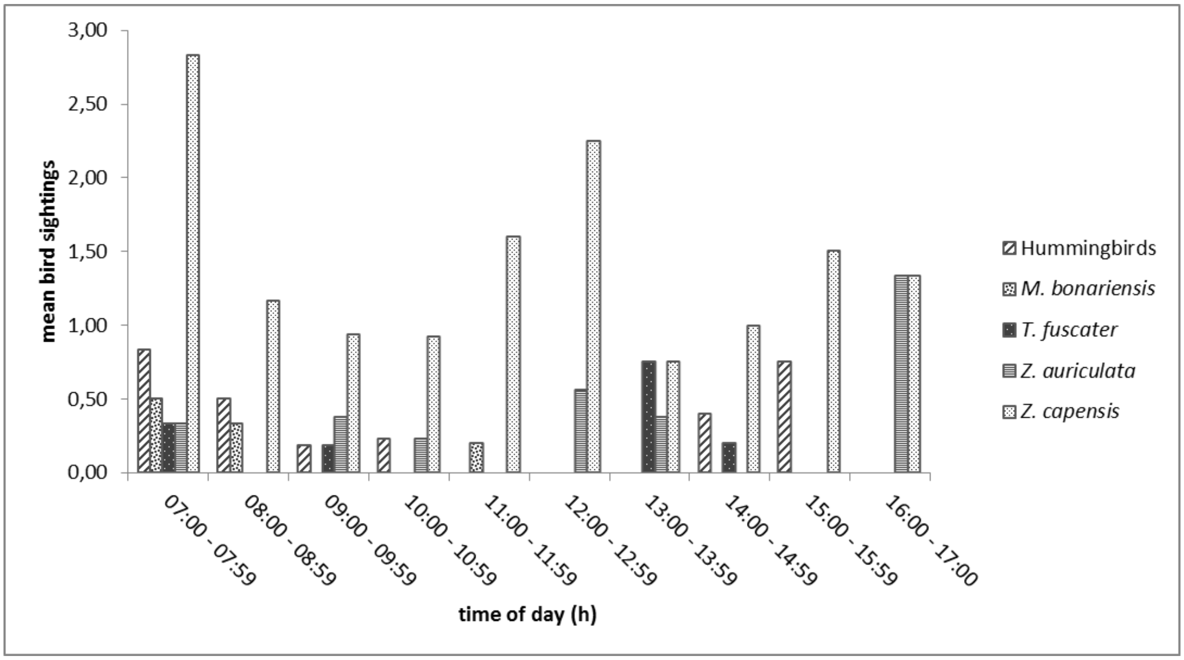


**Fig. 2** Mean bird sightings per species per time period surveyed. The data analyzed consists of 45.3 h of surveys on nine living walls. The most frequent bird species were *Zonotrichia capensis*, *Zenaida auriculata* and hummingbirds. Hummingbirds include *Colibri coruscans, Lesbia nuna,* and unidentified hummingbirds that likely correspond to *C. coruscans.*

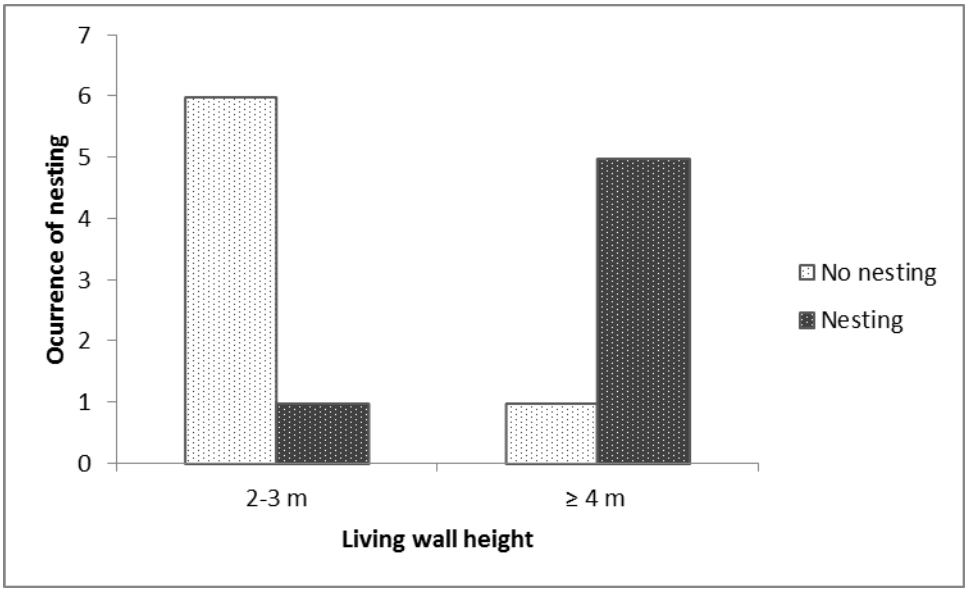


**Fig. 3** Nesting activity on 13 living walls in relation to wall height categories, 2 m – 3 m and ≥ 4 m. Birds discriminated between wall height categories more often than chance would predict (Fisher's Exact Test P= 0.025), and most nesting events occurred in living walls with heights ≥ 4 m.

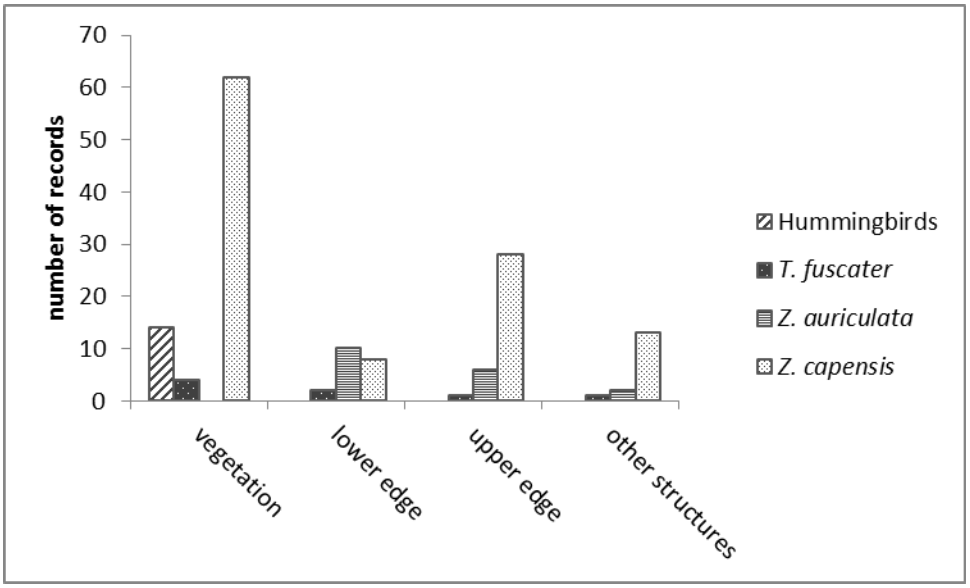


**Fig. 4** Birds recorded on any of four living wall zones. Bird species discriminated between living wall zones more often than chance would predict (Fisher's Exact Test: $P<0.01$).

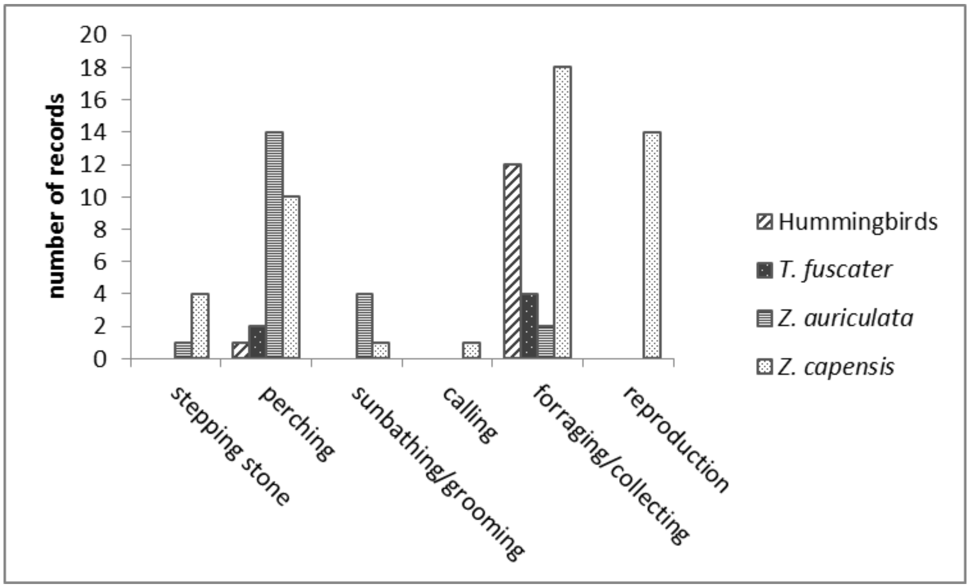


**Fig. 5** Birds recorded performing any of six activity categories: a) using the living wall's upper edge as a stepping stone to go from one spot to another, b) perching, c) sunbathing or grooming, d) calling, e) foraging or obtaining nest materials, and f) feeding chicks or checking on chicks. Bird species displayed differential activity in living walls more often than chance would predict (Fisher's Exact Test: $P<0.01$).

**Table 3** Spearman's Rank-Order Correlation coefficients for mean bird sightings per species per hour and living wall attributes. Significant correlations at the 0.05 level are starred. Hummingbirds include *Colibri coruscans, Lesbia nuna,* and unidentified hummingbirds that likely correspond to *C. coruscans.*

| Independent variables | Bird species | | | | |
|---|---|---|---|---|---|
| | Hummingbirds | *M. bonariensis* | *T. fuscater* | *Z. auriculata* | *Z. capensis* |
| Height (m) | 0.567 | 0.138 | 0.550 | 0.147 | 0.245 |
| Vegetation ($m^2$) | 0.416 | 0.251 | 0.707* | 0.204 | -0.109 |
| No. of plant genera | -0.383 | 0.046 | -0.321 | -0.236 | -0.194 |
| Distance to park (m) | 0.297 | -0.297 | -0.114 | -0.594 | -0.126 |
| Distance to forest reserve (m) | 0.426 | 0.068 | 0.342 | 0.027 | -0.345 |
| Distance to ecological waterway corridor (m) | -0.733* | -0.183 | -0.274 | 0.027 | 0.076 |
| Distance to ecological road corridor (m) | 0.416 | -0.046 | -0.137 | 0.452 | 0.042 |
| Tree cover area ($m^2$) | -0.436 | 0.388 | -0.068 | 0.505 | 0.311 |

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