Universidade de Aveiro Departamento de Biologia
Ano 2015

Mariana Rodrigues Morgado

INFLUENCE OF SOCIAL AND LAND USE FEATURES ON URBAN AVIFAUNA

INFLUÊNCIA DE FATORES SOCIAIS E DE USO DO SOLO NA AVIFAUNA URBANA

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Ecologia Aplicada, realizada sob a orientação científica do Prof. Doutor António Manuel da Silva Luís, Professor Auxiliar no Departamento de Biologia da Universidade de Aveiro, coorientação da Prof. Doutora Maria Luís Rocha Pinto, Professora Associada no Departamento de Ciências Sociais, Políticas e do Território da Universidade de Aveiro e da Prof. Doutora Maria Teresa Fidélis da Silva, Professora Auxiliar no Departamento de Ambiente e Ordenamento da Universidade de Aveiro.

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keywords

Avian diversity, Urbanization, Land use features, Social features.

abstract

Urbanization is a worldwide phenomenon that affects biodiversity, which induces the need to conserve the urban areas. Urban ecosystems are defined by human activities, habitat infrastructures and vegetation components. Nevertheless, little is known about the processes underlying the spatial variation of urban bird communities.

The aims of the present dissertation are (1) to investigate the relationship between avian diversity and abundance with land use and social features and (2) to study the vertical distribution of avian diversity, abundance and biomass in an urban environment. For this purpose, bird surveys by point counts were conducted during breeding season in eight neighbourhoods of Aveiro, Portugal. The data was analysed through descriptive analyses, statistical hypothesis testing and generalized linear models.

Most of the studied neighbourhoods were dominated by omnivorous species, namely *Columba livia* and *Passer domesticus*. The results also show that species richness is higher in neighbourhoods furthest away from esplanades, with higher density of trees, building height and density, alongside low imperviousness, busy streets and human population density. Moreover, neighbourhoods furthest away from esplanades, showing higher building age, height and density, busy streets but lower human population density, hold higher avian abundance. Medium height levels exhibit higher bird diversity, abundance and biomass than both lower and higher height levels.

These findings strongly suggest that focusing on a combination of local land use and social features, rather than single features, provide a better understanding of avian diversity and spatial structures of urban bird communities. Furthermore, due to the complexity of urban ecosystems, this investigation underlies the relevance of integrating social and urban planning researchers into urban ecological studies.

palavras-chave Diversidade de avifauna, Urbanização, Fatores de uso do solo, Fatores sociais.

resumo

A urbanização é um fenómeno mundial que afeta a biodiversidade, o que induz a necessidade de conservar as áreas urbanas. Os ecossistemas urbanos são definidos pelas atividades humanas, infraestruturas do habitat e componentes vegetais. No entanto, pouco se sabe sobre os processos inerentes à variação espacial local de comunidades de aves urbanas.

Os objetivos principais da presente dissertação consistem em (1) investigar a relação entre diversidade e abundância de aves, e fatores sociais e de uso do solo e (2) estudar a distribuição vertical da diversidade, abundância e biomassa de aves em ambiente urbano. Para este efeito foram realizados censos de avifauna por pontos durante a época de nidificação em oito zonas da cidade de Aveiro, Portugal. A análise de dados realizou-se com recurso a análise descritiva, testes de hipóteses e modelos lineares generalizados.

Os resultados indicam que espécies omnívoras como *Columba livia* e *Passer domesticus* são espécies dominantes na maioria das zonas de Aveiro. Os resultados mostram ainda que a riqueza específica é mais alta em zonas localizadas a uma maior distância de esplanadas, em ruas com mais movimento e com maiores densidades tanto de árvores como de edifícios mais altos, bem como menor percentagem de impermeabilidade do solo e menor densidade de população humana residente. Adicionalmente, zonas com maior densidade de edifícios mais velhos, mas também de maior altura, menor densidade de população humana residente, com ruas de maior movimento e maior distância a esplanadas, suportam maior abundância de avifauna. Ainda, existe maior diversidade, abundância e biomassa de avifauna no nível médio de altura do que nos níveis baixo e alto.

Estes resultados sugerem que a combinação de fatores sociais e de uso do solo locais, em detrimento da aplicação de fatores únicos, permitem uma melhor compreensão da biodiversidade e estruturas espaciais de comunidades de aves urbanas. Adicionalmente, devido à complexidade dos ecossistemas urbanos, é pertinente realçar a relevância de integrar investigadores das ciências sociais e de ordenamento do território em investigações de ecologia urbana.

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CHAPTER I – INTRODUCTION

1.1. Investigation theme

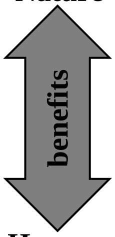
Since 1950, the world human population has increased by 275 per cent, to 6.97 billion people in 2011 (UN, 2012). This phenomenon led to a high expansion, both in size and number, of urban areas, where nowadays more than 50 per cent of the human population inhabits (PRB, 2013). Consequently, natural habitats have been seriously reduced and fragmented, which significantly threatens local and global biodiversity (Turner *et al.*, 2004). Moreover, as suggested by Mcdonald *et al.* (2008) urbanization has been the cause of extinction to several species (8 per cent of vertebrate species of IUCN), endangering many rare species and some protected areas.

The collaboration of stakeholders, such as international, national and local authorities, non-governmental agencies and private citizens, is crucial in managing urbanized areas as human decisions impact the urban landscape at different scales (Alberti *et al.*, 2003; Hostetler, 1999; McKinney, 2002; Novacek, 2008). Observing the everyday biodiversity leads people to consider their functional and evolution characteristics as well as allowing an increase in their knowledge and individual beliefs (Cosquer *et al.*, 2012). Nevertheless, as suggested by Miller (2005), the reality of Nature is highly distanced to the urban population.

Since the 1990's, investigators have been considering that the structure and functions of urban ecosystems are in many ways similar to natural ecosystems. Thus, as urbanization increases, urban areas should be considered as new habitats, rather than lost habitat for wildlife (Grimm *et al.*, 2008; McKinney, 2002; Miller and Hobbs, 2002). The considerations mentioned above enhance the importance of conserving urban biodiversity. Dearborn and Kark (2010) summarized seven key motivations for conserving these areas, which benefit both humans and nature (Figure 1).

In order to conserve urban biodiversity, investigators must understand how the urban ecosystems function. Birds are considered exceptional indicators of changes and stresses in urban ecosystems due to their sensitiveness to habitat changes. (Clergeau *et al.*, 1998; Strohbach *et al.* 2009). Accordingly, this dissertation will contribute to understand the urban ecosystems, especially the relationship between avian biodiversity and urban components, such as land use and social features.

Nature



- Preserve local biodiversity in urban environments and protect important populations or rare species
- Create stepping stones or corridors for natural populations
- Understand and facilitate responses to environmental changes
- Connect people with nature and provide environmental education
- Provide ecosystem services
- Fulfill ethical responsibilities
- Improve human well-being

Humans

Figure 1. Motivations for urban biodiversity conservation. Adapted from Dearborn and Kark (2002, p.3).

1.2. General background

1.2.1 Urbanization

Urbanization is the "process of transition from rural to a more urban society" (UNFPA, 2007, p. 7). The formation of cities not only includes the growth of human population in a certain area where buildings and monuments are built, but also self-sufficiency, production specialization and social complexity that organizes and facilitates productivity (Elmqvist *et al.*, 2013). Moreover, due to the resource availability, most cities have been established near waterbodies such as rivers, estuaries or along the coastline (World Resources Institute, 1996).

Nowadays, cities concentrate investment and employment opportunities, where an estimate of 80 per cent of the world's gross domestic product (GDP) is generated and consequently, the urban population is rapidly increasing. By 2050 the world urban population is expected to increase by 72 per cent, from 3.6 billion to 6.3 billion people, approximately the total world population in 2011. At the moment, about half of the world urban population lives in cities holding less than half a million inhabitants. In Europe, these cities accommodate 67 per cent of the urban population. (UN, 2012)

In Portugal, almost every city has fewer than 500,000 inhabitants, the exceptions being the Lisbon metropolitan area –1,459,194 people - and the Porto metropolitan area – 1,006,133 people - (UN, 2012). Nonetheless, in 2011, 72 per cent of the Portuguese population lived in Predominantly Urban Areas (Tipologia de Áreas Urbanas - TIPAU 2014[1]), which represents 18 per cent of the national territory (INE, 2013).

[1] **Tipologia de Áreas Urbanas (TIPAU 2014)** stands for a Portuguese territorial nomenclature based on urbanization intensity. Categories: Predominantly urban area (*Área predominantemente urbana* – APU); Averagely urban area (*Área mediamente urbana* – AMR); and Predominantly rural area (*Área predominantemente rural* – APR). (INE, 2013)

1.2.2 The impacts of urbanization

Urbanization stresses the environment through three main vectors: the conversion of land, the extraction, and in some cases depletion, of natural resources and the disposal of urban wastes. Anthropogenic activities such as agriculture, forestry and grazing represent a higher extent of land transformation than the expansion of cities worldwide (World Resources Institute, 1996).

These vectors cause several issues related to urbanization such as habitat loss, deterioration of habitat quality and natural habitat fragmentation which result in a more heterogeneous, ecologically fragmented and geometrically complex environment (Andersson, 2006; Collinge, 1996; Luck and Wu, 2002; Olff and Ritchie, 2002; Tratalos *et al.*, 2007). As consequence, urban areas are dramatically different from natural habitats - for instance artificial light, additional anthropogenic food, altered ambient noise, warmer microclimate, modified ecological processes (such as changed water cycle and soil functionality), higher ozone levels and increased number of exotic species (Luniak *et al.*, 1990; Patricelli and Blickley, 2006; Pickett *et al.*, 2008; Slabbekoorn and Ripmeester, 2008).

As urban ecosystems are extremely dynamic, species richness tends to decrease along an urban gradient (Marzluff, 2001). Some studies have formed hypotheses in order to identify biodiversity patterns concerning urban disturbances. Connell (1978) developed the Intermediate Disturbance Hypothesis (IDH) stating that species richness increases in areas with medium frequency disturbance. According to this author low disturbed areas hold dominant species and extremely disturbed areas hold highly adaptive species. However, several empirical and theoretical studies have refuted this hypothesis and according to Fox (2013) this theory should be abandoned. The Increasing Disturbance Hypothesis (YDH) defends that species richness decreases as the level of disturbance increases (Gray, 1989) and particularly, the Habitat Specialist Hypothesis predicts that only the number of forest-associated species decreases in more urbanized areas (Magura *et al.*, 2004).

1.2.3 Bird communities and urbanization

As birds are the most studied animal group in urban environments (Marzluff, 2001) and due to their sensitivity to habitat changes, this animal group is considered an excellent indicator for environmental studies (Clergeau *et al.*, 1998; Strohbach *et al.*, 2009). Some species have integrated urban areas by changing their behaviour, diet and in some cases even their life cycle in order to deal with anthropogenic pressure (Ditchkoff *et al.*, 2006).

Most of the literature on the relationships between avifauna and urbanization has focused on a gradient approach. Besides, urban ecologists typically use environmental factors in order to study biodiversity in urban areas, such as vegetation features (Daniels and Kirkpatrick, 2006; Sewell and Catterall, 1998). However, non-environmental factors, for instance town planning design, structural features of neighbourhoods, and even human resident population features, are also relevant components of an urban environment (Hostetler, 1999; Loss *et al.*, 2009). Several studies have related neighbourhood age and socioeconomic status to landscape vegetation in urban areas (Heezik, van *et al.*, 2013; Martin *et al.*, 2004; Sewell and Catterall, 1998; Smith *et al.*, 2005). Furthermore, Cohen *et al.* (2012) have demonstrated that relationships between household income, biodiversity of public semi-natural spaces, building density and floral diversity are extremely complex and non-linear.

Some studies have also begun to investigate the relationships between avifauna and local-scale urban and social features. For instance Loss *et al.* (2009) stated that housing age and per capita income were strong predictors of species richness and abundance of some species in Chicago, USA. Additionally, according to Pellissier *et al.* (2012) the abundance of omnivorous species was influenced by building heterogeneity in Paris, France. As reported in further studies, avian species richness and abundance decrease where the percentage of imperviousness is larger (Loss *et al.*, 2009; Melles *et al.*, 2003) and the number of trees is lower (Melles *et al.*, 2003; Ortega-Álvarez and MacGregor-Fors, 2009). Moreover, avian species richness is negatively associated with building age (Munyenyembe *et al.*, 1989; Palomino and Carrascal, 2006; Vale and Vale, 1976) probably due to the diversity and complex vegetation in the older neighbourhoods (Hope *et al.*, 2003; Martin *et al.*, 2004), but more recently Loss *et al*. (2009) came to the opposite conclusion. Furthermore, as suggested by Ortega-Álvarez and MacGregor-Fors (2009), the busiest streets contain less avian species and individuals. In addition, the authors Gaston and Evans (2004) concluded that regionally, the number of people is positively related to avian species richness and abundance.

In sum, Pickett *et al.* (1997) suggest that "humans, and their products and effects are already part of many component systems of the biosphere", which is massively evident in urban areas.

1.2.4 Basic concepts of Spatial Planning and Demography

In order to better understand the land use and social features considered in the present investigation, it is pertinent to briefly describe the basic concepts of spatial planning and demography.

<u>Spatial Planning</u>

As stated by UN (2008, p. 1) "the scope of spatial planning differs from one country to another, but most share a number of similarities". Accordingly, OECD (2001) enumerated the three main functions encompassed by almost every country (see Table 1).

Table 1. Fundamental functions of spatial planning. Adapted from OECD (2001, p. 11).

"Spatial planning provides a long or medium-term strategy for territories in pursuit of common objectives, incorporating different perspectives of sectoral policies;"
"Spatial planning deals with land use and physical development as a distinct sector of government activity alongside transport, agriculture, environment, etc.;"
"Spatial planning means the planning of sectoral policies according to different spatial scales."

Additionally, spatial planning promotes sustainable development and improves quality of life. The three essential benefits of spatial planning are: (1) economic – through the creation of stable and foreseeable conditions for investment and development; (2) social – by guaranteeing benefits for the society and/or local communities; and finally (3) environmental – through the conscious promotion of land and natural resources use. (UN, 2008)

Physical boundaries based on the morphological characteristics of land are defined as "land use" which is an important component of spatial planning (Seto *et al.*, 2014). In the present dissertation those morphological characteristics of land use are considered as "land use features", portraying the urban tissue.

<u>Demography</u>

Demography is the scientific study of the size, structure and development of population (Scheidel, 2006). According to Haupt *et al.* (2011, p. 2) "population factors have an important impact on many facets of life" such as history (e.g. wars, discovery of new medicines), prices of goods and services and political decisions. Furthermore, demographic studies provide knowledge about the levels and trends in population and its components as well as explanations of demographic change and respective implications for society (Haupt *et al.*, 2011).

Usually, demographic data is collected via censuses, birth and death rates, surveys, etc. used as counts and transformed into ratio and other data forms. "Counts" stands for the absolute number of a population or demographic event in a specified area at a given period of time (for instance, total population of a country at a given year) whereas a "ratio" is the relationship between two population subgroups (for example the ageing index – population over 65 divided by the population under 14 years-old at a specified year) (Haupt *et al.*, 2011). In this dissertation the demographic data is mentioned as "social features".

1.3. Objectives

Based on the considerations mentioned above, the main objective of this dissertation is to investigate the relationship between land use and social features, and avian metrics in an urban area. Hence, the specific objectives follow:

- To characterize the neighbourhoods based on the observed avian species and respective diet guilds;
- To characterize and compare neighbourhoods according to land use and social features as well as the avifauna;
- To evaluate possible linear relationships between pairs of explanatory variables (social and land use features) and response variables (avifauna);
- To determine if a group of explanatory variables (social and land use features) predict the response variables (avifauna);
- To characterize the avifauna in height levels (vertical distribution).

CHAPTER II – METHODOLOGY

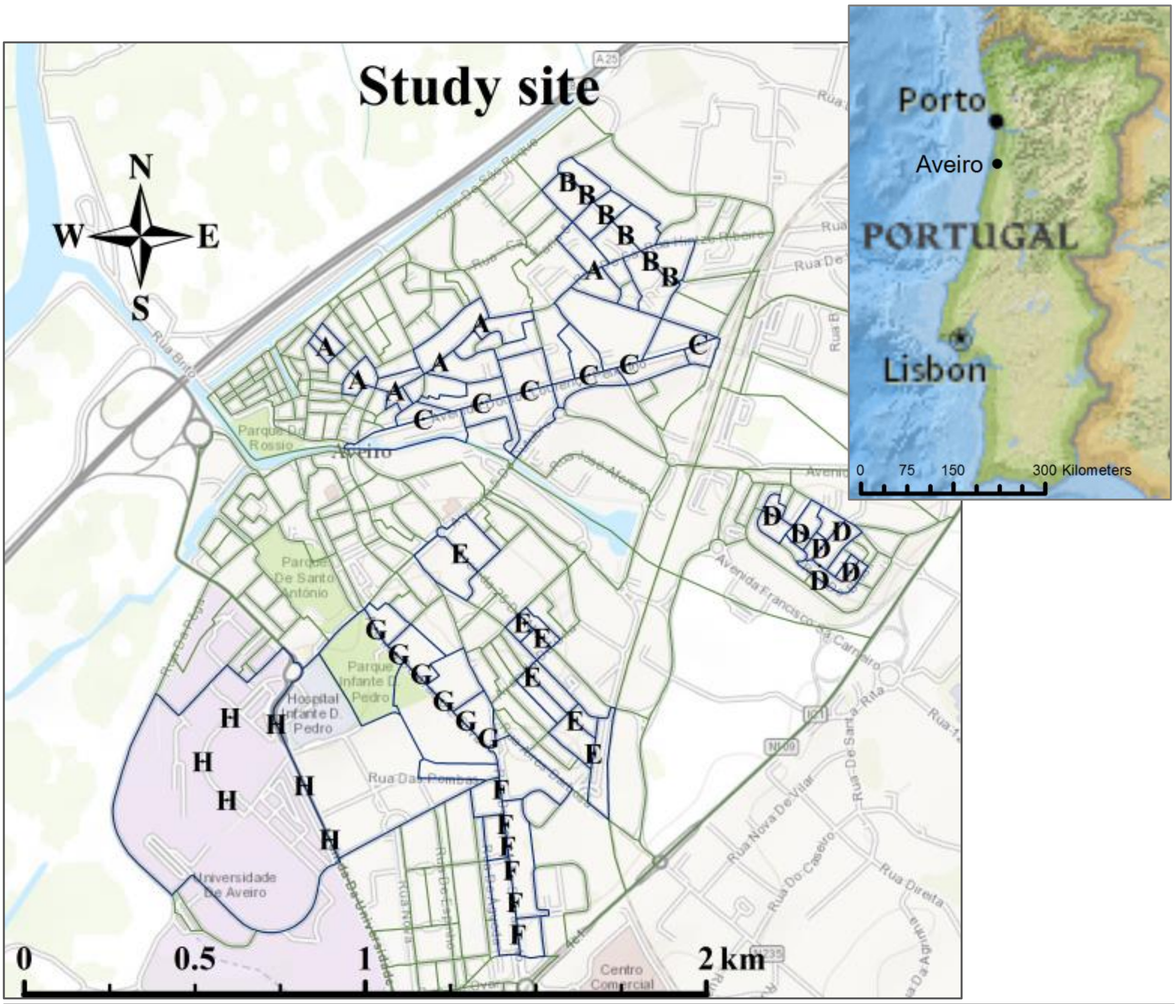
2.1 Study site

Aveiro is a coastal municipality in the centre of Portugal that includes the *União de Freguesias da Glória e Vera Cruz* parish with a resident population of 18,756 people (INE, 2011). This parish, a Predominantly Urban Area (Tipologia de Áreas Urbanas - TIPAU 2014), is located on the border of the lagoon of Aveiro, a Special Protection Area (SPA) under the Birds Directive of the Natura 2000 network – PTZPE0004 Ria de Aveiro (Natura 2000, 2015).

Eight neighbourhoods were selected in order to characterize different areas of the city in a local scale. The *Instituto Nacional de Estatística* website provides statistical and geographic data according to specific scales, the smallest being the “subsections” – equivalent to city blocks (INE, 2011). The representation of the neighbourhoods and subsections is presented on Figure 2.

Bairro da Beira-Mar (neighbourhood A), built in the 16th century, is located on the northwest limits of the city between the channels of the lagoon. This area was associated with sea-linked economic activities like salt and chandleries, and was later transformed into a residential area. The key spaces of this area are the people’s temples dedicated to the protector saints of seafarers and the noble houses of local lords. Furthermore, it is composed by small houses and has a compact layout that expresses popular characteristics. Bairro da Beira-Mar is divided in two units – the eastern and older section covering the higher and healthier parts and an outer section completely rebuilt in the 19th century as a squared urban design. (Tavares and Tavares, 2003)

Avenida Doutor Lourenço Peixinho (neighbourhood C) is one of the main city avenues, built in the 1920’s with the objective of linking the centre of the city to the railway station. This avenue is articulated with the older axes of the north and south and includes a pedestrian straight tree-lined central area. In the end of the 20th century the Avenida Doutor Lourenço Peixinho was remodelled, becoming more functional – first signs of the city’s urban modernization, especially concerning the tertiary economy (goods and services). Nowadays it is a mixed residential and commercial architectural project that includes buildings of modernist languages of two to three floors and 1970’s and 80’s buildings of seven to eight floors. (Paiva, 2013; Tavares and Tavares, 2003)



Neighbourhoods

A. Bairro da Beira-Mar
B. Bairro de Sá-Barrocas
C. Avenida Doutor Lourenço Peixinho
D. Bairro da Forca-Vouga
E. Bairro do Liceu
F. Rua Doutor Mário Sacramento
G. Avenida de Araújo e Silva
H. Universidade de Aveiro

INE subsections
Selected INE subsections

Figure 2. Study site. Neighbourhoods discriminated as letters located on the bird survey points.

Bairro de Sá-Barrocas and **Bairro da Forca-Vouga (neighbourhoods B and D respectively)** were built as urban extensions to the city according to small scale projects that neglected the existing urban fabric of Aveiro and fragmented the territory. Both neighbourhoods are mainly residential, highly dense and hold buildings of four floors on average. Bairro da Forca-Vouga, built in the 1980's, is a complex network of roads that also holds important local and regional services such as *Loja do Cidadão* (agglomeration of citizens' services) and *Cliria* (a private hospital). Whereas the northern oldest section of Bairro de Sá-Barrocas was built in the 1960's and 70's, the latest section was built in the

1990's as a straight axis (Avenida da Força-Aérea) that cut off the old connection axis (Rua de Sá) between the city centre and the city of Esgueira. (Pinho, 2007)

Bairro do Liceu (neighbourhood E) is a urban expansion project of the 1950's and 60's located between the railway line and the old city walls that was planned as a follow up to Moreira da Silva's "Regulator Plan" of 1948. This neighbourhood was built as an urban residential area for middle class around two schools. Moreover, the eastern sector was built as a late garden city (villas with front gardens) and the long central axis (Avenida 25 de Abril) is characterized by residential blocks with front gardens. Later, the first high-rise residential blocks of Aveiro were built in the western sector, reflecting the architectural expression of regional integration. (Tavares and Tavares, 2003)

Rua Doutor Mário Sacramento (neighbourhood F) and **Avenida Araújo e Silva (neighbourhood G),** are two main connection axis of the city of Aveiro that hold trees in either sidewalk. Avenida Araújo e Silva, built in the 1950's and 60's, is characterized by villas with front gardens. Besides, the backyards of the southern villas overlook the oldest and most relevant city park – Parque Infante D. Pedro – constructed in the 19^{th} century. This park holds a high diversity of native and exotic vegetation for which interactive illustrated keys to the woody plants were developed (Nimis *et al.*, 2010). In addition, Rua Doutor Mário Sacramento is a straight structural city axis built in the 1960's and 70's that connects Aveiro to EN109, a relevant regional axis that links several municipalities. This road is characterized by city blocks, with some front gardens. (personal observations)

Universidade de Aveiro (neighbourhood H) played an important role in the later transformation of Aveiro's urban fabric. It benefits from the dynamic flow of thousands of people during week days of the academic year and its proximity to the original nucleus of the old town and to city facilities like the public hospital, prison and seminary. Even though the university opened in 1973, the initial architectural design is dated of 1979 by Eduardo Rebelo de Andrade and Armindo do Espírito Santo e Silva. The plan was altered in 1990 under the direction of Nuno Portas, making the campus larger and more complex. Besides, due to the intervention of some of the most exceptional architects of Portugal (e.g. Álvaro Siza Vieira, Eduardo Souto de Moura, Alcino Soutinho, etc.), the campus of the Universidade de Aveiro is a true catalogue of recent Portuguese architecture. (Tavares and Tavares, 2003)

2.2 Hypothesis

In order to achieve the objectives mentioned in Chapter I, several hypotheses were formulated. Firstly, to characterize and compare Aveiro neighbourhoods according to the studied variables (Table 2), it was hypothesized:

H1: Each avifauna variable is significantly different between neighbourhoods.

H2: Each land use variable is significantly different between neighbourhoods.

H3: Each social variable is significantly different between neighbourhoods.

Table 2. List of studied variables.

Variable typology		Variable (units)	Source
Explanatory	Land use	Minimum distance to food establishments (m)	Calculated on **ArcGIS *software*** based on **personal observations**
		Minimum distance to esplanades (m)	Calculated on **ArcGIS *software*** based on **personal observations**
		Density of trees (no. of trees/m^2)	Calculated on **ArcGIS *software*** based on **personal observations in the 25m radius circles of the bird surveys**
		Imperviousness (%)	Calculated on **ArcGIS *software*** based on **personal observations in the 25m radius circles of the bird surveys**
		Building age (years)	Weighted average based on the **number of buildings** and their **minimum age**. Adapted from INE (2011).
		Building height (m)	Weighted average based on the **number of buildings**, **number of floors** and **the minimum height per floor.** Adapted from INE (2011) and Decreto-Lei n.º 38382/51 (1951).
		Building density (no. of buildings/m^2)	Calculated based on the **number of buildings** and the **area of the INE subsections**. Adapted from INE (2011).
		Housing density (no. of housings/m^2)	Calculated based on the **number of housings** and **the area of the INE subsections**. Adapted from INE (2011).
		Road level (ordinal scale)	Adapted from Plano Municipal de Mobilidade de Aveiro (2012). Ordinal scale (1- structural road; 2 – main road; 3 – secondary road; 4 – local access)
	Social	Human population density (no. of residents/m^2)	Calculated based on the **number of human residents** and the **area of the INE subsections**. Adapted from INE (2011).
		Household size (ratio)	Ratio between the number of **human residents** and the number of **families.** Adapted from INE (2011).
		Ageing Index (ratio)	Ratio between the number of **human residents over 65** and **under 14 years old.** Adapted from INE (2011).
Response	Avifauna	Species richness	**Bird surveys**
		Abundance	**Bird surveys**
		Biomass	Calculated based on **bird surveys** and **species biomass.** (Cramp, 1985, 1988; Cramp and Duncan, 1992; Cramp *et al.*, 1993, 1994)
		Shannon Index	Calculated based on **bird surveys**
		Pielou Index	Calculated based on **bird surveys**

Secondly, the relationships between variables were investigated. As stated in Chapter I, several studies successfully related avian metrics with land use and social variables (Gaston and Evans, 2004; Loss *et al.*, 2009; Melles *et al.*, 2003; Munyenyembe *et al.*, 1989; Ortega-Álvarez and MacGregor-Fors, 2009; Pellissier *et al.*, 2012). Furthermore, single variables might be correlated to avian metrics, yet the ecological processes are extremely complex and might not be influenced by single factors. To this end, the following hypotheses were formulated:

H4: Each land use variable has linear correlation with avian species richness.

H5: Each land use variable and social variable has linear correlation with avian abundance.

H6: A group of land use and social variables can predict avian species richness.

H7: A group of land use and social variables can predict avian abundance.

Finally, in order to investigate the vertical distribution of urban avifauna, it was hypothesized:

H8: Avian diversity, abundance and biomass vary according to height in urban environments.

2.3 Bird surveys

During the breeding season (March-May of 2015), five point count bird surveys were conducted in eight neighbourhoods of Aveiro, six points each identified in Figure 2, totalling 48 point counts – 240 samples. The size and position of the subsections mentioned above (INE, 2011) determined the location and radius of the point counts, set at 25 meters, as well as the minimum distance between points, set at 100m, half the distance recommended by Sutherland (2006). Additionally, even though DeGraaf *et al.* (1991) evidenced that 76.8% of the observations are made within 64 meters of a survey point (larger radius than the one selected for this study), it would not be possible to observe birds in a much larger radius due to the width and shape of most of the streets and subsections of the studied neighbourhoods. After a calming period of 1 minute, each point count lasted 10 minutes and every individual observed or heard in the fixed radius was recorded (Sutherland, 2006), except for waterbirds and birds of prey as suggested by Loss *et* al. (2009), due to their dispersion characteristics. All the bird surveys were performed by the author on relatively clear days during the first four hours after sunrise to coincide with bird activity peak (Sutherland, 2006).

In order to study the vertical distribution of birds, five additional bird surveys were conducted respecting the same rules as the bird surveys described above, with two exceptions. Firstly, the birds were counted in three height intervals:

- Low level: up to 2 meters in height (approximately below the trees' crowns);
- Medium level: between 2 and 15 meters in height;
- High level: above 15 meters in height (approximately above the trees' crowns).

Secondly, instead of 10 minutes, the point counts lasted for 1 minute and corresponded to instantaneous/"snapshot" counts to reduce errors associated to individual movements between different height levels.

Additionally, in order to compare bird counts from two perspectives – observing from the ground vs observing from above the buildings –, bird surveys were pre-tested by the utilization of an unmanned aerial vehicle (UAV). The 8 motored UAV was equipped with a stabilizer and a 16.1 Megapixels full HD camera. Each point count of neighbourhood A was overflown at heights ranging from 40 and 100 meters during 10 minutes, and the film was later analysed. Unfortunately, the pre-tests were unsuccessful due to the extreme difficulty in detecting and identifying the birds in the film.

2.4 Data analysis

The data analysis was performed in several stages recurring to different statistical methods according to the previously defined hypotheses and the nature of the variables. To begin with, the neighbourhoods were characterized through descriptive analysis of the data collected during the 10 minutes bird surveys. Secondly, statistical hypotheses testing were performed to each variable in order to investigate hypotheses **H1 to H3**. In the third stage, correlation coefficients were calculated to analyse linear relationships between pairs of explanatory (land use and social variables) and response variables (species richness and abundance) – hypotheses **H4 and H5**. Then, several multiple regressions were conducted in order to predict the response variables (hypotheses **H6 and H7**). Finally, a descriptive analysis of the 1 minute bird surveys was also performed to investigate the vertical distribution of avifauna (hypothesis **H8**).

The statistical analyses were computed using R version 3.1.2 (R Core Team, 2014), the graphics were executed on Microsoft Excel 2010 v.14.0.7153.5000 (64 bits) and the maps were drawn on ESRI® ArcMap™ v.10.0.

2.4.1 Statistical hypothesis testing

The statistical hypothesis tests determine whether significant differences exist between two or more samples, in this case neighbourhoods, for each studied variable: species richness, abundance, biomass, Shannon index, Pielou index, minimum distance to food establishments, minimum distance to esplanades, density of trees, imperviousness, building age, building height, building density, housing density, road level, human population density, household size and ageing index.

In order to perform parametric tests, the assumptions of normality - through Shapiro-Wilk (R function `shapiro.test(sample)`) and/or Kolmogorov-Smirnov one-sample (R function `ks.test(sample,"pnorm")`) tests - and homogeneity – through the Levene's test (R function `leveneTest(variable,factor)` from the package `{car}` (Fox and Weisberg, 2011)) - must be met. (Marôco, 2014).

When p-value $\geq \alpha = 0.05$ (95% confidence interval) for the assumptions tests, parametric tests can be performed, such as t-student tests to compare the means of two samples and one-way ANOVA to compare the means of more than two samples, which is the case of this study – eight samples corresponding to the eight neighbourhoods (Marôco, 2014).

However, when both the normality and homoscedasticity assumptions are not met, non-parametric tests must be utilized: for instance the Wilcoxon-Mann-Whitney test equivalent to the parametric test t-student and the Kruskal-Wallis, the non-parametric alternative to the *one-way* ANOVA. The Kruskal-Wallis test (R function `kruskal.test(variable~factor)`) assesses if two or more samples belong to the same population. In other words, when p-value $\leq \alpha = 0.05$ (95% confidence interval) the samples originate from populations with the same distribution (Marôco, 2014).

Additionally, a post hoc test is needed to assess multiple comparisons of means. In this case, pairwise comparisons with Bonferroni correction (R function `pairwise.t.test(variable,factor,"bonferroni")`) is considered appropriate due to the small size of the samples. When $p \leq \alpha = 0.05$ (95% confidence interval), for a given pair of samples (neighbourhoods), significant differences exist within that pair of neighbourhoods concerning the specified variable (Marôco, 2014).

2.4.2 Correlation and regression

In order to investigate the relationships between variables (**H4-H7**), it is possible to use correlation and regression techniques. As an exploratory technique, correlation determines whether two variables are significantly related without one being dependent of the other. For instance, the Pearson correlation coefficient (R function `cor.test(formula, method = "pearson")`) describes the strength of a linear relationship between a pair of variables. On the other hand, regression can be used in two contexts: a definitive context – to investigate the functional relationship between the response variable and one or more explanatory variables as well as its significance; or in a predictive context - where the explanatory variable(s) predicts the response variable (McKillup, 2006). This relationship might be factor dependent (cause-effect) or an association between the variables – the response variable and the explanatory variable(s) vary together (Marôco, 2014).

As mentioned in Chapter I, the ecological processes are extremely complex. Therefore a single explanatory variable is weaker than a set of explanatory variables for predicting one response variable and consequently, multiple regression models are adequate for this purpose. One of the most common statistical techniques is based on a linear relationship between the response and explanatory variables – the linear model (LM):

$$Y_j = \beta_0 + \beta_1 X_{1j} + \beta_2 X_{2j} + \cdots + \beta_p X_{pj} + \varepsilon_j \;\; (j = 1, \ldots, n)$$

Where β_i are the regression coefficients (in which β_0 is the intercept) and ε_j represents the residuals (Marôco, 2014). This can be simplified by aggregating the vectors X_{1j}, X_{2j} and X_{pj} into one matrix $\boldsymbol{X}$ (Anderson *et al.*, 2007):

$$Y = \mathrm{E}[Y] + \varepsilon, \qquad \mathrm{E}[Y] = \boldsymbol{X}.\beta$$

One of the main limitations of this model is the assumption of a normally distributed response variable. As consequence, an adaptation of the LMs – the Generalized Linear Models (GLMs) were created. In these models the response variable is distributed according to a member of the exponential family of distributions, for instance the Poisson, Gamma or Negative Binomial distributions (Anderson *et al.*, 2007). The differences between the components of LMs and GLMs are presented in Table 3.

Table 3. Components of Linear Models (LMs) and Generalized Linear Models (GLMs). Adapted from Anderson *et al.* (2007); McCullagh and Nelder (1989).

Components	**Linear Model (LM)** (Anderson *et al.*, 2007, p. 12)	**Generalized Linear Model (GLM)** (Anderson *et al.*, 2007, p. 13)
Random component	**(LM1)** Each component of Y must be independent and normally distributed; Y must have homoscedasticity.	**(GLM1)** Each component of Y must be independent and from a member of the exponential family of distributions.
Systematic component	**(LM2)** The model parameters must be combined to give a "linear predictor" (Linearity): $\eta = \boldsymbol{X}.\beta$	**(GLM2)** The model parameters must be combined to give a "linear predictor" (Linearity): $\eta = \boldsymbol{X}.\beta$
Link function	**(LM3)** The relationship between the first two components must be specified in a link function. In LM the link function is the identity function: $E[Y] \equiv \mu = \eta$	**(GLM3)** The relationship between the first two components must be specified in a link function, g: $E[Y] \equiv \mu = g^{-1}(\eta)$

Moreover, in case of count data, the authors McCullagh and Nelder (1989) advise the utilization of GLM with Poisson distribution, instead of a classical LM. Species richness and abundance - the response variables considered in this study - fit into this category and consequently, this specific model was chosen. The canonical link function for the Poisson distribution was used ($\eta = \log \mu$ (McCullagh and Nelder, 1989)).

The next step was to compute two GLMs with Poisson distribution – for species richness and abundance - (R function of package `{stats}`: `glm(formula,family=Poisson)`), including the explanatory variables. Then, it is important to perform subset models with fewer variables in order to find the best fitted models. The stepwise regression methods allow deleting or adding variables based on a chosen criteria (Rawlings *et al.*, 1998). According to Yamashita *et al.* (2007) the stepwise AIC (Akaike's Information Criteria) method is more reliable than other stepwise methods due to its extensibility to GLMs and non-normally distributed data. The AIC, developed by Akaike in 1973, was defined as an "estimate of the expected relative distance between the fitted model and the true mechanism (…) that actually generated the observed data" (Burnham and Anderson, 2003, p. 61). This method is especially relevant for model selection and therefore the function `stepAIC` (`{MASS}` package in R (Venables and Ripley, 2002)) was performed.

According to Burnham and Anderson (2003), it is possible to select the best fitted models through the differences between the AIC value of the best fitted model and the AIC of the remaining models (ΔAIC). As shown in Table 4, when $\Delta AIC_i \geq 2$ the level of empirical support for model *i* is substantial.

Table 4. Level of empirical support for models according to ΔAIC. Adapted from Burnham and Anderson (2003, p. 61).

ΔAIC_i	Level of empirical support for model *i*
0-2	Substantial
4-7	Considerably less
> 10	Essentially none

After selecting the best fitted models for each response variable, it is important to explore the adequacy of fit of each model, in other words, validate the models. The first step is to check for overdispersion Φ (Zuur *et al.*, 2011):

$$\Phi = \frac{D}{n - p}$$

D is the residual deviance of the model and $n - p$ represents the degrees of freedom. If Φ is much higher than 1, it suggests overdispersion. Poisson GLMs on ecological count data usually accuse overdispersion caused by a larger variation of the data than the mean, or the existence of many zeros. When overdispersion exists, Negative Binomial GLMs (R function `glm.nb(formula)` of the `{MASS}` package (Venables and Ripley, 2002)) should be performed instead of Poisson GLMs. (Zuur *et al.*, 2011).

The models are also validated by analysing the residuals. In particular the residuals should follow Normal distribution (McCullagh and Nelder, 1989) which can be checked through the Q-Q Normality plot, where the points should lie on or near the straight line that represents normality (Dobson, 2002). Additionally, the residuals should be plotted against the fitted values in order to check for homoscedasticity and finally, time and spatial sequence plots of the residuals allow checking the temporal and spatial independence – these three plots should not show any specific patterns (Dobson, 2002).

CHAPTER III – RESULTS

3.1. Sample Characterization

During the three months of the study, 20 bird species were identified. On average 14 species (SD = 2.15) and 549 individuals (SD = 119.55) were observed per neighbourhood, which corresponds to 67.337 ± 26.3327 kg of biomass. As shown in Table 5, neighbourhood H had the highest diversity – Shannon index of 3.187, Pielou index of 0.780 and a total of 17 species, followed by neighbourhood G. On the contrary, neighbourhood C showed the lowest diversity among all of neighbourhoods – Shannon index of 2.177 and Pielou index of 0.588 (Table 5).

By analysing the abundance, neighbourhood B showed the lowest abundance while neighbourhood E had the most individuals. Moreover, the combined biomass of neighbourhoods C and E, the ones with the higher total biomass (114.0kg and 102.3kg respectively) represents about 40% of the global biomass (538.5kg) (Table 5).

Table 5. Species richness, abundance, biomass, Shannon index and Pielou index per neighbourhood. Global species richness, abundance and biomass represent the totals for each variable. Global Shannon index and global Pielou index were calculated based on every sample of the eight neighbourhoods.

Variable	A	B	C	D	E	F	G	H	Global
Species Richness	12	14	13	13	16	11	17	17	20
Abundance	561	351	664	455	719	565	647	430	4392
Biomass (kg)	66.9	32.8	114.0	51.2	102.3	63.1	66.9	41.3	538.5
Shannon Index	2.437	2.601	2.177	2.223	2.486	2.520	2.916	3.187	2.790
Pielou Index	0.680	0.683	0.588	0.601	0.622	0.728	0.713	0.780	0.646

As shown in Table 6, the most common species were *Apus apus*, *Columba livia*, *Passer domesticus*, *Serinus serinus*, *Streptopelia decaocto* and *Turdus merula*, which were present in every neighbourhood. However, only *P. domesticus*, *C. livia* and *A. apus* were observed in at least one sample of each 48 point counts. These three species were also the most frequent in terms of occurrences – *P. domesticus* (26.8% of total occurrences), *C. livia* (25.5%) and *A. apus* (20.2%; see Appendix 2). Also in Table 6, it is possible to observe that in neighbourhoods A and B, *A. apus* had the highest mean abundances (5.93 ± 7.514 and 3.53 ± 6.672 respectively), whereas in neighbourhood C, *C. livia* was the species with the higher mean abundance (10.70 ± 10.820), as for the remaining neighbourhoods, *P. domesticus* was the most abundant species.

Additionally, species *Chloris chloris*, *Motacilla alba*, *Phoenicurus ochruros* and *Sturnus unicolor* were present in 7 of the 8 neighbourhoods, while species *Corvus corone*, *Dendrocopus major* and *Pica pica* were observed in less than four neighbourhoods.

Table 6. Mean abundance and standard deviation of each species per neighbourhood.

Species		A	B	C	D	E	F	G	H	Global
Apus apus	**Mean**	5.93	3.53	6.17	1.53	2.47	3.43	4.33	2.23	3.70
	SD	7.514	6.672	8.050	3.284	4.039	5.714	8.592	6.328	6.702
Carduelis carduelis	**Mean**				0.03	0.13	0.17		0.33	0.08
	SD				0.180	0.499	0.522		0.745	0.389
Chloris chloris	**Mean**		0.03	0.17	0.50	0.47	0.27	0.60	0.60	0.35
	SD		0.109	0.373	0.957	0.921	0.629	0.841	1.020	0.776
Columba livia	**Mean**	5.07	0.33	10.70	4.23	7.47	3.23	3.30	1.40	4.67
	SD	8.442	0.267	10.820	5.602	6.652	4.271	3.278	1.705	6.754
Corvus corone	**Mean**		0.01					0.03		0.01
	SD		0.030					0.180		0.091
Cyanistes caeruleus	**Mean**				0.03	0.13	0.07	0.43	0.07	0.09
	SD				0.180	0.427	0.359	0.761	0.249	0.376
Delichon urbicum	**Mean**	0.43	0.04	0.27				0.17	0.17	0.16
	SD	1.086	0.085	0.512				0.734	0.522	0.580
Dendrocopus major	**Mean**							0.03		0.00
	SD							0.180		0.064
Hirundo rustica	**Mean**	1.23		0.07		0.10		0.03	0.03	0.18
	SD	3.127		0.249		0.396		0.180	0.180	1.190
Motacilla alba	**Mean**	0.03	0.02	0.20	0.07	0.03		0.13	0.23	0.10
	SD	0.180	0.066	0.542	0.249	0.180		0.499	0.616	0.396
Parus major	**Mean**					0.10	0.03	0.07	0.10	0.04
	SD					0.300	0.180	0.249	0.539	0.247
Passer domesticus	**Mean**	3.97	0.61	1.90	6.93	7.70	6.23	5.60	3.30	4.91
	SD	5.063	0.431	2.285	3.687	5.100	3.159	3.720	2.747	4.135
Phoenicurus ochruros	**Mean**	0.10	0.01	0.10	0.20	0.03		0.23	0.30	0.13
	SD	0.300	0.030	0.300	0.600	0.180		0.616	0.586	0.420
Pica pica	**Mean**				0.10	0.03				0.02
	SD				0.300	0.180				0.128
Ptyonoprogne rupestris	**Mean**	0.13	0.07	0.97					0.07	0.20
	SD	0.562	0.133	1.402					0.359	0.695
Serinus serinus	**Mean**	0.03	0.01	0.23	0.37	0.57	0.77	1.43	0.77	0.53
	SD	0.180	0.030	0.496	0.706	0.883	1.086	2.348	0.989	1.162
Streptopelia decaocto	**Mean**	1.27	0.11	0.80	0.07	3.43	3.43	3.33	2.77	1.97
	SD	1.289	0.184	1.137	0.249	2.216	2.616	2.534	2.729	2.341
Sturnus unicolor	**Mean**	0.07	0.07	0.30	0.23	0.13		0.07	0.20	0.18
	SD	0.249	0.264	1.130	0.616	0.718		0.359	1.077	0.879
Sylvia atricapilla	**Mean**		0.01			0.07	0.10	0.17	0.20	0.08
	SD		0.042			0.249	0.396	0.453	0.476	0.307
Turdus merula	**Mean**	0.43	0.06	0.27	0.87	1.10	1.10	1.60	1.57	0.91
	SD	0.667	0.108	0.629	0.991	1.300	1.012	1.800	1.230	1.208

By categorizing the species by diet guilds (see Appendix 3), every neighbourhood is dominated by individuals of omnivorous species (>45%), especially neighbourhood D (Figure 3). Considering the insectivorous and granivorous guilds, neighbourhoods E, F and H had more individuals of granivorous species than individuals of insectivorous species in opposition to neighbourhoods A, B, C, D and G.

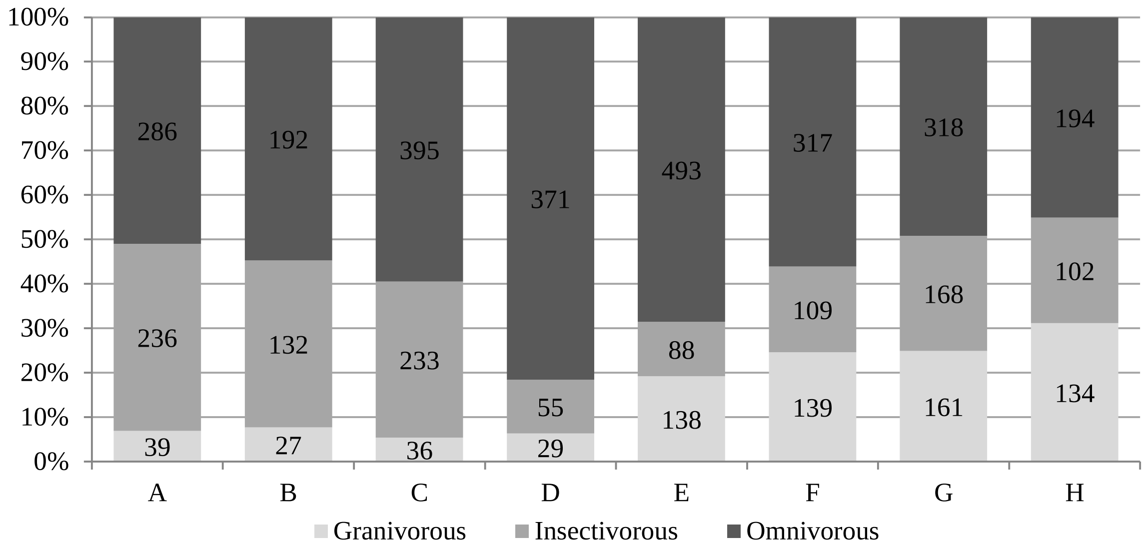


Figure 3. Relative abundance of species categorized by diet guilds in different neighbourhoods. Numbers correspond to absolute values of abundance.

3.2.Characterization and comparison of neighbourhoods per variable

In order to investigate whether the neighbourhoods are significantly different from one another based on each variable, statistical hypothesis tests were used. None of the variables respected both assumptions for parametric tests: normality (p-value > 0.05 in the Shapiro-Wilk and Kolmogorov-Smirnov one sample tests; see Appendix 4) and homoscedasticity (p > 0.05 in the Levene's tests; see Appendix 5).

Consequently, non-parametric tests Kruskal-Wallis were performed to each variable to evaluate whether significant differences exist between the neighbourhoods. The results of these tests are presented in Table 7, where p–value ≤ 0.05 for every variable, therefore the neighbourhoods are significantly different amongst themselves concerning all the variables.

Table 7. Kruskal-Wallis tests for each variable.

Variable	Statistic	df	p-value
Species richness	36.827	7	0.000
Abundance	43.884	7	0.000
Biomass	43.507	7	0.000
Shannon Index	44.021	7	0.000
Pielou Index	33.349	7	0.000
Minimum distance to food establishments	29.736	7	0.000
Minimum distance to esplanades	21.491	7	0.003
Density of trees	28.904	7	0.000
Imperviousness	15.582	7	0.029
Building age	39.148	7	0.000
Building height	37.602	7	0.000
Building density	37.279	7	0.000
Housing density	37.099	7	0.000
Human population density	33.007	7	0.000
Household size	34.124	7	0.000
Ageing Index	21.738	7	0.003

Additionally, post hoc Bonferroni tests were performed to assess multiple comparisons of means. When $p \leq \alpha = 0.05$ for a given pair of neighbourhoods concerning a variable, significant differences exist within that pair of neighbourhoods. Nevertheless, the Bonferroni test does not indicate which neighbourhood of the pair has the highest mean, which can be consulted in the table of calculated means for each neighbourhood and variable (see Appendix 6). This information is also displayed on Figures 4, 5, 6 and 7 organised in a colour scheme.

3.2.1. Avian species richness

The results of the Bonferroni test for species richness show that both neighbourhoods G and H are significantly different from neighbourhoods B and D, and neighbourhood also significantly differs from neighbourhoods A and C ($p \leq 0.05$; see Appendix 7). By combining these results with the means in Appendix 6 and Figure 4.a: (1) neighbourhood G has significantly more species than neighbourhoods A, B, C and D; and (2) neighbourhood H has significantly higher species richness than neighbourhoods B and D.

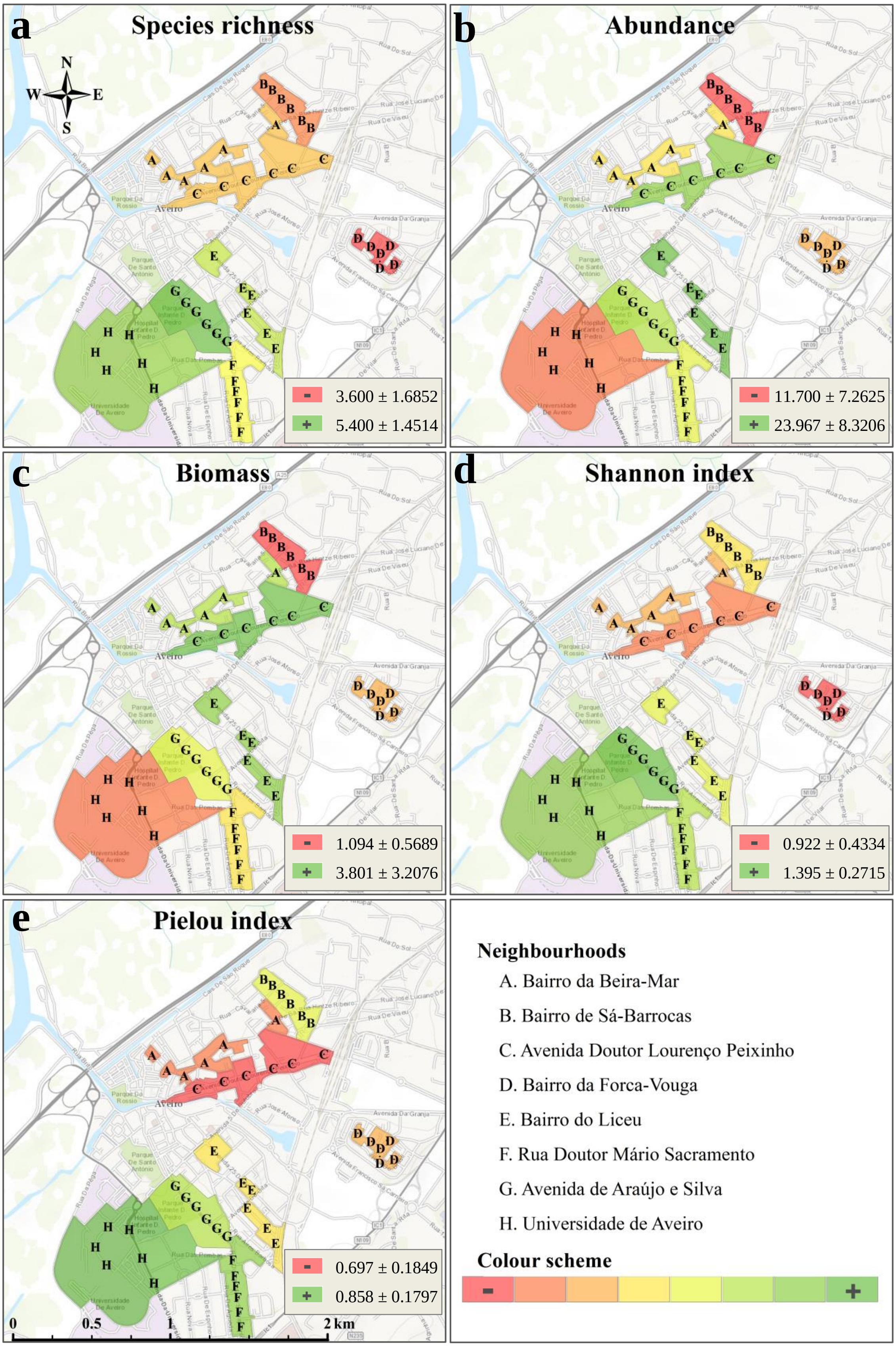


Figure 4. Maps of the study area for variables: (a) species richness, (b) abundance, (c) biomass (kg), (d) Shannon index and (e) Pielou index. Colour scheme based on the means of the variables for each neighbourhood. Neighbourhoods discriminated as letters located on the bird survey points.

3.2.2. Avian abundance

Concerning the abundance, neighbourhood B significantly differs from neighbourhoods C, E and G, and neighbourhood E is significantly different from both neighbourhoods D and H (Bonferroni tests $p \leq 0.05$; see Appendix 7.). These results combined with the information in Figure 4.b and Appendix 6, reveal that: (1) neighbourhood B has significantly less avifauna individuals than neighbourhoods C, E and G; and (2) neighbourhood E has higher abundance than neighbourhoods D and H.

3.2.3. Avian biomass

For the variable biomass, neighbourhood B is significantly different from neighbourhoods C and E, neighbourhood C significantly differs from neighbourhoods D, F and H, and neighbourhood E has significant differences from neighbourhoods D and H (Bonferroni tests $p \leq 0.05$; see Appendix 7). As shown in Figure 4.c and Appendix 6: (1) neighbourhood B has significantly less biomass than both neighbourhoods C and E; (2) neighbourhood C shows significantly more biomass than neighbourhoods D, F and H; and (3) neighbourhood E has significantly higher mean of biomass than neighbourhoods D and H.

3.2.4. Avian diversity

On account of the Shannon index, both neighbourhoods G and H are significantly different from neighbourhoods A, B, C and D (Bonferroni tests $p \leq 0.05$; see Appendix 7). By comparing the means of the Shannon index, neighbourhoods G and H are significantly more diverse than neighbourhoods A, B, C and D (Figure 4.d and Appendix 6).

As for the Pielou index, the results of the Bonferroni tests indicated that neighbourhood C is significantly different from neighbourhoods F, G and H ($p \leq 0.05$; see Appendix 7). The means in Appendix 6 and the representation of Figure 4.e conjugated with the Bonferroni tests led to the conclusion that neighbourhood C has less species equitability than neighbourhoods F, G and H.

By combining the two indexes, neighbourhoods E, F, G and H had the most diversity among the neighbourhoods whereas neighbourhoods A, C and D were the least diverse.

3.2.5. Minimum distance to food establishments

As suggested by the combination of the results of the Bonferroni tests ($p \leq 0.05$; see Appendix 7) and the representation in Figure 5.a of the means for this variable available in Appendix 6: (1) neighbourhoods A and C are significantly closer to food establishments than neighbourhoods D, G and H; and (2) neighbourhood D is significantly further away to food establishments than neighbourhood F.

3.2.6. Minimum distance to esplanades

According to the results of the Bonferroni tests for this variable, neighbourhood D is significantly different from neighbourhoods A, B, C and F ($p \leq 0.05$; see Appendix 7). As perceived in Figure 5.b and Appendix 6, neighbourhoods A, B, C and F are significantly furthest to esplanades than neighbourhood D.

3.2.7. Density of trees

Concerning the density of trees, both neighbourhoods A and C are significantly different from neighbourhoods E, F, G and H (Bonferroni tests $p \leq 0.05$; see Appendix 7). By combining these results with Figure 5.c and respective means in Appendix 6, neighbourhoods A and C have significantly less trees than neighbourhoods E, F, G and H.

3.2.8. Imperviousness

The results of the Bonferroni tests for the percentage of imperviousness show that neighbourhood H is significantly different from neighbourhoods A and C (Bonferroni tests $p \leq 0.05$; see Appendix 7). These results combined with Figure 5.d and respective means in Appendix 6 evince that both neighbourhoods A and C have significantly higher imperviousness than neighbourhood H.

3.2.9. Building features

By combining the Bonferroni tests results ($p \leq 0.05$; see Appendix 7) and the representation of the means of Appendix 6 in Figure 5.e, it can be concluded that for the variable building age: (1) neighbourhood A is significantly older than all the other neighbourhoods; whereas (2) neighbourhood C is significantly older than neighbourhoods B and D; and (3) neighbourhood D is significantly more recent than neighbourhoods C, E, F, G and H.

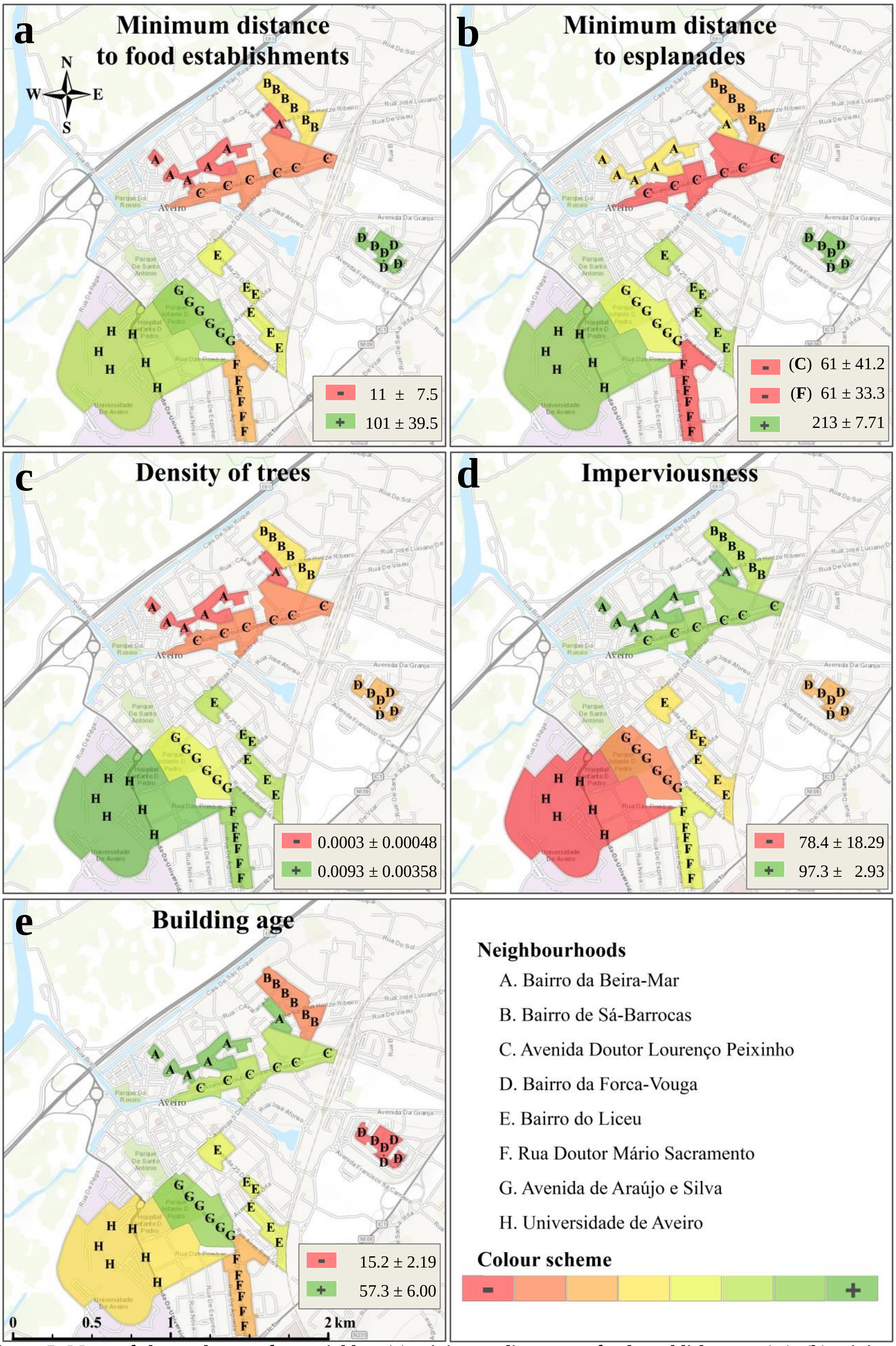


Figure 5. Maps of the study area for variables: (a) minimum distance to food establishments (m), (b) minimum distance to esplanades (m), (c) density of trees (trees/m^2), (d) imperviousness (%) and (e) building age (years). Colour scheme based on the means of the variables for each neighbourhood. Neighbourhoods discriminated as letters located on the bird survey points.

The conjugation of the Bonferroni tests results for building height ($p \leq 0.05$; see Appendix 7) and the colour scheme in Figure 6.a of the means in Appendix 6 show that neighbourhoods A, G and H have significantly shorter buildings than neighbourhoods B, C, D, E and F.

As for building density, the Bonferroni tests show that neighbourhood A is significantly different from all the other neighbourhoods and neighbourhood H is significantly different from neighbourhoods B, C, D and E (Bonferroni tests $p \leq 0.05$; see Appendix 7). The representation of the means in Appendix 6 and Figure 6.b show that: (1) neighbourhood A has significantly higher building density than all the other neighbourhoods whereas (2) neighbourhood H has significantly higher building density than neighbourhoods B, C, D and E.

According to the Bonferroni tests results ($p \leq 0.05$; see Appendix 7) as well as the means calculated in Appendix 6 represented in Figure 6.c: (1) neighbourhood B has significantly higher housing density than all the remaining neighbourhoods; whereas (2) neighbourhood D has significantly higher housing density than neighbourhood H; and (3) both neighbourhoods G and H have significantly lower housing density than neighbourhoods A, B, C, E and F.

Furthermore, by analysing the means for building and housing densities (Appendix 6) it is possible to conclude that neighbourhoods with higher differences between housing and building densities have more buildings with a higher number of housing units, particularly neighbourhood B.

3.2.10. Road level

In the case of road level, it was not possible to perform Shapiro-Wilk, Kolmogorov-Smirnov one sample, Levene's, Kruskal-Wallis or Bonferroni tests because five of the neighbourhoods only have one category for this variable and therefore it is impossible to have sample distributions and calculate means. As shown in Figure 6.d neighbourhoods B, C, E, F and G have road level 2 while neighbourhood D has road level 4. Half the point counts from neighbourhoods A and F belong to roads with level 3 while the other half has road level 4 (neighbourhood A) and level 1 (neighbourhood H). Lower road levels are indicators of more relevant and busy streets.

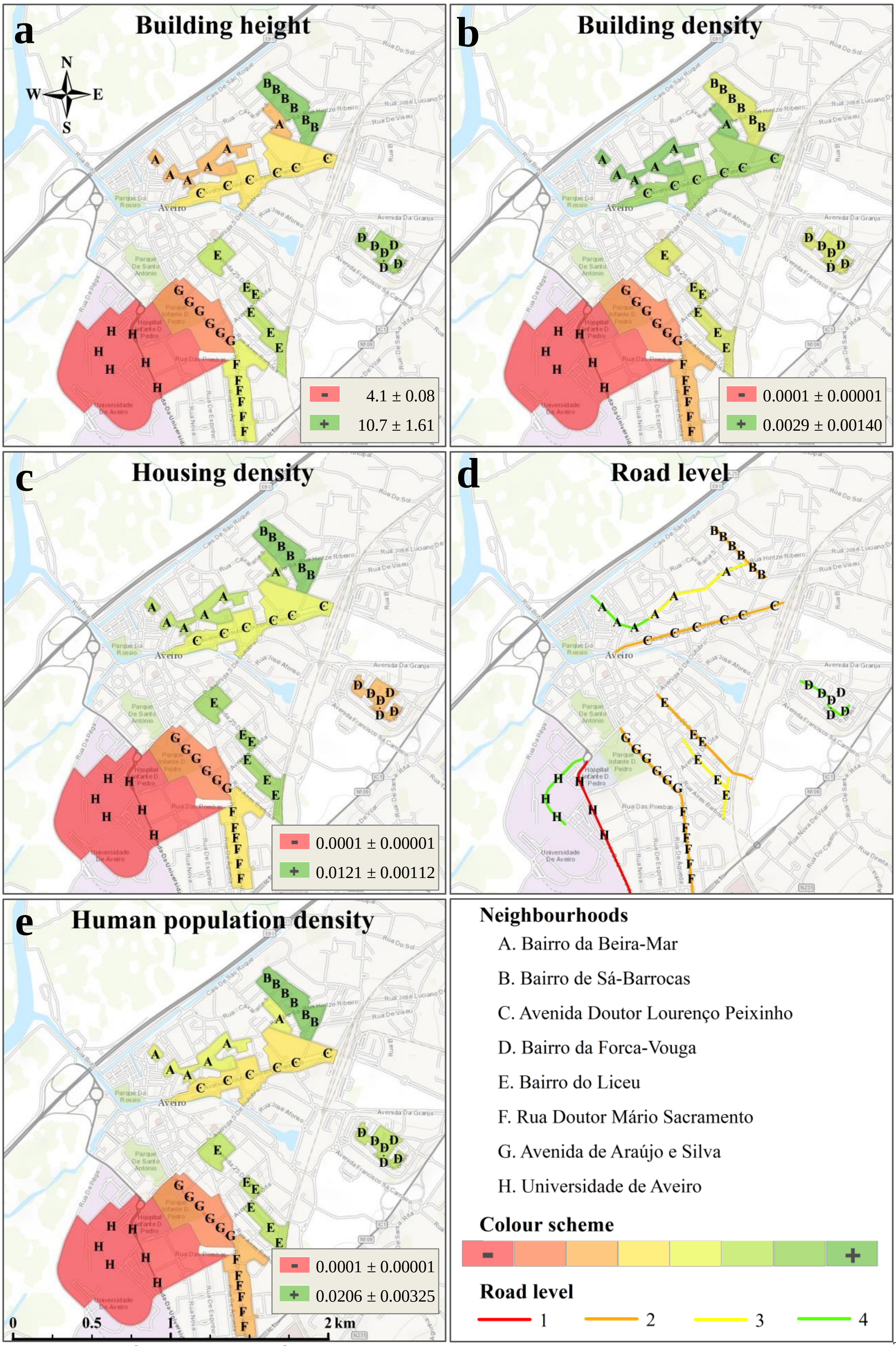


Figure 6. Maps of the study area for variables: (a) building height (m), (b) building density (buildings/m^2), (c) housing density (housings/m^2), (d) road level and (e) human population density (persons/m^2). Colour scheme of maps (a), (b), (c) and (e) based on the means of the variables for each neighbourhood. Neighbourhoods discriminated as letters located on the bird survey points.

3.2.11. Human population density

The Bonferroni tests results for this variable ($p \leq 0.05$; see Appendix 7) combined with the means in Appendix 6 represented in Figure 6.e show that: (1) neighbourhood B has significantly higher human population density than the remaining neighbourhoods; whereas (2) neighbourhood H has significantly lower human population density than all of the other neighbourhoods; and finally (3) both neighbourhoods D and E have a significantly higher human population density than neighbourhood G.

3.2.12. Household size

As for the household size: Figure 7.a, the means in Appendix 6 and the Bonferroni tests results ($p \leq 0.05$; see Appendix 7) demonstrate that neighbourhood H has significantly larger families than neighbourhood D, while both of these neighbourhoods have significantly bigger households than the remaining neighbourhoods. However, neighbourhood H has a particularly low human population density (0.0001 ± 0.00001; see Appendix 6) and consequently the results above concerning this neighbourhood lose some reliability.

3.2.13. Ageing index

The combination of the results in Appendix 7 (Bonferroni tests $p \leq 0.05$), Figure 7.b and respective means in Appendix 6, leads to the conclusion that (1) neighbourhood B has significantly younger people than neighbourhoods E, G and H; (2) neighbourhood D also has significantly younger people than neighbourhoods G and H; and (3) neighbourhood H has significantly older people than neighbourhood F. Again, the human population density of neighbourhood H is extremely low (0.0001 ± 0.00001; see Appendix 6) and therefore the conclusions mentioned above concerning this neighbourhood are not very reliable.

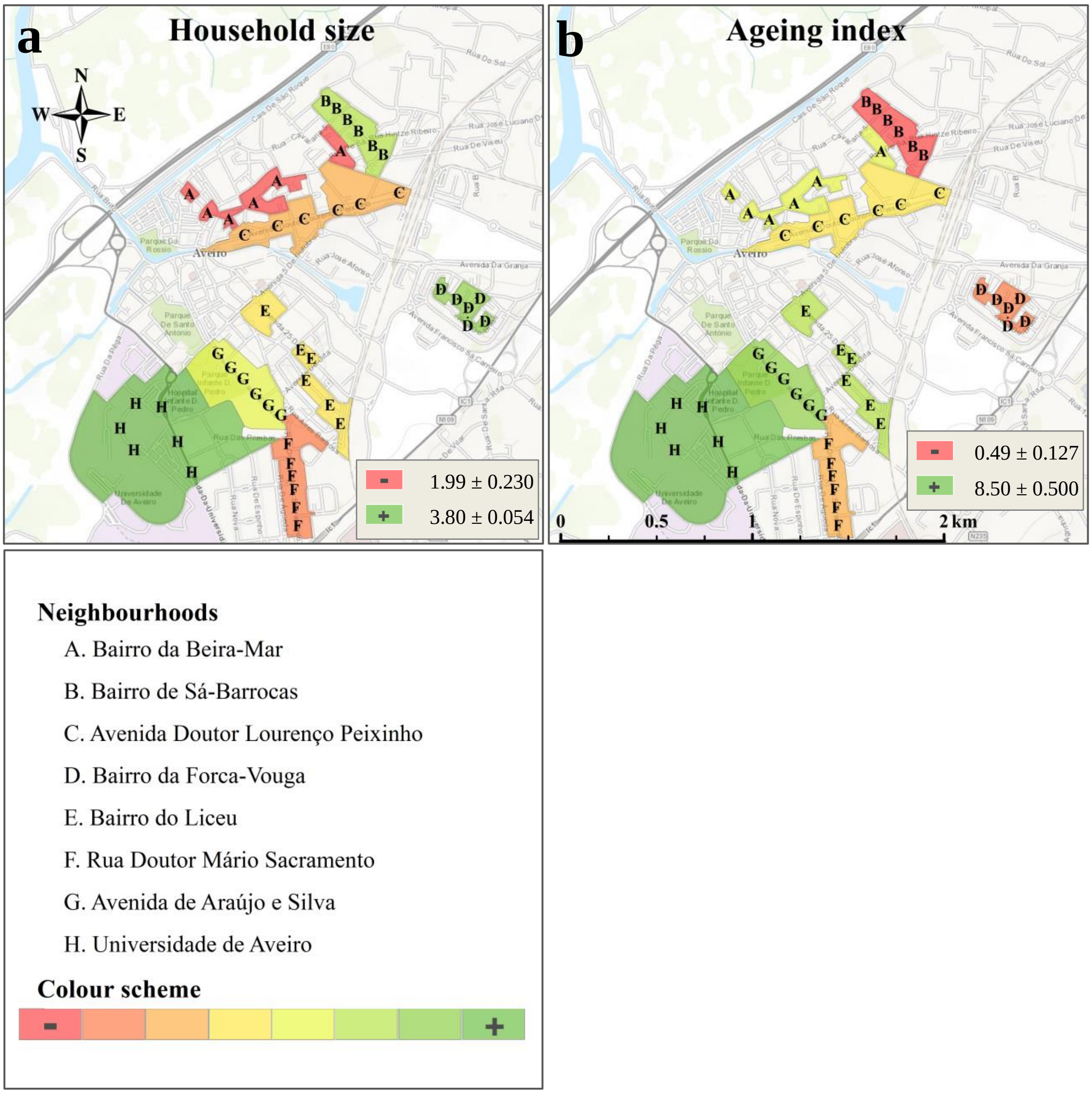


Figure 7. Maps of the study area for variables: (a) household size and (b) Ageing index. Colour scheme based on the means of the variables for each neighbourhood. Neighbourhoods discriminated as letters located on the bird survey points.

3.3. Associations between explanatory and avian variables

In order to investigate whether minimum distance to food, minimum distance to esplanades, density of trees, imperviousness, building age, height and density, road level and human population linearly correlate to species richness or global abundance, Pearson correlation coefficients were calculated (Appendix 8). These coefficients were also calculated for the abundance of species *Columba livia* and *Passer domesticus* - which represent more than 50% of the global abundance – regarding the same features as well as household size and ageing index. However there was no relevant linear correlation (r = -1 would indicate maximum negative linear correlation and r = 1 would indicate maximum positive linear correlation) for any pair of variables.

Due to the complexity of ecological processes as well as the lack of strong correlations, multiple regression models considering the features mentioned above were used to predict species richness as well as global abundance and the abundances of *C. livia* and *P. domesticus* (also referred as response variables). Neighbourhood H was drawn from these analyses due to the unreliability of the variables household size and ageing index associated to this neighbourhood. Preliminary data analyses were conducted to choose likely candidate models for each response variable. After computing Poisson GLMs for the four response variables, a stepwise AIC was performed to choose the best fitted models with smaller sets of predictors. By analysing the ΔAIC, three models were selected as the best fitted for species richness, whereas two models were selected as the best fitted for each remaining response variable (see Appendix 9.1). However, the best fitted models for global, *C. livia* and *P. domesticus* abundances accused overdispersion (Φ) (see Appendixes 9.1.2, 9.1.3 and 9.1.4) and consequently, Negative Binomial GLMs (link function: $\eta = \log \mu$) were performed for these three response variables. Then, the stepwise AIC selected two likely candidate Negative Binomial models for global abundance and the abundance of *C. livia* (Appendices 9.2.1 and 9.2.2) and three likely candidate Negative Binomial models for the abundance of *P. domesticus* (Appendix 9.2.3).

For the best fitted models – two Poisson GLMs for species richness, three Negative Binomial GLMs for global abundance and two Negative Binomial GLMs for the abundances of *C. livia* and *P. domesticus* – the Q-Q normality plots show a few outliers and the residuals in sampling order express a slight dependence on time (see Appendix 9.3).

Table 8 shows the values of the regression coefficients for variables related to species richness and global, *C. livia* and *P. domesticus* abundances averaged across the selected models (see Appendices 9.1.1, 9.2.1, 9.2.2 and 9.2.3 for full results of model selection).

Spatial variation of species richness is positively associated to minimum distance to esplanades, building height as well as both densities of trees and buildings, and negatively associated to imperviousness, road level and human population density.

Table 8. Estimated regression coefficients for intercept values, explanatory variables for best multiple regression models selected using AIC (Akaike's Information Criteria). Full AIC results are presented in Appendix 9. Coefficients for variables that appeared in more than one model with ΔAIC ≤ 2 were averaged across models.

Variable	Regression coefficients			
	Species richness	Abundance		
		Global	*Columba livia*	*Passer domesticus*
Intercept	2.5464	2.6992	2.5605	2.0445
Minimum distance to food establishments	-	-	-0.0049	-
Minimum distance to esplanades	0.0001	0.0008	0.0069	0.0017
Density of trees	18.7398	-	-112.5500	98.4350
Imperviousness	-0.0107	-	-	0.0194
Building age	-	0.0059	-	-0.0220
Building height	0.0083	0.0858	0.1900	-0.0813
Building density	115.5996	190.7569	172.7000	-182.6000
Road level	-0.1160	-0.1700	-0.3488	0.4945
Human Population density	-17.7172	-53.4823	-61.1950	-
Household size	N/A	N/A	-0.5885	-1.1635
Ageing Index	N/A	N/A	-	0.0293

Global abundance is positively associated to minimum distance to esplanades and every building feature, and negatively associated to road level and human population density.

The abundance of *C. livia* is positively related to minimum distance to esplanades, building age and height. This response variable is negatively related to minimum distance to food establishments, density of trees, road level and human population density.

The abundance of *P. domesticus* responds in the opposite way concerning some variables – it is positively associated to density of trees and road level whereas negatively associated to building height and density. Additionally, this variable positively responds to minimum distance to esplanades, imperviousness and ageing index, and negatively responds to building age and household size. The absolute values of these coefficients might however be biased due to the small units of the density variables and large units of the distances.

3.4. Vertical distribution of avifauna

In addition to the investigation of the relationship between the avian, land use and social variables, and as mentioned in Chapter II an analysis of the vertical distribution of avifauna was also performed. In this particular bird survey, only 18 species were observed, which include the same species observed in the 10 minutes point counts, except for *Corvus corone* and *Pica pica*.

As shown in Table 9, the medium level had the highest total species richness, abundance and biomass, followed by the high level. The medium level was also the most diverse, according to the Shannon index (2.721) and presented the highest species equitability (Pielou index of 0.653). As for the high and low levels, both Shannon and Pielou indexes have similar values, even though the higher level showed especially higher values abundance and biomass values than the lower level.

Table 9. Species richness, abundance, biomass, Shannon index and Pielou index per height level. Species richness, abundance and biomass represent the totals for each height level. Shannon index and Pielou index were calculated based on every sample of the respective height level.

Height levels	Species richness	Abundance	Biomass (kg)	Shannon index	Pielou index
High	12	756	79.2	1.552	0.490
Medium	18	1027	108.0	2.721	0.653
Low	9	149	9.3	1.662	0.464

By the analysis of the mean abundances of each bird species per height level, it is possible to conclude that *Apus apus* was the most abundant species in the high level, whereas in the medium and low levels, the most abundant species is *Passer domesticus* (Table 10). It is also important to enhance that the species that occurred in more than one height level were most abundant in the intermediate level, with the exception of *Apus apus* and *Phoenicurus ochruros* (both most abundant in the higher level).

Table 10. Mean abundance and standard deviation of each species per height level.

Species	High level		Medium level		Low level	
	Mean	SD	Mean	SD	Mean	SD
Apus apus	1.950	3.7369	0.721	2.5935	0.008	0.1288
Carduelis carduelis	-	-	0.058	0.3718	-	-
Chloris chloris	0.008	0.0909	0.108	0.4041	-	-
Columba livia	0.721	2.7052	0.833	2.6452	0.033	0.2392

Cyanistes caeruleus	-	-	0.013	0.1111	-	-
Delichon urbicum	0.033	0.3399	0.050	0.2533	-	-
Dendrocopus major	-	-	0.004	0.0644	-	-
Hirundo rustica	-	-	0.013	0.1932	-	-
Motacilla alba	0.004	0.0644	0.013	0.1111	0.008	0.0909
Parus major	-	-	0.008	0.1288	-	-
Passer domesticus	0.258	0.7637	1.533	2.0018	0.421	1.2324
Phoenicurus ochruros	0.021	0.2318	0.017	0.1280	0.004	0.0644
Ptyonoprogne rupestris	0.033	0.2014	0.054	0.3668		
Serinus serinus	0.008	0.0909	0.146	0.3974	0.004	0.0644
Streptopelia decaocto	0.088	0.3935	0.471	0.9350	0.025	0.1809
Sturnus unicolor	0.008	0.1288	0.033	0.2560	-	-
Sylvia atricapilla	-	-	0.008	0.0909	0.004	0.0644
Turdus merula	0.017	0.1572	0.196	0.5469	0.113	0.5551

In Figure 8 the total species richness, abundance and biomass in each neighbourhood per height level is presented. Firstly, for the low level, species richness ranged between 2 and 5 species across the neighbourhoods, whereas in the high level it ranged between 4 and 7 species. As for the medium level, neighbourhood A had the lowest species richness (S = 5) while neighbourhood E showed the highest number of species (S = 13).

Secondly, even though neighbourhood E had notably the highest absolute values for total abundance in every height level, neighbourhood B showed the highest relative frequency of abundance amongst neighbourhoods for the medium level (83%) and the same happened with neighbourhood H for the higher level (55%). Nevertheless, except for neighbourhood E, no more than 10% of the total individuals observed in each neighbourhood were located in the lower level. (Figure 8)

Thirdly and finally, as shown on Figure 8, neighbourhood E also presented the highest absolute values for total biomass in each height level. However, for the higher level, neighbourhood H had the highest relative frequency of biomass amongst neighbourhoods (69%) whereas neighbourhood F showed the highest percentage for the medium level (72%), followed by neighbourhood B (70%). Additionally, for both abundance and biomass only one neighbourhood showed greater relative frequency in the high level (55% and 69% respectively) opposed to the medium level (36% and 25% respectively).

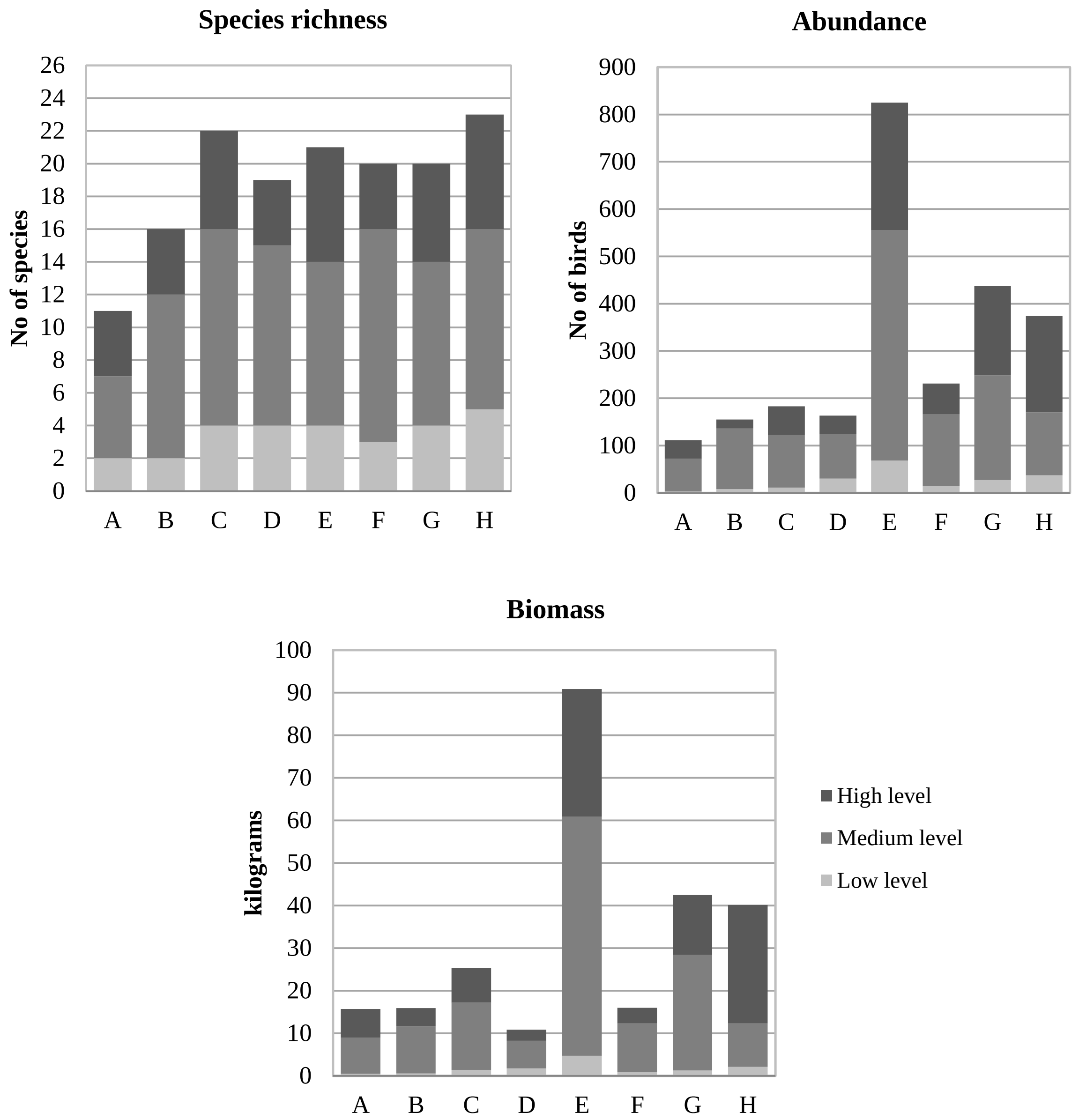


Figure 8. Total species richness, abundance and biomass per height level in each neighbourhood. Note: sum of species richness of the three height levels does not correspond to the total number of observed species.

CHAPTER IV – DISCUSSION

In this study the influence of social and land use features on urban avifauna was investigated. The results showed that sets of certain features successfully predict species richness, global abundance, as well as the abundances of the common species Feral Pigeon (*Columba livia*) and House Sparrow (*Passer domesticus*), even though single features were not linearly related to the avifauna. Moreover, the results suggest that the studied features, as well as the avian diversity, abundance and biomass significantly vary in a local urban scale. Finally, the results demonstrated that a vertical distribution of avifauna exists; in particular most species are present in a medium height level.

4.1. The avian urban community of Aveiro

The urban bird communities are typically different from the bird communities of adjacent natural habitats (Blair, 1996; Clergeau *et al.*, 1998; Melles *et al.*, 2003; Rolando *et al.*, 1997). Usually, urban bird communities exhibit low biodiversity, which according to Carvalho (2012) was the case of Aveiro in 2011. However, in the present investigation the global avian biodiversity of the urban area of Aveiro was considered moderate (H' = 2.790 and P = 0.646). Possible justifications for this discrepancy might be the different methodologies used or possible temporal variation of the bird community.

The selected features appear to be good characterizers of the urban area of Aveiro, showing the local complexity of the city. However, according to Melles *et al.* (2003) focusing solely on local features does not take into account the surroundings that might influence avian communities in an urban area. Additionally, Hostetler and Holling (2000) pointed out that many birds may respond to landscape structure in different scales. According to the same authors body size is an approximate indicator of the scales that certain species respond to landscape structure.

Species richness varied among the neighbourhoods, in particular between neighbourhoods G and H (higher species richness) and neighbourhoods A, B, C and D (lower species richness). Hence, neighbourhoods G and H showed the higher total diversity – Shannon indexes of 2.916 and 3.187 and Pielou indexes of 0.713 and 0.780 respectively. According to the Poisson GLMs, the number of species is higher in areas furthest away from esplanades, with higher trees and building densities as well as building height, and lower imperviousness, human population density and road level. Neighbourhoods with higher density of trees and lower percentage of imperviousness hold higher species richness (Loss *et al.*, 2009; Melles *et al.*, 2003; Ortega-Álvarez and MacGregor-Fors, 2009). Even though the variable road level was not strongly related to the percentage of imperviousness or the density of trees (Pearson correlation coefficients of -0.33 and -0.06 respectively), the relationships are negative, as many low level roads are avenues with a grass or shrub central reservations and some trees (personal observation), and consequently, lower level roads were related to higher species richness.

At a regional scale, species richness is positively associated to the human resident population (Gaston and Evans, 2004). However our results show that at a local scale, species richness appears to be lower in areas where more humans inhabit. Additionally, species richness was expected to decrease in areas with higher densities of buildings (Evans *et al.*, 2009) as well as higher buildings, as according to the Pearson correlation coefficients (-0.13 and -0.21 respectively), the relationships between species richness and these features were negative. Nevertheless, the Poisson GLMs reversed these relationships, probably due to the influence of the remaining explanatory variables (Dobson, 2002).

The best fitted Negative Binomial GLMs for global abundance showed that it was positively related to minimum distance to esplanades, building age, height and density, and negatively related to road level and human population density. In particular, global abundance increases in busier streets (low road level) whereas in Mexico City, it increases in areas with more pedestrians/min and less cars/min (Ortega-Álvarez and MacGregor-Fors, 2009). Additionally, this investigation supports the findings of Loss *et al.* (2009) – global abundance is higher in older neighbourhoods.

As in many urban areas, the Aveiro bird communities hold more individuals of omnivorous species, such as the Feral Pigeon (*Columba livia*) and the House Sparrow (*Passer domesticus*), than species from other diet guilds (Carvalho, 2012; Clergeau *et al.*, 1998; Ortega-Álvarez and MacGregor-Fors, 2009). Apart from this diet guild, neighbourhoods with higher density of trees (neighbourhoods E – Bairro do Liceu, F – Avenida Araújo e Silva and H – Universidade de Aveiro) appear to hold more individuals of granivorous species (for instance *Streptopelia decaocto* and *Serinus serinus*) than of insectivorous species (such as *Apus apus* and *Motacilla alba*). One possible justification for these results could be that areas with more trees provide specific resources for granivorous species (Hulme and Benkman, 2009) and therefore might favour them.

As suggested by Carvalho (2012) and the results of this study, the Feral Pigeon (*C. livia*) and House Sparrow (*P. domesticus*) are the dominant species of the urban area of Aveiro. These two gregarious species are not affected by urban spatial planning and are consequently highly adapted to urban areas (Emlen, 1974).

The results of the best fitted Negative Binomial GLMs suggest that species *C. livia* and *P. domesticus* respond differently to local land use and building features: (1) as the density of trees and road level increase, the abundance of *C. livia* decreases whereas the abundance of *P. domesticus* increases; and (2) as the building height and density increase, the abundance of *C. livia* increases and the abundance of *P. domesticus* decreases. These results suggest that even though *P. domesticus* is an urban exploiter, it still relies on the presence of trees compared to *C. livia*, which is more related to building features. *C. livia* breeds and feeds in urbanized areas, especially in historic centres, where building density is higher (neighbourhoods A and C), as well as other types of neighbourhoods as long as the building features promote its presence (Sacchi *et al.*, 2002), which is the case of neighbourhood E. Even though Bairro do Liceu (neighbourhood E) was built following a garden-city concept, the architecture of its buildings offers optimal nesting sites for this species. These results also suggest that in future research, these two species should be analysed separately. Both the abundances of *C. livia* and *P. domesticus* were additionally related to household size which suggests that these species are present in areas with smaller households, where people feed the Feral Pigeons (Ferreira, 2014) and subsequently their fellow urban exploiter House Sparrow. The abundance of Feral Pigeons was expected to increase in areas with higher ageing index, once according to Ferreira (2014) older people enjoy feeding this species; however this relationship was not present according to both the Pearson correlation coefficient and Negative Binomial GLMs.

The relationships between species richness and abundance with building height were not considered relevant (Pearson correlation coefficients of -0.21 and -0.03 respectively). However, the study of the avian vertical distribution revealed that every observed species was present in medium height, coinciding with the trees' crowns. Furthermore, this height level showed the highest diversity (H'=2.721 and P=0.653), which suggests its relevance for most species.

4.2.Urban planning recommendations

As suggested by Hostetler (1999), human decisions impact the urban landscape at different scales. Moreover, Savard *et al.* (2000) presented a multiscale approach to enhance bird diversity and abundance in cities. In a larger scale, the same authors advise the conservation and restoration of bird habitats in the city surroundings and the consolidation of the right vegetation corridors linking those habitats to the city. Additionally, in their study the importance of city natural and recreational parks for avian diversity is enhanced, especially size and shape of the parks as well as the structural diversity of vegetation. The implementation of bird feeders and nest boxes for particular species in urban parks is also recommended.

In medium and local scales Savard *et al.* (2000) suggest to increase the volume and diversity of native vegetation in the city to enhance insect and bird diversity, for example along streets. Specifically, city urban planners and homeowners should plant conifer trees (greatly used for bird cover in winter), fruit trees (to attract frugivorous species) and shrubs (Savard *et al.*, 2000) as well as decrease the size or eliminate the impermeable/terraced spaces (Smith *et al.*, 2005).

Furthermore, the populations of *Columba livia* (Feral Pigeon) are increasingly dominant, sometimes becoming a pest in urban areas. Due to some issues related to this species such as public health risks (as Feral Pigeons are reservoirs and potential vectors of animal and human diseases) and infrastructural damages to the buildings (caused by Feral Pigeons droppings), a need for pest control is evident in some cities (Giunchi *et al.*, 2012). As suggested by Ferreira (2014), most private citizens of Aveiro are comfortable non-aggressive solutions, for instance transferring the Feral Pigeons to local dovecotes and/or natural habitats as well as removing them with birds of prey or even removing their nests and eggs. Other possible and probably easier solution would be the elimination of common nesting sites, such as degraded buildings (Giunchi *et al.*, 2012), by sealing them.

In particular, and based on the results of the present investigation, it is recommended that key stakeholders - such as city urban planners, companies and NGO's (Non-Governmental Organizations) as well as private citizens - support for nature conservation in the city (Snep *et al.*, 2015) through the implementation of the suggestions itemized in Table 11. It is crucial to highlight the relevance of these suggestions in order to enhance and maintain avian diversity in the urban area of Aveiro.

Table 11. Specific urban planning recommendations for the city of Aveiro. Adapted from Savard *et al*. (2000), Smith *et al.* (2005) and Snep *et al* (2015).

	Neighbourhoods	Increase vegetation volume	Increase vegetation diversity (native)	Increase permeable surfaces	Increase the number of gardens	Restore or seal degraded buildings	Implement bird feeders	Implement nest boxes
A	Bairro da Beira-Mar	X	X	X	X*	X		
B	Bairro de Sá-Barrocas	X	X	X	X*			
C	Avenida Doutor Lourenço Peixinho	X	X	X	X*	X		
D	Bairro da Forca-Vouga	X	X	X				
E	Bairro do Liceu	X	X	X				
F	Rua Doutor Mário Sacramento	X	X	X				
G	Avenida Araújo e Silva		X					
H	Universidade de Aveiro	X	X					
	City parks	X	X				X	X

* e.g. roof gardens if lack of ground space.

4.3. Limitations and future urban avifauna research

A possible limitation to this investigation would be the small distance between the point counts as well as the reduced size of the radius, which could have caused spatial dependence, yet the residuals of every selected model did not show this type of dependence. Furthermore, the fact that this study focused on local scale features, enhancing the complexity of the urban fabric of Aveiro, might have compromised the predictions provided by the models. Moreover, this study excluded possible relationships between the urban avian communities and the outskirts of the city.

As consequence, future research on the urban bird communities of Aveiro should not only focus on local features but also in an urbanization gradient. For instance, bird surveys could be performed in subjacent suburban and rural areas (Melles *et al.*, 2003); and features such as distance to artificial green spaces and natural habitats, as well as vegetation structure should be included. Furthermore, studies of this nature could be performed in several urban areas in order to compare avian communities in different urban environments.

Finally, the inclusion of social and urban planning researchers successfully enriched this investigation, which enhances the relevance of interdisciplinary collaboration when studying biodiversity in urban environments.

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APPENDIX 1

Field survey data sheet.

Neighbourhood	**Points**	**Date**
Observer Mariana Morgado		
Volunteers		
Weather		
Notes		

Hour	Point	Level	1 minute survey	10 minutes survey
		3		
		2		
		1		
		3		
		2		
		1		
		3		
		2		
		1		
		3		
		2		
		1		
		3		
		2		
		1		
		3		
		2		
		1		

APPENDIX 2

Absolute and relative frequencies of the observed bird species.

Species	Absolute frequency	Relative frequency
Apus apus	889	0.202
Carduelis carduelis	20	0.005
Chloris chloris	84	0.019
Columba livia	1121	0.255
Corvus corone	2	0.000
Cyanistes caeruleus	22	0.005
Delichon urbicum	39	0.009
Dendrocopus major	1	0.000
Hirundo rustica	44	0.010
Motacilla alba	24	0.005
Parus major	9	0.002
Passer domesticus	1178	0.268
Phoenicurus ochruros	30	0.007
Pica pica	4	0.001
Ptyonoprogne rupestris	47	0.011
Serinus serinus	126	0.029
Streptopelia decaocto	473	0.108
Sturnus unicolor	43	0.010
Sylvia atricapilla	18	0.004
Turdus merula	218	0.050
Total	4392	1.000

APPENDIX 3

Diet guild of each observed bird species.

Species	Diet guild	Reference
Apus apus	Insectivorous	(Cramp, 1985, p. 660)
Carduelis carduelis	Granivorous	(Cramp *et al.*, 1994, p. 573)
Chloris chloris	Granivorous	(Cramp *et al.*, 1994, p. 553)
Columba livia	Omnivorous	(Cramp, 1985, p. 287)
Corvus corone	Omnivorous	(Cramp *et al.*, 1994, p. 177)
Cyanistes caeruleus	Insectivorous	(Cramp *et al.*, 1993, p. 251)
Delichon urbicum	Insectivorous	(Cramp, 1988, p. 289)
Dendrocopus major	Insectivorous	(Cramp, 1985, p. 859)
Hirundo rustica	Insectivorous	(Cramp, 1985, p. 266)
Motacilla alba	Insectivorous	(Cramp, 1985, p. 459)
Parus major	Insectivorous	(Cramp *et al.*, 1993, p. 259)
Passer domesticus	Omnivorous	(Cramp *et al.*, 1994, p. 294)
Phoenicurus ochruros	Insectivorous	(Cramp, 1985, p. 699)
Pica pica	Omnivorous	(Cramp *et al.*, 1994, p. 58)
Ptyonoprogne rupestris	Insectivorous	(Cramp, 1988, p. 256)
Serinus serinus	Granivorous	(Cramp *et al.*, 1994, p. 513)
Streptopelia decaocto	Granivorous	(Cramp, 1985, p. 344)
Sturnus unicolor	Omnivorous	(Cramp *et al.*, 1994, p. 262)
Sylvia atricapilla	Insectivorous	(Cramp and Duncan, 1992, p. 502)
Turdus merula	Omnivorous	(Cramp, 1988, p. 953)

APPENDIX 4

Tests of normality (Shapiro-Wilk test and Kolmogorov-Smirnov one sample test) performed to each neighbourhood sample for avian, land use and social variables.

Variable	Neighbourhood	Shapiro-Wilk			Kolmogorov-Smirnov		
		Statistic	df	p-value	Statistic	df	p-value
Species richness	A	0.945	30	0.123	0.911	30	0.000
	B	0.916	30	0.021	0.944	30	0.000
	C	0.906	30	0.012	0.977	30	0.000
	D	0.901	30	0.009	0.911	30	0.000
	E	0.922	30	0.029	0.977	30	0.000
	F	0.940	30	0.090	0.977	30	0.000
	G	0.848	30	0.001	1.000	30	0.000
	H	0.966	30	0.447	0.944	30	0.000
Abundance	A	0.837	30	0.000	0.977	30	0.000
	B	0.844	30	0.000	0.999	30	0.000
	C	0.975	30	0.670	0.999	30	0.000
	D	0.932	30	0.055	1.000	30	0.000
	E	0.980	30	0.830	1.000	30	0.000
	F	0.928	30	0.045	1.000	30	0.000
	G	0.906	30	0.012	1.000	30	0.000
	H	0.917	30	0.023	0.965	30	0.000
Biomass	A	0.691	30	0.000	1.000	30	0.000
	B	0.960	30	0.306	1.000	30	0.000
	C	0.880	30	0.003	1.000	30	0.000
	D	0.754	30	0.000	1.000	30	0.000
	E	0.928	30	0.044	1.000	30	0.000
	F	0.725	30	0.000	1.000	30	0.000
	G	0.889	30	0.005	1.000	30	0.000
	H	0.952	30	0.189	0.967	30	0.000
Shannon Index	A	0.905	30	0.011	0.558	30	0.000
	B	0.965	30	0.522	0.626	30	0.000
	C	0.991	30	0.994	0.636	30	0.000
	D	0.973	30	0.631	0.599	30	0.000
	E	0.948	30	0.149	0.736	30	0.000
	F	0.978	30	0.763	0.723	30	0.000
	G	0.938	30	0.079	0.824	30	0.000
	H	0.950	30	0.170	0.682	30	0.000
Pielou Index	A	0.812	30	0.000	0.559	30	0.000
	B	0.689	30	0.000	0.656	30	0.000
	C	0.929	30	0.046	0.622	30	0.000
	D	0.804	30	0.000	0.604	30	0.000
	E	0.919	30	0.026	0.708	30	0.000
	F	0.942	30	0.106	0.742	30	0.000
	G	0.899	30	0.008	0.715	30	0.000
	H	0.580	30	0.000	0.712	30	0.000
Minimum distance to food establishments	A	0.839	6	0.129	1.000	6	0.000
	B	0.903	6	0.394	1.000	6	0.000

	C	0.958	6	0.804	1.000	6	0.000
	D	0.855	6	0.174	1.000	6	0.000
	E	0.915	6	0.470	1.000	6	0.000
	F	0.963	6	0.846	1.000	6	0.000
	G	0.876	6	0.253	1.000	6	0.000
	H	0.945	6	0.701	1.000	6	0.000
Minimum distance to esplanades	A	0.895	6	0.343	1.000	6	0.000
	B	0.894	6	0.342	1.000	6	0.000
	C	0.852	6	0.162	1.000	6	0.000
	D	0.989	6	0.986	1.000	6	0.000
	E	0.882	6	0.279	1.000	6	0.000
	F	0.796	6	0.055	1.000	6	0.000
	G	0.865	6	0.206	1.000	6	0.000
	H	0.843	6	0.137	1.000	6	0.000
Density of trees	A	0.640	6	0.001	0.500	6	0.100
	B	0.942	6	0.671	0.501	6	0.099
	C	0.976	6	0.932	0.500	6	0.100
	D	0.932	6	0.593	0.500	6	0.100
	E	0.908	6	0.422	0.502	6	0.097
	F	0.870	6	0.228	0.501	6	0.098
	G	0.751	6	0.203	0.502	6	0.097
	H	0.923	6	0.528	0.502	6	0.064
Imperviousness	A	0.715	6	0.009	1.000	6	0.000
	B	0.654	6	0.002	1.000	6	0.000
	C	0.822	6	0.091	1.000	6	0.000
	D	0.935	6	0.621	1.000	6	0.000
	E	0.940	6	0.658	1.000	6	0.000
	F	9.769	6	0.030	1.000	6	0.000
	G	0.966	6	0.861	1.000	6	0.000
	H	0.849	6	0.155	1.000	6	0.000
Building age	A	0.956	6	0.789	1.000	6	0.000
	B	0.776	6	0.034	1.000	6	0.000
	C	0.964	6	0.852	1.000	6	0.000
	D	0.915	6	0.473	1.000	6	0.000
	E	0.895	6	0.343	1.000	6	0.000
	F	0.904	6	0.399	1.000	6	0.000
	G	0.641	6	0.001	1.000	6	0.000
	H	0.683	6	0.004	1.000	6	0.000
Building height	A	0.956	6	0.789	1.000	6	0.000
	B	0.776	6	0.035	1.000	6	0.000
	C	0.964	6	0.852	1.000	6	0.000
	D	0.915	6	0.473	1.000	6	0.000
	E	0.895	6	0.343	1.000	6	0.000
	F	0.904	6	0.399	1.000	6	0.000
	G	0.641	6	0.001	1.000	6	0.000
	H	0.683	6	0.004	1.000	6	0.000
Building density	A	0.771	6	0.032	0.501	6	0.065
	B	0.856	6	0.177	0.500	6	0.099
	C	0.901	6	0.379	0.500	6	0.065

	D	0.933	6	0.604	0.500	6	0.065
	E	0.913	6	0.459	0.500	6	0.065
	F	0.777	6	0.036	0.500	6	0.099
	G	0.914	6	0.462	0.500	6	0.100
	H	0.683	6	0.004	0.500	6	0.100
Housing density	A	0.865	6	0.207	0.501	6	0.064
	B	0.891	6	0.323	0.504	6	0.095
	C	0.947	6	0.713	0.500	6	0.065
	D	0.789	6	0.046	0.501	6	0.065
	E	0.888	6	0.309	0.502	6	0.064
	F	0.620	6	0.001	0.502	6	0.097
	G	0.912	6	0.450	0.500	6	0.099
	H	0.683	6	0.004	0.500	6	0.100
Human population density	A	0.896	6	0.349	0.502	6	0.064
	B	0.809	6	0.070	0.506	6	0.092
	C	0.977	6	0.934	0.500	6	0.065
	D	0.819	6	0.086	0.502	6	0.064
	E	0.908	6	0.425	0.503	6	0.063
	F	0.923	6	0.524	0.502	6	0.097
	G	0.885	6	0.292	0.500	6	0.099
	H	0.683	6	0.004	0.500	6	0.100
Household size	A	0.918	6	0.490	0.938	6	0.000
	B	0.744	6	0.017	0.984	6	0.000
	C	0.947	6	0.712	0.966	6	0.000
	D	0.918	6	0.488	0.992	6	0.000
	E	0.920	6	0.506	0.973	6	0.000
	F	0.912	6	0.446	0.975	6	0.000
	G	0.814	6	0.079	0.965	6	0.000
	H	0.683	6	0.004	1.000	6	0.000
Ageing Index	A	0.939	6	0.651	0.888	6	0.000
	B	0.894	6	0.337	0.619	6	0.020
	C	0.781	6	0.040	0.945	6	0.000
	D	0.946	6	0.703	0.569	6	0.023
	E	0.702	6	0.006	0.954	6	0.000
	F	0.675	6	0.003	0.971	6	0.000
	G	0.755	6	0.022	0.998	6	0.000
	H	0.683	6	0.004	1.000	6	0.000

APPENDIX 5

Tests of homoscedasticity (Levene's test) calculated between the eight neighbourhood samples for each variable.

Variable	Levene's test		
	Statistic	**df**	**p-value**
Minimum distance to food establishments	3.887	7	0.003
Minimum distance to esplanades	1.054	7	0.410
Density of trees	1.348	7	0.254
Imperviousness	6.725	7	0.000
Building age	2.692	7	0.022
Building height	3.548	7	0.005
Building density	2.093	7	0.067
Housing density	2.113	7	0.064
Human Population density	2.490	7	0.032
Household size	1.120	7	0.370
Ageing Index	1.384	7	0.239

APPENDIX 6

Means and standard deviation values for neighbourhood and variable.

Species richness									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Global**
Mean	3.967	3.633	3.967	3.600	4.833	4.367	5.400	4.967	4.342
SD	1.6224	1.3034	1.2243	1.6852	1.0980	1.2512	1.4514	2.1830	1.6355
Abundance									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Global**
Mean	18.700	11.700	22.133	15.167	23.967	18.833	21.567	14.333	18.300
SD	15.4513	7.2625	11.4767	8.4146	8.3206	5.6041	10.3269	9.8601	10.7561
Biomass (kg)									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Global**
Mean	2.231	1.094	3.801	1.707	3.409	2.103	2.231	1.378	2.245
SD	2.7917	0.5689	3.2076	1.7254	2.1246	1.5449	1.3284	0.9133	2.1519
Shannon index									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Global**
Mean	0.975	1.015	0.933	0.922	1.218	1.220	1.395	1.326	1.125
SD	0.4186	0.3680	0.3358	0.4334	0.2691	0.3095	0.2715	0.4694	0.4058
Pielou index									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Global**
Mean	0.713	0.806	0.697	0.732	0.786	0.849	0.845	0.858	0.786
SD	0.2516	0.1995	0.1849	0.2420	0.0964	0.0864	0.0979	0.1797	0.1883
Minimum distance to food establishments (m)									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Global**
Mean	11	51	20	101	63	40	92	86	58
SD	7.5	32.4	2.7	39.5	40.0	9.8	35.0	28.3	42.1
Minimum distance to esplanades (km)									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Global**
Mean	81	66	61	213	146	61	133	160	115
SD	58.2	38.2	41.2	77.1	87.4	33.3	40.1	63.7	78.4
Density of trees (trees/m^2)									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Global**
Mean	0.0003	0.0051	0.0021	0.0050	0.0077	0.0081	0.0074	0.0093	0.0056
SD	0.00048	0.00202	0.00145	0.00307	0.00234	0.00268	0.00166	0.00358	0.00375
Imperviousness (%)									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Global**
Mean	97.3	95.1	96.9	86.3	91.2	93.3	85.4	78.4	90.5
SD	3.93	5.20	1.68	8.90	4.23	6.09	7.30	18.29	10.44
Building age (years)									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Global**
Mean	57.3	25.9	45.0	15.2	36.0	34.3	45.2	35.9	36.9
SD	6.00	5.45	7.44	2.19	6.69	6.23	3.79	0.46	13.12

Building height (m)									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Global**
Mean	6.3	10.7	8.9	10.4	10.2	8.9	6.3	4.1	8.2
SD	0.64	1.61	0.96	1.07	2.26	0.28	1.01	0.08	2.53
Building density (buildings/m^2)									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Global**
Mean	0.0029	0.0013	0.0014	0.0013	0.0013	0.0009	0.0005	0.0001	0.0012
SD	0.00140	0.00040	0.00051	0.00014	0.00037	0.00009	0.00020	0.00001	0.00098
Housing density (housings/m^2)									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Global**
Mean	0.0060	0.0121	0.0057	0.0047	0.0077	0.0056	0.0010	0.0001	0.0054
SD	0.00223	0.00112	0.00285	0.00273	0.00240	0.00103	0.00060	0.00001	0.00400
Human population density (persons/m^2)									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Global**
Mean	0.0086	0.0206	0.0077	0.0098	0.0098	0.0066	0.0015	0.0001	0.0081
SD	0.00364	0.00325	0.00441	0.00461	0.00243	0.00134	0.00096	0.00001	0.00657
Household size									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Global**
Mean	1.99	2.23	2.03	2.70	2.06	1.99	2.13	3.80	2.37
SD	0.230	0.081	0.156	0.152	0.099	0.025	0.272	0.054	0.606
Ageing index									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Global**
Mean	4.16	0.49	3.93	0.62	5.23	3.39	5.87	8.50	4.02
SD	1.660	0.127	2.793	0.339	4.873	0.971	2.104	0.500	3.345

APPENDIX 7

Post-hoc tests for multiple comparisons of means (Bonferroni method) for each variable.

Variable	Pairs of neighbourhoods		p-value	Variable	Pairs of neighbourhoods		p-value
Species richness	A	B	1.000	**Abundance**	A	B	0.229
		C	1.000			C	1.000
		D	1.000			D	1.000
		E	0.845			E	1.000
		F	1.000			F	1.000
		G	0.011			G	1.000
		H	0.351			H	1.000
	B	C	1.000		B	C	0.003
		D	1.000			D	1.000
		E	0.079			E	0.000
		F	1.000			F	0.197
		G	0.000			G	0.006
		H	0.026			H	1.000
	C	D	1.000		C	D	0.236
		E	0.845			E	1.000
		F	1.000			F	1.000
		G	0.011			G	1.000
		H	0.351			H	0.091
	D	E	0.060		D	E	0.026
		F	1.000			F	1.000
		G	0.000			G	0.433
		H	0.019			H	1.000
	E	F	1.000		E	F	1.000
		G	1.000			G	1.000
		H	1.000			H	0.008
	F	G	0.277		F	G	1.000
		H	1.000			H	1.000
	G	H	1.000		G	H	0.176
Biomass	A	B	0.798	**Shannon Index**	A	B	1.000
		C	0.073			C	1.000
		D	1.000			D	1.000
		E	0.653			E	0.337
		F	1.000			F	0.322
		G	1.000			G	0.001
		H	1.000			H	0.009
	B	C	0.000		B	C	1.000
		D	1.000			D	1.000
		E	0.000			E	0.993
		F	1.000			F	0.956
		G	0.798			G	0.003
		H	1.000			H	0.040
	C	D	0.002		C	D	1.000
		E	1.000			E	0.092
		F	0.032			F	0.088
		G	0.073			G	0.000
		H	0.000			H	0.002
	D	E	0.031		D	E	0.066
		F	1.000			F	0.063
		G	1.000			G	0.000
		H	1.000			H	0.001

	E	F	0.337
		G	0.652
		H	0.003
	F	G	1.000
		H	1.000
	G	H	1.000
Pielou Index	A	B	1.000
		C	1.000
		D	1.000
		E	1.000
		F	0.113
		G	0.150
		H	0.062
	B	C	0.579
		D	1.000
		E	1.000
		F	1.000
		G	1.000
		H	1.000
	C	D	1.000
		E	1.000
		F	0.037
		G	0.050
		H	0.019
	D	E	1.000
		F	0.372
		G	0.478
		H	0.218
	E	F	1.000
		G	1.000
		H	1.000
	F	G	1.000
		H	1.000
	G	H	1.000
Minimum distance to esplanades	A	B	1.000
		C	1.000
		D	0.024
		E	1.000
		F	1.000
		G	1.000
		H	1.000
	B	C	1.000
		D	0.008
		E	1.000
		F	1.000
		G	1.000
		H	0.410

	E	F	1.000
		G	1.000
		H	1.000
	F	G	1.000
		H	1.000
	G	H	1.000
Minimum distance to food establishments	A	B	0.791
		C	1.000
		D	0.000
		E	0.168
		F	1.000
		G	0.002
		H	0.004
	B	C	1.000
		D	0.248
		E	1.000
		F	1.000
		G	0.862
		H	1.000
	C	D	0.001
		E	0.569
		F	1.000
		G	0.007
		H	0.018
	D	E	1.000
		F	0.045
		G	1.000
		H	1.000
	E	F	1.000
		G	1.000
		H	1.000
	F	G	0.181
		H	0.405
	G	H	1.000
Density of trees	A	B	0.077
		C	1.000
		D	0.089
		E	0.000
		F	0.000
		G	0.001
		H	0.000
	B	C	1.000
		D	1.000
		E	1.000
		F	1.000
		G	1.000
		H	0.189

	C	D	0.005		C	D	1.000
		E	0.737			E	0.015
		F	1.000			F	0.007
		G	1.000			G	0.029
		H	0.292			H	0.001
	D	E	1.000		D	E	1.000
		F	0.005			F	1.000
		G	0.996			G	1.000
		H	1.000			H	0.163
	E	F	0.706		E	F	1.000
		G	1.000			G	1.000
		H	1.000			H	1.000
	F	G	1.000		F	G	1.000
		H	0.279			H	1.000
	G	H	1.000		G	H	1.000
Imperviousness	A	B	1.000	**Building age**	A	B	0.000
		C	1.000			C	0.018
		D	1.000			D	0.000
		E	1.000			E	0.000
		F	1.000			F	0.000
		G	0.903			G	0.022
		H	0.030			H	0.000
	B	C	1.000		B	C	0.000
		D	1.000			D	0.073
		E	1.000			E	0.121
		F	1.000			F	0.445
		G	1.000			G	0.000
		H	0.093			H	0.132
	C	D	1.000		C	D	0.000
		E	1.000			E	0.303
		F	1.000			F	0.080
		G	1.000			G	1.000
		H	0.037			H	0.280
	D	E	1.000		D	E	0.000
		F	1.000			F	0.000
		G	1.000			G	0.000
		H	1.000			H	0.000
	E	F	1.000		E	F	1.000
		G	1.000			G	0.254
		H	0.596			H	1.000
	F	G	1.000		F	G	0.066
		H	0.232			H	1.000
	G	H	1.000		G	H	0.235
Building height	A	B	0.000	**Building density**	A	B	0.003
		C	0.040			C	0.003

		D	0.000
		E	0.000
		F	0.036
		G	1.000
		H	0.185
	B	C	0.607
		D	1.000
		E	1.000
		F	0.664
		G	0.000
		H	0.000
	C	D	1.000
		E	1.000
		F	1.000
		G	0.035
		H	0.000
	D	E	1.000
		F	1.000
		G	0.000
		H	0.000
	E	F	1.000
		G	0.000
		H	0.000
	F	G	0.038
		H	0.000
	G	H	0.206
Housing density	A	B	0.000
		C	1.000
		D	1.000
		E	1.000
		F	1.000
		G	0.005
		H	0.000
	B	C	0.000
		D	0.000
		E	0.020
		F	0.000
		G	0.000
		H	0.000
	C	D	1.000
		E	1.000
		F	1.000
		G	0.011
		H	0.001
	D	E	0.507
		F	1.000

		D	0.002
		E	0.001
		F	0.000
		G	0.000
		H	0.000
	B	C	1.000
		D	1.000
		E	1.000
		F	1.000
		G	0.531
		H	0.033
	C	D	1.000
		E	1.000
		F	1.000
		G	0.410
		H	0.024
	D	E	1.000
		F	1.000
		G	0.548
		H	0.034
	E	F	1.000
		G	0.690
		H	0.045
	F	G	1.000
		H	0.883
	G	H	1.000
Human Population density	A	B	0.000
		C	1.000
		D	1.000
		E	1.000
		F	1.000
		G	0.019
		H	0.002
	B	C	0.000
		D	0.000
		E	0.000
		F	0.000
		G	0.000
		H	0.000
	C	D	1.000
		E	1.000
		F	1.000
		G	0.067
		H	0.007
	D	E	1.000
		F	1.000

		G	0.106
		H	0.011
	E	F	1.000
		G	0.000
		H	0.000
	F	G	0.014
		H	0.001
	G	H	1.000
Household size	A	B	0.546
		C	1.000
		D	0.000
		E	1.000
		F	1.000
		G	1.000
		H	0.000
	B	C	1.000
		D	0.001
		E	1.000
		F	0.551
		G	1.000
		H	0.000
	C	D	0.000
		E	1.000
		F	1.000
		G	1.000
		H	0.000
	D	E	0.000
		F	0.000
		G	0.000
		H	0.000
	E	F	1.000
		G	1.000
		H	0.000
	F	G	1.000
		H	0.000
	G	H	0.000

		G	0.003
		H	0.000
	E	F	1.000
		G	0.003
		H	0.000
	F	G	0.339
		H	0.043
	G	H	1.000
Ageing Index	A	B	0.366
		C	1.000
		D	0.461
		E	1.000
		F	1.000
		G	1.000
		H	0.109
	B	C	0.546
		D	1.000
		E	0.049
		F	1.000
		G	0.013
		H	0.000
	C	D	0.682
		E	1.000
		F	1.000
		G	1.000
		H	0.069
	D	E	0.064
		F	1.000
		G	0.018
		H	0.000
	E	F	1.000
		G	1.000
		H	0.728
	F	G	1.000
		H	0.023
	G	H	1.000

APPENDIX 8

Pearson correlation coefficients.

Variable	Pearson correlation coefficients			
	Species richness	**Abundance**		
		Global	***Columba livia***	***Passer domesticus***
Minimum distance to food establishments	0.15	-0.06	-0.16	0.14
Minimum distance to esplanades	0.10	0.00	0.00	0.18
Density of trees	0.31	0.03	-0.20	0.21
Imperviousness	-0.34	-0.06	0.11	-0.18
Building age	0.12	0.19	0.13	-0.20
Building height	-0.21	-0.01	0.12	0.16
Building density	-0.13	0.01	0.08	-0.04
Road level	-0.03	-0.11	-0.17	0.13
Human Population density	-0.30	-0.17	0.01	-0.03
Household size	N/A	N/A	-0.18	-0.09
Ageing Index	N/A	N/A	0.00	-0.06

APPENDIX 9

9.1. Poisson Generalized Linear Models

9.1.1. Full model selection for Species richness

	Model	K	AIC	ΔAIC	ω_i	Φ
1	3, 4, 7, 8, 9	6	787.13	0.00	0.623	0.453
2	3, 4, 6, 7, 8, 9	7	789.05	1.92	0.238	0.447
3	2, 3, 4, 6, 7, 8, 9	8	790.98	3.85	0.091	0.449
4	2, 3, 4, 5, 6, 7, 8, 9	9	792.88	5.75	0.035	0.451
5	Global	10	794.84	7.71	0.013	0.453

9.1.2. Full model selection for Global Abundance

	Model	K	AIC	ΔAIC	ω_i	Φ
1	2, 3, 5, 6, 7, 8, 9, 10	8	2047.70	0.00	0.568	5.264
2	2, 3, 4, 5, 6, 7, 8, 9, 10	9	2048.90	1.20	0.312	5.286
3	Global	10	2050.80	3.10	0.121	5.312

9.1.3. Full model selection for Abundance of *Columba livia*

	Model	K	AIC	ΔAIC	ω_i	Φ
1	1, 2, 3, 5, 6, 7, 8, 9, 10	10	1902.10	0.00	0.571	6.739
2	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	11	1903.30	1.20	0.313	6.768
3	Global	12	1905.30	3.20	0.115	6.802

9.1.4. Full model selection for Abundance of *Passer domesticus*

	Model	K	AIC	ΔAIC	ω_i	Φ
1	2, 3, 4, 6, 7, 8, 9, 10, 11	10	1255.80	0.00	0.6394652	3.100
2	1, 2, 3, 4, 6, 7, 8, 9, 10, 11	11	1257.60	1.80	0.2599871	3.114
3	Global	12	1259.50	3.70	0.1005477	3.130

Model Potential candidate models. Global model includes all variables.

K Number of model parameters (including regression intercept).

AIC Akaike's Information Criteria.

ΔAIC AIC differences (ΔAIC ≤ 2 indicates strong support for model).

ω_i Akaike weight of evidence (Indicates relative support for model).

Φ Overdispersion parameter.

Variable	Description
1	Minimum distance to food establishments
2	Minimum distance to esplanades
3	Density of trees
4	Imperviousness
5	Building age
6	Building height
7	Building density
8	Road level
9	Human Population density
10	Size of Household
11	Ageing Index

9.2. Negative Binomial Generalized Linear Models

9.2.1. Full model selection for Global Abundance

	Model	K	AIC	ΔAIC	ω_i	Φ
1	6, 7, 8, 9	5	1530.80	0.00	0.388	1.060
2	2, 6, 7, 8, 9	6	1531.50	0.70	0.274	1.064
3	2, 5, 6, 7, 8, 9	7	1532.10	1.30	0.203	1.070
4	2, 3, 5, 6, 7, 8, 9	8	1533.80	3.00	0.087	1.075
5	2, 3, 4, 5, 6, 7, 8, 9	9	1535.60	4.80	0.035	1.081
6	Global	10	1537.50	6.70	0.014	1.086

9.2.2. Full model selection for Abundance of *Columba livia*

	Model	K	AIC	ΔAIC	ω_i	Φ
1	1, 2, 3, 6, 8, 9, 10	8	1121.00	0.00	0.549	1.155
2	1, 2, 3, 6, 7, 8, 9, 10	9	1122.40	1.40	0.273	1.161
3	1, 2, 3, 5, 6, 7, 8, 9, 10	10	1124.10	3.10	0.117	1.167
4	1, 2, 3, 5, 6, 7, 8, 9, 10, 11	11	1126.00	5.00	0.045	1.173
5	Global	12	1128.00	7.00	0.017	1.179

9.2.3. Full model selection for Abundance of *Passer domesticus*

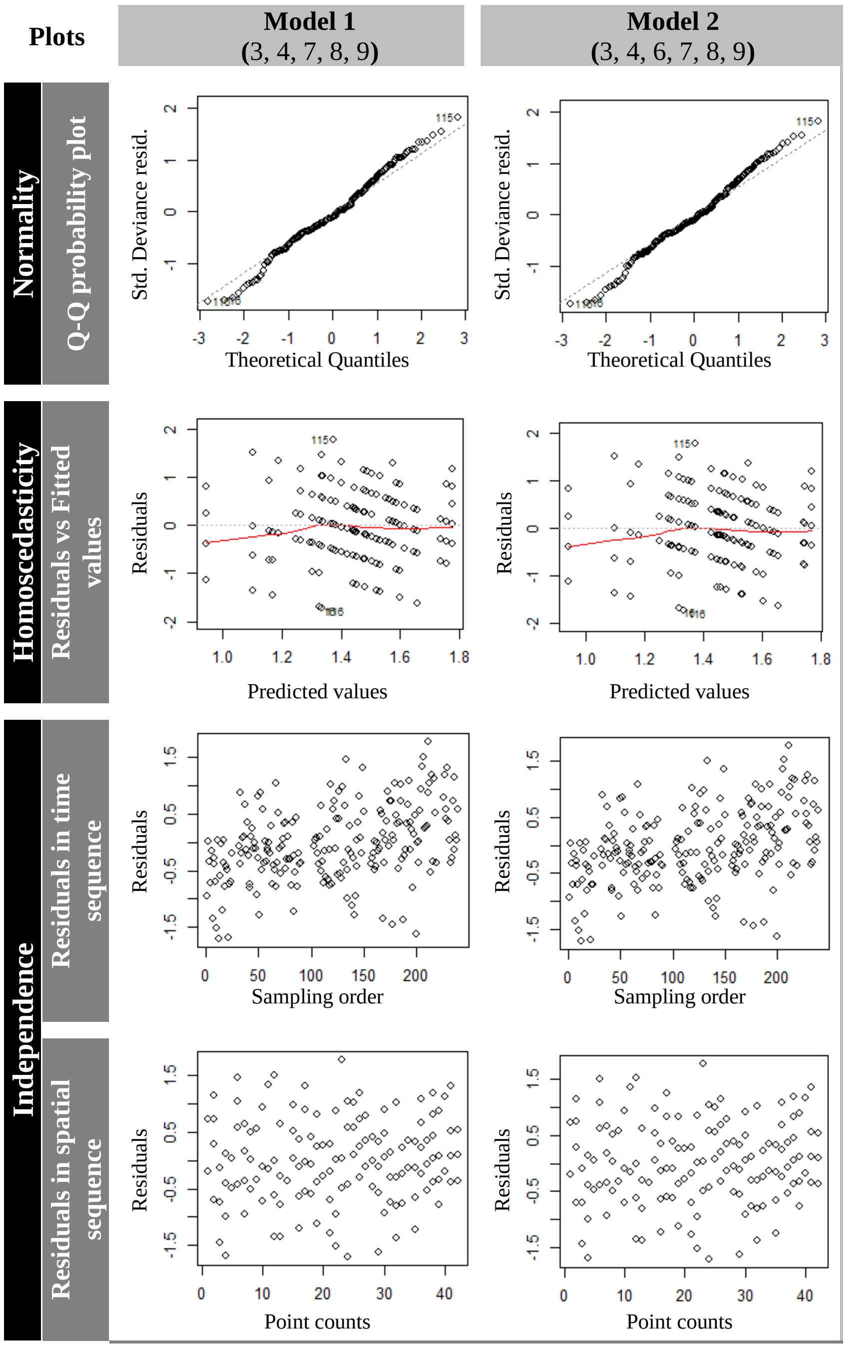
	Model	K	AIC	ΔAIC	ω_i	Φ
1	2, 3, 4, 5, 6, 7, 8, 10	9	1104.50	0.00	0.494	1.257
2	2, 3, 4, 5, 6, 7, 8, 10, 11	10	1105.30	0.80	0.331	1.267
3	1, 2, 3, 4, 5, 6, 7, 8, 10, 11	11	1107.20	2.70	0.128	1.273
4	Global	12	1109.20	4.70	0.047	1.279

Model	Potential candidate models. Global model includes all variables.
K	Number of model parameters (including regression intercept).
AIC	Akaike's Information Criteria.
ΔAIC	AIC differences (ΔAIC ≤ 2 indicates strong support for model).
ω_i	Akaike weight of evidence (Indicates relative support for model).
Φ	Overdispersion parameter.

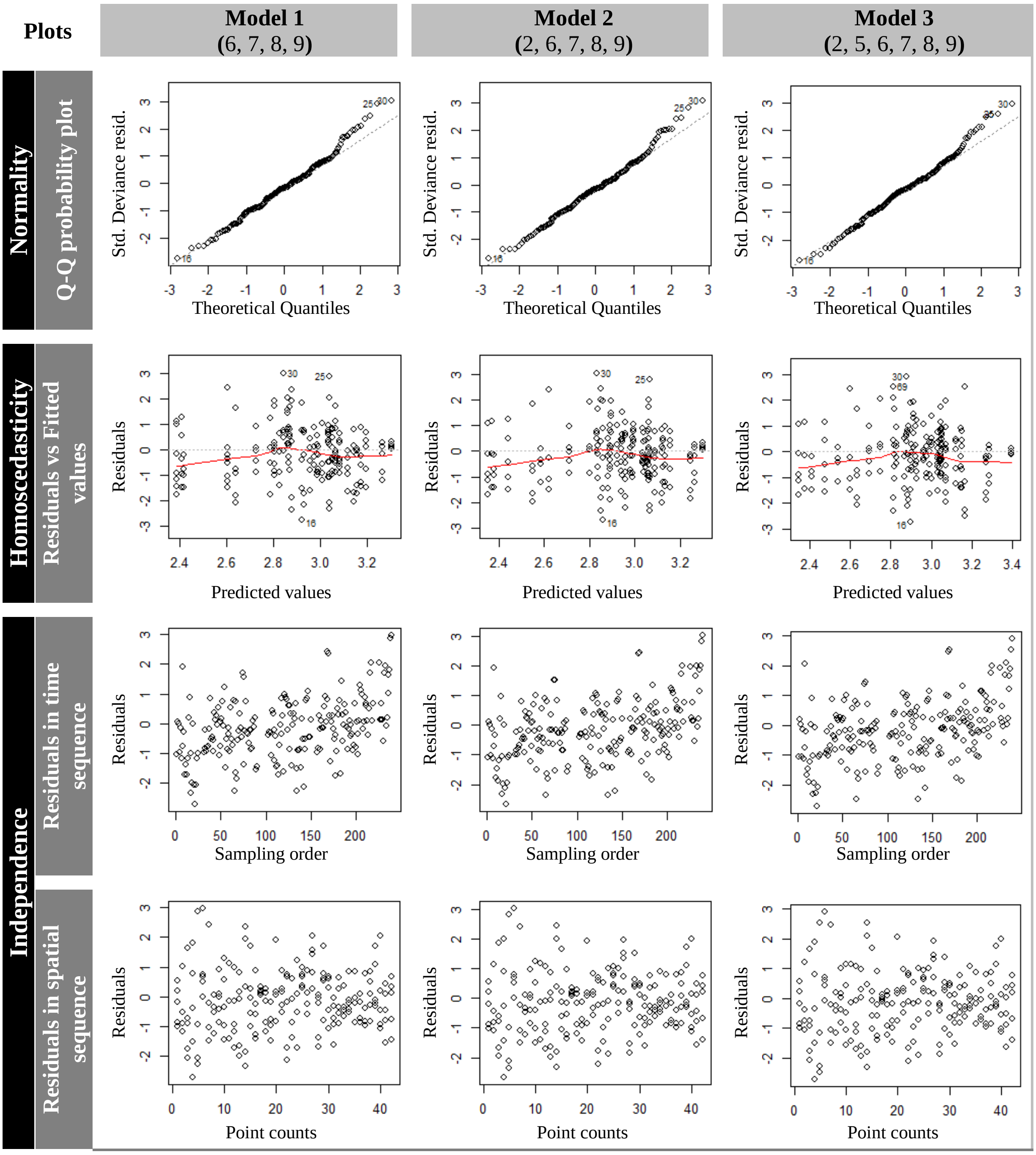
Variable	Description
1	Minimum distance to food establishments
2	Minimum distance to esplanades
3	Density of trees
4	Imperviousness
5	Building age
6	Building height
7	Building density
8	Road level
9	Human Population density
10	Size of Household
11	Ageing Index

9.3. Residuals for best fitted models

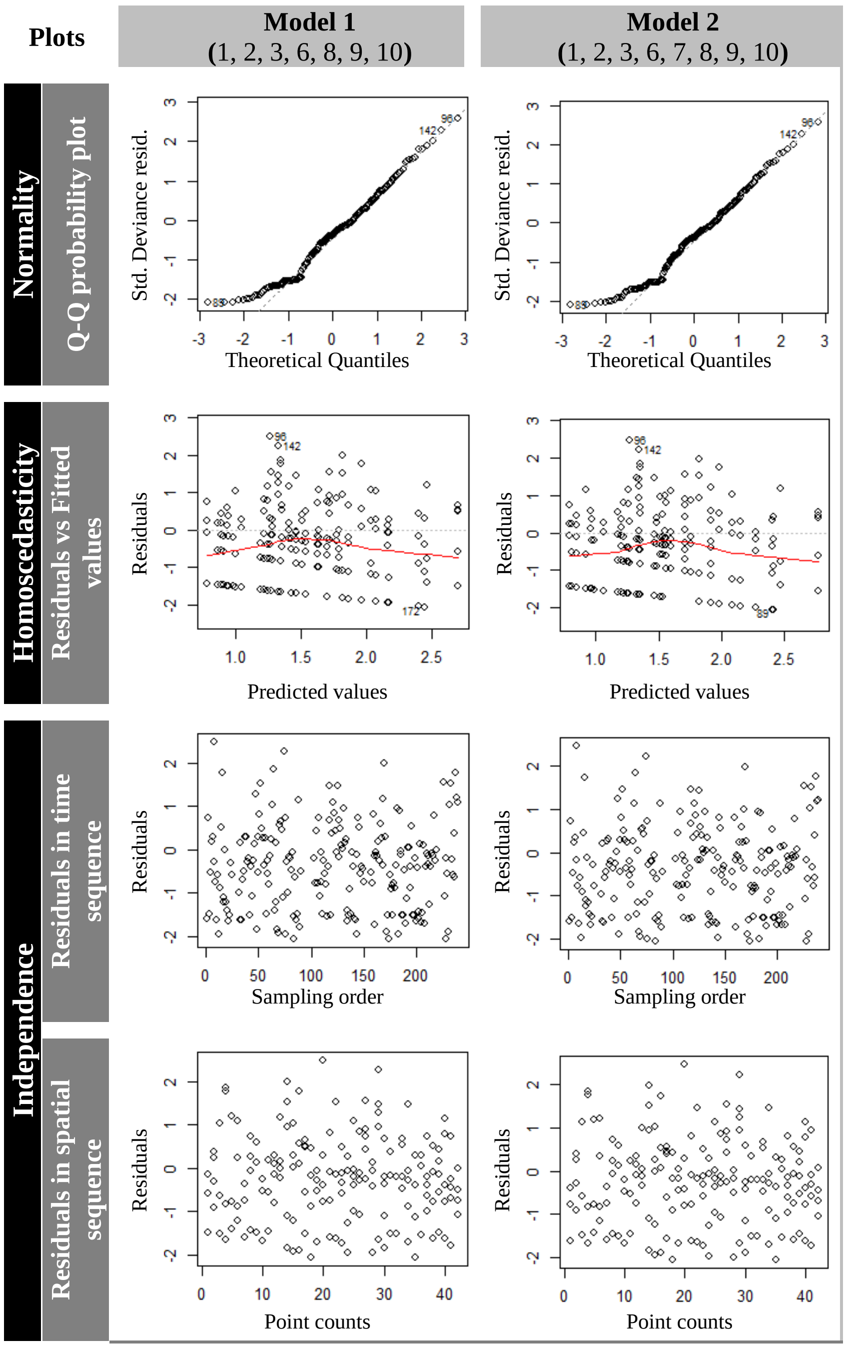
9.3.1. Species Richness



9.3.2. Global Abundance



9.3.3. Abundance of *Columba livia*



9.3.4. Abundance of *Passer domesticus*