Urban Ecology. Bird Diversity in Cities in Southern Chile

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Abstract. Urbanisation is a dominant demographic trend and an important component of the earth’s global transformation. It has unprecedented socioeconomic, cultural and environmental implications, and poses a threat to the conservation of biodiversity, as it can provoke alterations in ecological systems and lead to poor functioning of urban systems as they are currently structured. From the ecological point of view, the city is a fragmented, heterogeneous, complex mosaic of habitats, including ecosystems with different degrees of alteration. Urban systems contain only small areas of fragments of original vegetation and/or artificial green spaces, leading to a drastic decrease from their original abundance and diversity. However, green spaces, including original fragments, can help to conserve bird diversity, improving the functioning of these artificial systems in the medium term. This study looks at the characteristics and benefits of urban ecology in the framework of sustainable development, and carries out a meta-analysis of research into bird diversity in four cities in southern Chile, using ecological indices (Shannon-Wiener, $\beta$ diversity between cities). The results reveal that there is low evenness in the four cities and that the city with the highest evenness is Valdivia ($J= 0.78$). There is clear dominance by a few bird species (e.g. the exotic species house sparrow *Passer domesticus* and rock pigeon *Columba livia*, and the native species rufous-collared sparrow *Zonotrichia capensis*, austral thrush *Turdus falklandii*, southern lapwing *Vanellus chilensis*, and chimango caracara *Milvago chimango*). $\beta$ diversity is low as the four cities show similarity greater than 50%. Birds reject paved surfaces in squares and prefer areas with native bushes and trees, with nearby bodies of water and large spaces (parks rather than squares). The study proposes technical recommendations and suggests further research.

1. Introduction
Urban ecosystems include not only urban hubs but also suburban areas and villages that are connected with urbanized areas where the population density is higher. The boundaries are established in the same way and for the same reasons as the boundaries of any other ecosystem [1]. Although the city is partly artificial, its surroundings are normally partly natural and there is a profound interaction between the two systems [2]. The urban ecosystem can be divided into four “colours” [3]: a matrix of "grey" infrastructure that includes structures and buildings; the “green” infrastructure that brings together remnants of vegetation and planted areas (e.g. green areas, front and back domestic gardens); a "blue" infrastructure comprising water bodies (e.g. wetlands); and a "brown" infrastructure that includes all vacant building land. These four systems are affected by various factors [4] e.g.: (a) the predominant climate; (b) the substrate the city is built on; (c) the resident organisms (plants, animals,
micro-organisms and humans); (d) the elevation and slope; and (e) the time over which the city has developed, constituting the history of the system. This determines the lines of research that must be addressed in urban ecology, such as urban climate, urban hydrology, urban soils, urban biodiversity, urban trophic networks, the biogeochemistry of urban systems and the role of humans in those systems. This research analysed the characteristics and benefits of urban ecology in the framework of sustainable development and undertook a meta-analysis of research into bird diversity in four cities in southern Chile.

2. Urban ecology

This is an interdisciplinary science that brings together natural and social sciences to research urban ecological systems [5] and contributes the most active intersections between biophysical and social processes [6]. However, this discipline is not progressing as fast as it should, because it is rarely included as a criterion in urban, land and economic planning [7], even though planners and citizens are calling for the design of more sustainable urban environments. Like all ecosystems, the urban ecosystem needs to be addressed by studying its components, structure and function.

The discipline is addressed from two angles [8]: scientific study and urban planning. In science it has been used to study the distribution and abundance of organisms in cities. In planning, its focus has been on the design of environmental services and in reducing environmental impacts [9]. These approaches are complementary: ecologists, botanists and zoologists record, structure and explain how, in spite of everything, natural systems subsist within a city, while planners, urban designers and architects contribute rules and a sustainable urban design.

Urban ecology is applied to interventions not only in parks and squares but throughout the green infrastructure, including private front and back yards and vacant land. In Brazil, the plant richness of private back gardens was quantified and found to be similar to that of nearby natural ecosystems. In fact, some species being grown by people in their back yards are classified as under threat of extinction [10]. While each back yard is small, when added together they achieve substantial dimensions in cities. For instance, 19.5% of the area of Dayton in the USA is taken up by front and back domestic gardens [11]. In the Metropolitan area of Santiago (MAS) in Chile, urban front domestic gardens (homegardens) comprise 26% of the urban area while 37% is covered with trees and bushes, making up a total of 12,000 hectares of vegetation in front domestic gardens, equal to 19% of MAS. This is 3.7 times greater than the area of public green areas [12].

3. The benefits of urban ecology

A city that includes urban ecology in its planning will help to improve the quality of life of its inhabitants, while also contributing towards optimum governance of nature by restoring ecosystem services through an increase in green infrastructure. This is particularly important when cities are located in areas of high environmental importance, like wetlands (e.g. lakes, lagoons, rivers, estuaries) and native forests, an advantage that exists in many cities in southern Chile.

Urban flora mitigates heat islands and its leaves absorb atmospheric pollutants and fix CO₂. People are less exposed to ultraviolet radiation in urban areas with abundant woody vegetation. Urban ecosystems with more extensive green areas and native vegetation are more resilient, attract more biological diversity and present better provision of ecosystem services [13]; they also provide control of the hydric processes of runoff and flooding, reduce noise levels and lower people’s stress through the beautification of cities [14,15].

Urban green areas are used by some species of the original fauna, contributing to the functioning of these artificial ecosystems in the long-term, while helping to conserve a certain level of representation of the original diversity and improving the quality of life of the inhabitants. Green areas can contribute to the conservation of autochthonous diversity [16], as has been shown in various Latin American cities [17]. Cities can therefore be just as important a lever for biological conservation as protected wild areas [18].
A vision of sustainable development can be discerned in contemporary green area management and planning [19]. This has been a neostructural trend in urban planning and management since the early twenty-first century as the State has resumed its organisational functions and assumed its environmental and social dimensions more actively, at the same time as it has distanced itself from neoliberalism [20,21].

4. Urban ecology in Chile

More than 40 studies have been published about the urban ecology of big cities in southern Chile [22]; however, most of them report research related to pollution and the loss of ecosystem services, focusing on atmospheric pollution and aquatic systems. In the city of Concepción (southern Chile), research was carried out into the changes in land use in the city between 1975 and 2000. This showed a net loss resulting from urbanisation of 1734 ha of wetlands (23% of the original) and 1417 ha (9%) of agricultural, forestry and shrubland. The authors also documented 113 species of exotic plants in the city, while only a few native species were managing to survive [23]. This decrease in native plant species and increase in exotic plants has also been documented in southern Chile in Valdivia [24] and Punta Arenas [25].

A 1975 publication documenting the presence of native birds in cities in central Chile was a pioneer study in the country [26]. In Santiago, 17 species of birds have been recorded in squares [27], and 27 species in parks [28]. Other studies recorded 25 native bird species in “island hills” (remnant fragments of native vegetation) within the urban radius, with nine nesting species [29], similar to the 22 species and eight nesting species documented in nearby rural ecosystems [30]. Island hills have more native vegetation than parks (68.8% vs. 27.4%), and the percentage of native vegetation correlates positively with bird richness. There is a significant preference for native species [29], which has also been documented in Chile by other authors [31,32,33]. A large sampling campaign in Santiago recorded 36 species of birds in parks, island hills and vacant sites [33].

5. Comparing bird diversity in cities in southern Chile

Studies of bird diversity in four cities of southern Chile were included in the meta-analysis (Table 1). The structures of bird populations in each city for which there was information were characterised as follows: (a) Shannon-Wiener index, using the following formula: H′ = - Σ (pi × log2 pi), where pi is the proportion of the total number of individuals in the sample corresponding to the species. The values ranged between zero when there was only one species and the maximum (H′max) corresponding to log2 S (S=species richness). The Pielou index (J) was also calculated, using the equation: J = H′ / H′max. This index describes the species uniformity within a community. It therefore measures the proportion of diversity observed (H′) in relation to the maximum expected diversity (H′max). Its values fluctuate between 0 (minimum heterogeneity) and 1 (maximum heterogeneity, that is to say the species are equally abundant) [34]. (b) β diversity (between cities) is represented by a dissimilarity dendrogram based on the Bray-Curtis index [35], and by the unweighted pair group method with arithmetic mean (UPGMA). The level of significance (p = 0.05) of the results of the dendrogram was determined by calculating the 95% percentile of similarity pseudoranges obtained by bootstrapping with 10,000 iterations. These indices are calculated based on the frequencies provided in the publications analysed.

In Concepción, 27 species were documented but the study was limited to a university campus [36], with 10 census sites and the results grouped by human traffic, vegetation cover and the presence of water bodies. The diversity was higher in sites with little human presence, with micro wetlands and with trees and bushes. In Temuco, bird diversity was studied in squares, parks and the median strips of wide avenues (Figure 1). Significant differences were found between these types of green space, with a negative correlation with areas of bare soil and a positive correlation with the size of the green areas and the native origin of the bushes. No correlation was found with vehicle flow [32].
In Valdivia, 23 bird species were registered in squares [37], and guilds were studied according to habitat use. It was established that the most frequent species were those that used trees as sites for nesting and perching and fed on the ground or among the foliage. This city is close to the Pacific Ocean and surrounded by wetlands and fragments of native forest, which explains the presence of some birds from aquatic environments [38]. It is to be hoped that the diversity is greater than that documented as the research did not include all of the extensive urban wetlands in the city. In Osorno 34 species of birds were registered in two urban parks (squares were not included in the census). Both parks border a river and therefore have riverside habitats; one has a fragment of original native forest. This explains the occurrence of aquatic bird species (e.g. ducks, egrets) and the fact that some of them nest, although the authors unfortunately did not report on this topic in depth [39]. A review of the urban-rural gradients for each city is needed to put the results into context [40,41,42].

A few species dominate in each of the four cities, such as rufous-collared sparrows *Zonotrichia capensis*, austral thrushes *Turdus falklandii*, southern lapwings *Vanellus chilensis*, house sparrows *Passer domesticus*, rock pigeons *Columba livia* and chimango caracaras *Milvago chimango*. The Shannon-Wiener and Pielou indices show low evenness in the three cities, i.e. within the guild of birds there are a few species with high frequency and many species with low frequency. The city with the greatest evenness is Valdivia (J= 0.78) (Table 1)
Table 1. Bird diversity in four cities in southern Chile.

* = exotic species. n/i = no information.

β diversity is low (Figure 2) as the four cities show similarity greater than 50%. The cluster of Valdivia and Temuco has a similarity of 75.4%. Osorno is the city with the greatest dissimilarity; it is closest to Valdivia with 58.2% similarity.
6. Conclusions
(a) In the cities studied, a few species dominate (low evenness); (b) The four cities have many species in common, with few differences (low β diversity); (c) The diversity is greater in large areas (parks versus squares); (d) Birds prefer native species of bushes and trees; (e) Birds reject paved areas in squares and prefer herbaceous areas, bushes and trees; (f) Bird diversity varies significantly by type of ecosystem (e.g. squares, parks, hills, wetlands, streets), and areas with trees and bushes and with bodies of water nearby are preferred; (g) The majority of these studies analyse the frequency, abundance and diversity of birds and their relationship with factors like area, the proportion of native versus exotic vegetation, vegetation diversity and proximity to the sources of organisms (mountains, water courses); (h) There is scant knowledge about reproductive aspects of birds, their relationship with the vegetation and the degree of urbanization of green spaces; (i) These studies did not consider all the ecosystems present in the cities, nor did they analyse the effect of suburban ecosystems or those that are close to very natural areas.

7. Recommendations
Several authors in Chile have made recommendations that are rarely considered [30]. Some of the following recommendations have been selected from previous works, while others have been added for application in the practical sphere and the short term: (a) Reforest squares, parks, front and back yard, and public gardens with native species of bushes and trees originally from that area; (b) Maintain and increase native plants and trees with flowers and fruit that are eaten by fauna; (c) Maintain existing large, leafy trees and limit how much they are pruned. If necessary, demand that electricity cables be run underground. Retain cavities as refuges; (d) Carry out an urban environmental education programme to motivate citizens to intervene in their front and back gardens with native species and devices for fauna (e.g. nesting boxes, perches).

When researching urban ecosystems, the following are recommended: (a) Standardise research methods so they are comparable; (b) Carry out long-term research that considers what habitat resources are available and their use, the preference or avoidance of environments and the effect of the urban-rural gradient; (c) Carry out research into the landscape connections between rural, suburban and urban areas, considering the presence of regional green corridors and green areas with high/dense vegetation that offer a real or potential habitat for fauna.

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