Heliyon 9 (2023) e20135

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Assessment of the ecological role of historic centres based on the relationship between biodiversity and urban composition

C.P. Buenaño [a], J.A. García-Esparza [a,*], A.J. Castelló [b], P. Altaba [a], A. Valentín [b]

[a] *School of Technology and Experimental Sciences, Universitat Jaume I, Spain*
[b] *Territorial Office in Comunidad Valenciana, SEO/Birdlife, Spain*

A R T I C L E I N F O

Keywords:
Historic environment
Urban landscape
Birds distribution
Urban habitat
Green built heritage

A B S T R A C T

Historic centres provide their inhabitants with identity and well-being. Although studies focus on the conservation of the built environment, in recent years the environmental component of historic centres has also been analysed. Issues such as ecosystem services and biodiversity have become more pressing due to rapid population growth, development and the climate crisis. Green spaces in historic centres often conserve biodiversity, as they tend to be protected spaces. This article presents two case studies in Castellón de la Plana (Spain) with the aim of analysing the relationship between the built environment and avian biodiversity. The study uses a four-phase process. The first phase incorporates a review of recent literature to select biodiversity indicators, while the second focuses on open data analysis and incorporation into GIS software. The third phase consists of field data collection and the mapping of biodiversity indicators. Finally, phase four involves the preparation of thematic maps, which allows us to visualize behavioural patterns connecting bird colonies with the morphology of the built environment in order to draw relevant conclusions that can help improve biodiversity. The analysis allowed the calculation of eight indicators and the identification of building typologies, the percentage of green areas and the inspection of features promoting avian biodiversity. In total, 31 bird species were detected, 27 in the historic centre of Castellón and 26 in the historic centre of the *Grao* district. Among them, the mapping distribution of three endangered species demonstrates their dependence on these historic built habitats. *Apus apus, Passer domesticus* and *Delichon urbicum* are present in 97, 82 and 56% of grids, respectively, with ANOVA correlation confirming these species densities found. The study is somewhat limited in the use of the line transect method due to the potential structural biases intrinsic to the unique nature of the districts assessed.

1. Introduction

Cultural heritage assets such as historic buildings, urban fabric and monuments, together with their intangible aspects and interrelationships, are the legacy of past humanity and provide the inhabitants of these cities with a sense of place, identity and well-being [1,2]. This heritage of historic cities includes monuments and memorial buildings [3], urban landscapes and green spaces [1,4].

Most historic urban centres are also living communities [5], with city landscapes immersed in a constant transformation process brought about by population growth and development [2]. Over time, however, this transformation leads to severe problems which

* Corresponding author.
E-mail address: juan.garcia@uji.es (J.A. García-Esparza).

https://doi.org/10.1016/j.heliyon.2023.e20135
Received 23 June 2023; Received in revised form 11 September 2023; Accepted 12 September 2023
Available online 16 September 2023

hinder sustainable development [6], often leading to the exclusion of green areas from urban centres [7]. In environmental terms, notable challenges faced include the increasing rates of habitat destruction and loss of species [8]. As a result, cities designated as historic heritage are considered to be at an advantage, since the fragments of vegetation that they often preserve - parks, squares and gardens - permit the existence of biodiversity [7].

Some authors [9,10] hold that urbanization exerts enormous pressure on flora and fauna on a global scale. Development alters, eliminates, and replaces the natural habitat which supports a pre-existing plant or animal species, making it difficult for it to survive [9]. This means that many species cannot tolerate these alterations and are displaced. In contrast, other authors [11,12] state that new niches created by urbanization allow certain species to survive based on their tolerance. This survival is made possible by the presence of fewer predators or the availability of food waste from humans.

In order to measure the effect of urbanization on biodiversity the scientific community studies certain species, most frequently plants and birds [13]. Birds depend on local environmental characteristics and are often used to measure the degree of urbanization [7]. Factors favouring diversity, including vegetation structure, building characteristics and configuration, food supply, temperature, and artificial light [13], have also been identified. For example, varying the height of buildings in urban renewal projects rather than grouping buildings of a similar size can benefit avifauna [14].

The sustainable management of heritage offers a possible way to address the adverse effects of urbanization [15,16], paving the way for meeting the needs of present and future generations [4]. Sustainability has also brought about a shift in the perception, understanding and management of cultural heritage [3,17]. Good management and design can result in resilient cities, adapting to the needs that arise over time [4]. Efforts are underway worldwide to include ecosystem services and their values in policy, finance, and management [18].

Thus, the value of planning lies in the response it provides to new habitability needs while respecting biodiversity [8]. There is a drive to implement green infrastructures to partially counterbalance the impact of urbanization [19]. The heterogeneous urban vegetation and the effects of interaction with the local ecology and the built environment can provide economic benefits, namely increasing residential prices [20]. However, cities are not merely occupied by humans but also by various animal and plant species, and maintaining heritage spaces allows small patches of vegetation to serve as favourable habitats for these other urban inhabitants [7]. This text uses the term “built environment” to refer to the urban fabric and land, as an anthropic space sometimes occupied by natural capital, contributing to fundamental ecosystem services in order to help cities face current and future environmental issues [21].

At present, studies on the management of historic centres focus on issues such as tourism and social participation [5], regeneration of urban spaces [22], vulnerability studies [3], disaster management, and urban landscape perception [23]. Others examine the impact of cultural heritage on sustainability [24] while the management of green spaces is viewed from the environmental perspective of sustainability. A notable example in the Mediterranean is a study in Catalonia (Spain) analysing for the first time how different socio-ecological factors relating to the management of public urban green spaces can influence bird nesting [25].

In fact, the inclusion of high-rise buildings, a practice carried out in cities such as Vienna, Seville and Malaga with the construction of skyscrapers, constitutes a striking example of the mismanagement of historic centres in urban upgrades [22].

Current methodologies on biodiversity in urban centres focus on the study of building heights [14], green areas [20,26], hydraulic infrastructures [6,27,28] and groundwater [29]. While data collection can be performed through on-site analysis, behavioural mapping and surveys [30] other research uses indicators theoretically to contrast information on the inclusion and collaboration of local residents in conservation projects [31,32]. Furthermore, certain indicators are used to quantify the benefits of biodiversity on human health [18,33,34], land-use change [35,36] and the impact of nature conservation on the provision of ecosystem services [8,37,38].

Areas with higher building cover tend to be associated with fewer varieties of bird species following the replacement of habitat by impervious surfaces or the reduction in size of vegetated patches [39]. As buildings undeniably make life difficult for wildlife, current studies have concentrated on the study of urban lay-outs. However, these urban lay-outs are not the only factor affecting the full preservation of biodiversity [39]. The value of this study lies in its emphasis on the potential positive role of building features in preserving biodiversity [7], providing ecosystem services, including improved air and water quality [40], food supply, climate stabilization, flood protection [18], heat island [20], and human health benefits [33,34].

This study has identified existing research on the effect of urbanization on bird species in the urban-rural gradient [41], with other studies also assessing the quality of urban landscapes [42], the effects of climate change on bird populations [43], and the impact of urban roof gardens on bird and butterfly species assemblages [44]. More recently, research has examined the characteristics of birds which favour the urban realm and their nesting preferences [45] and the relationship between land use and biodiversity [7]. The novelty of this research puts forward the intersection of urban morphology and biodiversity, specifically analysing building form and other elements which encourage the presence of birds. Disciplines such as architecture, biology and environmental sciences are incorporated to combine fieldwork results and geographical and architectural-based analysis. This sheds light on the ecological implications of urban morphology and building shape for stimulating the presence of certain species for the effective management of urban ecosystems.

The main aim of this study is to analyse the relationship between the built environment and avian biodiversity in two case studies in Castellón de la Plana (Spain). Another secondary objective is to evaluate the strengths and weaknesses of current infrastructures and urban lay-out through biodiversity indicators. Like many of the maritime cities of the western Mediterranean coast Castellón, which has a population of 170,244 inhabitants is built on a plane and surrounded by low-rise mountains. The city centre is located 40 m above sea level. The survey results could be compared to those of many other cities with similar contexts in the Mediterranean region. Unlike Valencia and Alicante, Castellón de la Plana lacks a Green Plan for the city. For the Chair of Historic Centres at Universitat Jaume I, this study represented our commitment to preliminary analysis of the habitats found in the historic districts of the city and to be used as a basis for the future Green Plan.

The results of this study could aid understanding of the impact of building composition and green spaces on biodiversity. Moreover, it could be helpful to decision-makers and urban planners when establishing land use order and regulating the conditions for the transformation of the future city. When addressing major urban environmental problems urban spaces must necessarily be taken into account by city managers [21].

2. Materials and methods

2.1. Area of study

The city of Castellón de la Plana is located on the eastern coast of Spain (Fig. 1), 4 km from the sea, and therefore has a temperate Mediterranean climate [46]. Although in the past this region was predominantly agricultural [47], over time it has become a services hub as the capital of an industrialized area [48], leading in turn to the expansion of the city. Due to its history and development, the city has been organized into four distinct zones: the historic centre, the urban expansion, the agricultural zone, and the maritime district.

The chosen study area is located in the historic centre of Castellón de la Plana and its maritime district, *El Grao* (Fig. 2). Both areas were selected for their constructive characteristics. While the buildings in the historic centre display Modernist touches on some facades that are still reminiscent of medieval times, the buildings in the *Grao* district are renovated former fishermen's huts. However, both locations have buildings with architectural heritage, close to green spaces. The historic centre is 0.84 km^2 and the maritime district is 0.32 km^2. The building composition includes.

- Single-family townhouses
- Residential blocks with several apartments per floor
- Other buildings with commercial premises on the ground floor and all other floors devoted to residential use

The *Grao* area is linked to the city centre by two avenues, leaving an undeveloped area of at least 3 km^2 between the centre and the first buildings of the *Grao*. This area, free of buildings, contains orchards, citrus groves and abandoned agricultural areas or areas used for composting. The study site is an old neighbourhood connected to the largest green area in the *Grao* district, Pinar Park. The surrounding urban space features building complexes made up of single-family housing blocks built a few decades ago. These are also essential to connectivity, a factor which can aid or hinder urban fauna.

2.2. Methodology

A diagram briefly summarizing the stages of the methodology is shown in Fig. 3.

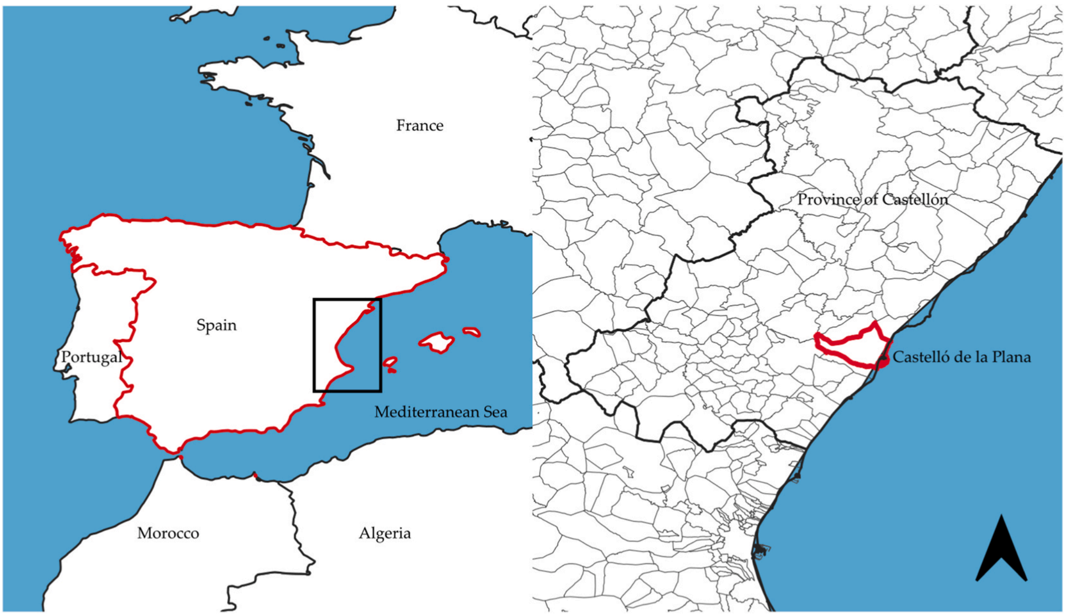


Fig. 1. Location of Castellón de la Plana.

Fig. 2. Study area.

2.2.1. Stage 1

The first stage focused on a search for biodiversity indicators whose high number made an extensive literature review necessary. All contributions found were obtained from Web of Science and Google Scholar. The first general search was carried out using the term "biodiversity indicators", which provided 5208 results. In the second search, date filters were applied to include only papers from the last five years, also specifying the term "urban" in the title of the article. This search returned 50 results. The third search, which was the most specific, was limited to the last five years, and included the term "biodiversity indicators" in the title and "urban studies" in the subject. In this case only five scientific articles were identified when these searches were conducted in March 2022.

Indicators were selected from a tabular database of 125 indicators matching the topic and characteristics of the study. Each row and column featured a different indicator, subcategory and category. The context, which could be environmental, economic or social, was also indicated. Finally, the reference and the journal from which the information was extracted were also included. Eight indicators were selected from this preliminary search for two reasons: because they were repeated in several studies and made comparison possible and because this information could be extracted from the cartography and consulted in open sources (Table 1).

2.2.2. Stage 2

The second stage contains all the procedures relating to GIS information. QGIS software version 1.16 was used, with information obtained from the Catalogue of the Institut Cartogràfic Valencià and the Spanish Cadastral Downloader Inspire, a QGIS plugin for downloading cadastral data. Vector, raster and tabular data layers have been used. In order to locate the predominant features of the buildings on the map, the study area was zoned and attribute fields were created to mark balconies, eave slopes, overhangs and projections. In the attribute table, the field with the word "yes" was used to indicate the presence of a certain building feature. A total of 13,435 buildings were reviewed in the historic centre and 1835 in the *Grao*.

The buildings were checked individually, using photographs from the cadastre's electronic headquarters and satellite navigation. The 'surface point' tool was then used to create the heat map, which was then modified to aid understanding of the results. The QGIS "heat map" tool generates variable densities depending on the number of points distributed on the map from a radius of interaction. For all elements, a 100-point radius with different colour bands was used to visualize the concentration of points. This tool showed the map locations of predominant building features that could favour or hinder urban wildlife. Green areas in the historic centre and the *Grao* district of Castellón de la Plana were also analysed, divided into subcategories defined as parks, squares, scrublands and private green areas. The location on the map was established by tracing polygons using the orthophoto and a 3D tour with Google Earth. The study of the historic centre of Castellón required a subcategory of private green spaces to be included given the existence of surfaces observed in private plots in aerial views. However, in the *Grao* de Castellón area, the subcategory of private green spaces was eliminated as these spaces were not found in the satellite images or in the fieldwork.

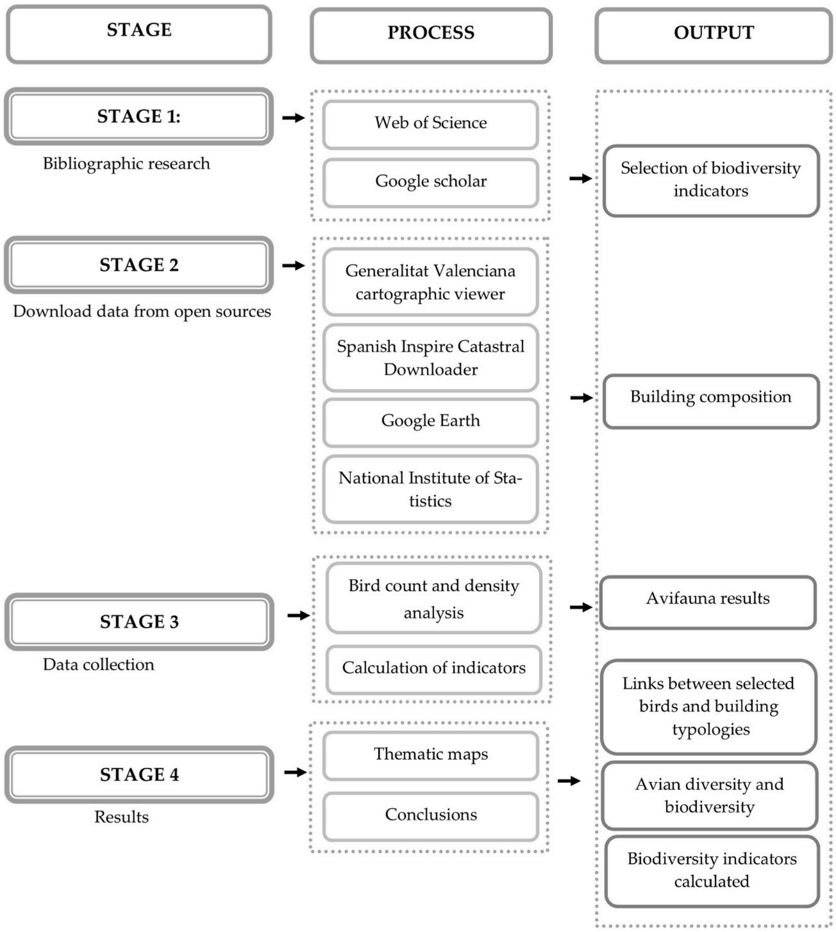


Fig. 3. Research stages and output of each stage.

Table 1
Selected indicators.

Indicator	Description
Height of building	Number of floors above ground
Building density	Number of dwellings in total area
Use of building	Residential, industrial, office or utility use
Functionality	Functional, deficient or dilapidated
Proportion of green areas	Proportion of area covered by gardens, parks and shrubberies
Green-concrete proportion	Ratio of building area to green space
Blue infrastructure	Number of artificial and natural lakes, lagoons or ponds
Green area per capita	Surface area of green areas per inhabitant

2.2.3. Stage 3

The third phase focused on data collection, a bird count which was carried out in two seasons: summer and winter. Initially, a bird count was carried out to ascertain the avifauna of the study areas, with the collaboration of SEO Birdlife, the Spanish ornithological society. The two areas of study were divided into 100 × 100 m grids (Fig. 4), used as a geographical unit on which the results were referenced. Of the total of 151 delimited grids, 106 were sampled in the historic centre of Castellón and 45 in the *Grao* with the line transect method. The transects in the two study subareas were covered on foot at an approximately constant speed of 2 km/h. The analyses considered all birds located in a 20-m band either side of the transects.

The tours were repeated over a six-week-long period of sampling, standardizing the time allocated to each grid and recording the number of birds detected in each tour, as well as the number of species, and the specific habitat for each observation. Four daytime and one night-time census days were observed. The daytime censuses were carried out at dawn and before dusk, with at least one day per grid in each of these schedules. The non-invasive method used to obtain data relied solely on observation and did not affect any specimens or their habitats. Therefore, this research does not raise any ethical concerns on the study of bird species.

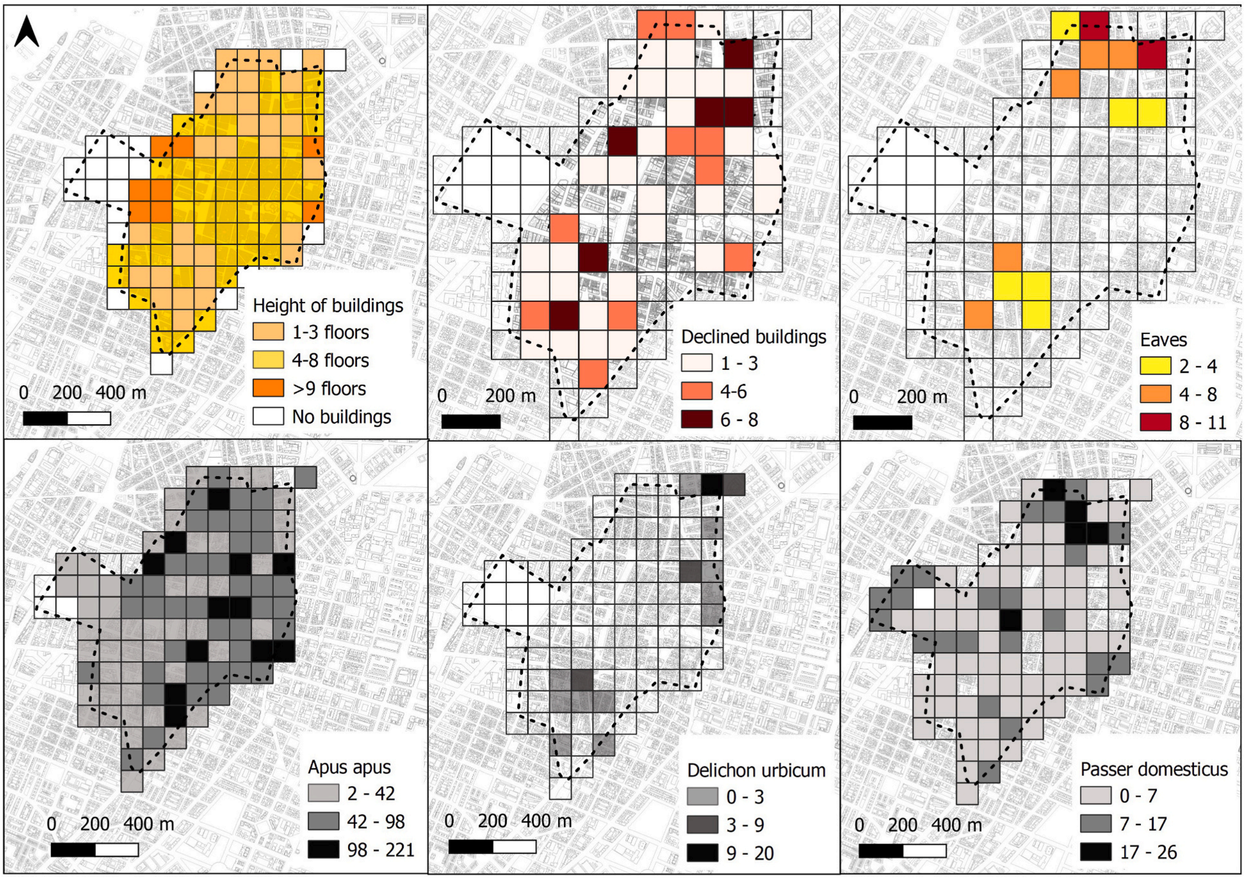


Fig. 4. Links between birds and building typology in historic centre.

Subsequently, data were obtained after calculating the previously selected biodiversity indicators. As the only cartographic information that could be used from the outset was the number of green areas and built environments, new calculations were needed to complete the missing information. The number of inhabitants for calculations per capita was obtained from information provided by the National Institute of Statistics using the formula:

Population = number of inhabitants per dwelling × dwellings.

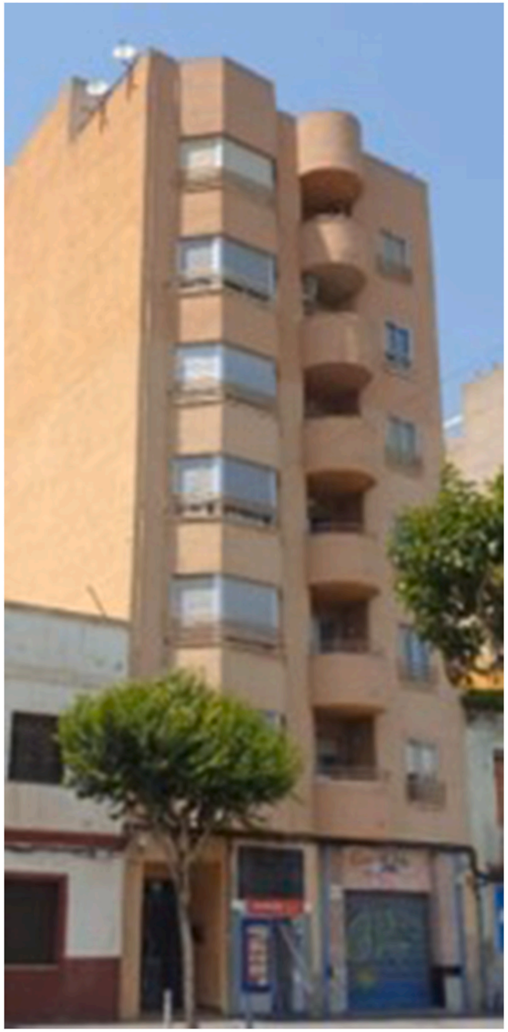
In the study by Pellisier et al., 2012, buildings in Paris were classified into three height ranges based on their knowledge of the city. In this case, three ranges were also proposed: the first for buildings one to three stories high, the second for buildings with a height ranging from 4 to 8 floors, and a third and final range which includes all buildings at least nine stories high.

Biodiversity indicators will be presented after calculation (Table 6). An orthophoto and a 3D walk with Google Earth were used to define the green spaces and represent them on the map with polygons. The blue infrastructure indicator was recorded based on the absence or presence of water bodies. The green area per capita indicator was calculated by adding up all the green area surfaces and dividing the total by the total number of inhabitants. The green area was also used to calculate the proportion of Green areas and Green concrete proportion by dividing them by the built-up area. These data were extracted from the QGIS attribute table. The indicators of height of building, use of building and functionality were taken from the attribute table data available from the Spanish Inspire Cadastral Downloader. The functionality percentage was calculated with the number of buildings in the "functional" category and the total number of buildings in each area.

2.2.4. Stage 4

The possible relationships between bird density and the four typologies of building composition were performed statistically. Each grid in the plot was assigned the predominant typology. Then, for the density data in each sub-area and the breeding and wintering seasons, an ANOVA test was used on log-transformed data. When significant results were obtained, a post hoc analysis was performed using the Bonferroni correction, in order to discriminate possible differences in mean density values in areas with different building typologies. For samples with a low number of observations ($n \leq 17$), the Kruskal-Wall test was applied. A significance level of 95% was established in all cases.

Table 2
Building composition of Castellón.

Type1	Type2	Type3
		
Description: from one to three floors. Represents 59% of 13,435 buildings in the historic centre and 62% of 1835 buildings in the *Grao* district.	**Description:** from four to eight floors. Represents 34% of 13,435 buildings in the historic centre and 32% of 1835 buildings in the *Grao* district.	**Description:** nine floors or more. Represents 7% of 13,435 buildings in the historic centre and 6% of 1835 buildings in the *Grao* district.

3. Results

3.1. Results of building composition

In the case of the historic centre of Castellón de la Plana, the building analysis showed that the height of the buildings varies from 1 to 18 stories. The most common typology is terraced constructions two stories high, and it is common to find multi-story buildings next to single-family terraced ones.

The total sample of buildings was standardized to exemplify the habitats and correlate the presence of birds to buildings. Type 1 corresponds to historic buildings made of traditional materials and found in the old town and on the outskirts of the historic centre as well as in the *Grao*. Type 2 are light constructions that are in residential areas in more compact blocks. Type 3 corresponds to constructions from the last 50 years with more modern materials and simplistic architecture, found in various positions in commercial areas and large avenues in the centre of Castellón and on the *Grao* seafront. According to the cadastre information, the morphology of the two districts combines three main types of buildings from different urban development periods (Table 2).

The configuration in terms of heights differs between the historic centre and the *Grao* in Castellón. In the historic centre, most buildings are under three stories high, while those that are at least nine floors high are distributed across the central part of the study area. In the periphery, these buildings tend to be lower in height. In contrast, in the *Grao* district, there is a much higher number of buildings at least four stories high, while the number of buildings over nine stories high is also more substantial. The tallest buildings are located near the seafront, which is also one of the most commercial streets in the maritime district.

Building typologies are analysed to confirm the characteristics that facilitate biodiversity as well as those that limit it. Elements such as eaves and roof slopes, for example, are potential bird nesting sites. In the historic centre of Castellón, the elements most frequently found are balconies and other overhanging elements. Eaves are infrequent, although they are occasionally seen in the northern part of the historic centre, further supporting the statement that this area has few high-rise buildings and a predominance of traditional construction.

In the *Grao* area however, balconies are rare, while cantilevers are the most frequent construction element. The type of construction found in this area is more recent and modern than those in the historic centre, where any balconies are usually interior. Eaves are only seen in the old town. Sloping elements are also found predominantly and frequently in the residential area, where modern design incorporates pitched elements on the facade and roof.

3.2. Avifauna results

A total of 11,769 individual examples of 32 different bird species have been identified: *Upupa epops, Otus scops, Delichon urbicum, Parus major, Periparus ater, Falco tinnunculus, Psittacula krameri, Sylvia atricapilla, Sturnus unicolor, Egretta garzetta, Bubulcus ibis, Ichthyaetus audouinii, Larus michahellis, unidentified laridae, Hirundo rustica, Passer domesticus, Falco eleonorae, Carduelis carduelis, Motacilla alba, Turdus merula, Aegithalos cauclatus, Plegadis falcinellus, Columba livia, Columba palumbus, unidentified columbida, Muscicapa striata, Erithaus rubecula, Serinus serinus, Streptopelia decaocto, Pica pica, Apus apus.* From this, 59.7% of the total corresponded to *Apus apus*, 12.4% to the *Columba livia*, and 9.6% to the *Passer domesticus*.

The three species selected displayed a closer association with buildings and urban areas and have seen their populations decline in recent years. The main characteristics of all three species are detailed in Table 3.

3.3. Links between selected birds and building typologies

The number of birds observed in the historic centre has been linked to the height of buildings, the presence of buildings in a poor state of conservation, and eaves (see Fig. 4). The first map (top left row) represents the most frequent heights in each quadrant by

Table 3
Selected bird species and habitat results.

Species of bird	*Apus apus*	*Passer domesticus*	*Delichon urbicum*
Percentage of	59.7%.	9.6%.	2.1%
Geographical distribution	Iberian Peninsula.	Globally	Palaearctic during the breeding season and spend the winter in Africa.
Habitat	Represented in 97.14% of the grids in the historic centre (n = 105). The highest densities were recorded in the central and southern zones (Fig. 6a). Zones with a predominance of type 1 and 2 buildings (Table 2 and Fig. 4).	Represented in 82.86% of the grids in the historic centre (n = 87). The highest densities were recorded to the north of the study area, as well as in the surroundings of Ribalta Park (Fig. 6a). Areas with large open spaces and type 1 buildings.	Detected in more than half of the grids sampled in the *Grao* (56.82%; n = 44). This species, related to urban areas, revealed higher density values in the central zone of this study subarea (Fig. 6b). Areas with a predominance of type 1 buildings (Table 2 and Fig. 5).
Urban nesting	Nest in cracks and holes, spaces which are found in old buildings due to their materials or state of conservation. Also found in smaller numbers on cliffs, slopes and holes in trees. Nests are always found inside hollows.	Usually choosing to nest in holes or cracks of roofs, joints, facades or balconies of all sorts of buildings.	They prefer corners and roofs. The nests hang from the eaves, forming an inner chamber completely closed except for an entrance and exit opening.

colour. The second (top middle row) displays the presence of buildings in a state of ruinous conservation according to the information found on the cadastre page. The third map (top right row) shows the number of eaves. The lower row of the figure shows the distribution of the selected birds. It is important to note that each species has concentrations in different quadrants. According to the cross-referenced data, the presence of the *Apus apus* or common swift (lower left row) is associated with building heights of between four and eight stories. There is no association with buildings in a poor state of conservation and no clear relationship is observed with the presence of eaves. The greatest concentration in the grid takes the form of a diagonal line which seems to be oriented towards the periphery of the urban nucleus, towards the east, where there are avenues of exit and entrance to an urban expansion zone with more open areas. The *Delichon urbicum* or house martin (bottom row centre) flies over areas with one to three-story buildings and is found both in sectors with buildings in poor condition and in some areas with eaves. *Passer domesticus* or house sparrows (bottom row right) were recorded in buildings between four and eight stories high and near green spaces. Their presence is associated with buildings in poor condition, and they are found in the highest concentrations around buildings with eaves in the northern part of the study area.

The distribution of birds in the *Grao* district is shown in Fig. 5. Each species has a characteristic distribution that can be linked to different features. Between 98 and 176 *Apus apus* or common swifts were recorded in areas with a predominance of one-to three-floor-high buildings, while fewer specimens were found in areas with buildings of nine floors or more. Their presence was linked to buildings in poor condition and the proximity of eaves, with the highest concentrations found in the area section with the least presence of water. The *Delichon urbicum* or house martins were found in a broader range of buildings between one and eight floors high but were noticeably absent in areas with the tallest buildings. They do not appear to be associated with buildings in poor condition or with eaves. The presence of *Passer domesticus* or sparrows coincides with areas where buildings are predominantly between one and three floors high. Sparrows do not tend to be linked specifically to buildings in poor condition or eaves as they are distributed evenly throughout almost the entire grid, with between 9 and 31 specimens per square.

3.3.1. *Avian diversity and biodiversity*

The possible relationships between bird density and different building types were studied, divided into 4 categories: 0 is linked to non-built spaces; 1 refers to buildings up to 4 stories high; 2 denotes buildings between 4 and 9 stories high; 3 represents buildings of 9 stories or more. Each 100 × 100 m grid was assigned the predominant typology. For the density data in each area and the reproductive and winter seasons, an ANOVA test was carried out using log-transformed data. When significant results were obtained ($p < 0.05$) an

Table 4
Relation between bird density and building typologies.

Area	Period	Species	ANOVA P value (ANOVA α = 0.05	Post hoc *t*-test	P value T test (Bonferroni α = 0.008333)
Historic centre of Castellón	Reproduction	House Sparrow	0.059392	NA	
		Rock dove	0.035114[a]	T0 vs T1	0.03856319
				T0 vs T2	0.88760017
				T0 vs T3	0.84245496
				T1 vs T2	0.00284849[a]
				T1 vs T3	0.14692606
				T2 vs T3	0.58684726
		Common Swift	0.003811[a]	T0 vs T1	0.01166851
				T0 vs T2	0.03045776
				T0 vs T3	0.04235591
				T1 vs T2	0.21891046
				T1 vs T3	0.89678595
				T2 vs T3	0.48908155
	Winter	House Sparrow	0.44162	NA	
		Eurasian Crag Martin	0.558096	NA	
		Rock dove	0.26234	NA	
Grao	Reproduction	Common House Martin	0.487666	NA	
		House Sparrow	0.751898	NA	
		Common Swift	5.45751441 E−06[a]	T0 vs T1	0.00085364
				T0 vs T2	5.13718 E−07[a]
				T0 vs T3	0.00595731[a]
				T1 vs T2	0.24423608
				T1 vs T3	0.59406941
				T2 vs T3	0.98018911
	Winter	House Sparrow	0.007725[a]	T0 vs T1	0.00116612[a]
				T0 vs T2	0.55858019
				T0 vs T3	0.0118968[a]
				T1 vs T2	0.0559371
				T1 vs T3	0.71400017
				T2 vs T3	0.17573137
			Kruskal-Wallis H	GL	P Value (α = 0.05)
		Eurasian Crag Martin	2.4107	2	0.2996
		Rock pigeon	38.7189	3	0,.504

[a] Means significant differences.

analysis was performed using the Bonferroni correction in order to discriminate possible differences in the mean density values in areas with different constructive typologies. For samples with a low number of observations ($n \leq 17$), the Kruskal-Wallis test was applied and a significance level of 95% was established in all cases.

The common swift, *Apus apus*, has a greater presence in built-up areas than in green areas. The rock pigeon, *Columba livia*, is more often associated with type 2 buildings. The house sparrow, *Passer domesticus*, is more likely to inhabit green areas. Table 4 shows the correlations between bird density and the four building typologies.

The graph in Fig. 6 shows the density of birds in each of the grids during the breeding season. In the historic centre, higher densities were recorded towards the periphery of the city, connected to other parks and undeveloped land spaces. Residential areas and areas with taller buildings displayed lower densities. Although something similar occurs in the Grao area, it should be emphasized that as it is a very small area it is more difficult to establish conclusive relationships.

A heat map of avian biodiversity is shown in Fig. 7, where the lightest colour is close to zero and the darkest red to 2.2 of the Shannon index. The *Grao* is the area with the most significant number of cells showing the highest diversity. Although the tests carried out focused on building typologies and heights, the presence of green spaces was considered the best complement in terms of diversity. In the historic centre, only a large park to the west (Fig. 7 top row) and a small park to the east have well-established historic green infrastructures. In contrast, in the rest of the city, especially in the southern sector, there is little or no green space, while in the northern sector green space is not widespread. In these squares we find a predominance of concrete over trees, shrubs or landscaped areas. However, an interesting pattern emerges linking the presence of birds to the two most important gardens in the centre, to the east and west. This pattern may be conditioned by their arrangement in the urban fabric, as they are well connected to the avenues leading in and out of the historic centre.

In the *Grao* neighbourhood, the situation is different. The area has a large park and, in the built-up area, the rows of bushes surrounding the large blocks of flats serve as foraging grounds for the birds. The data collected show an undeniable link to these green areas (Fig. 7, bottom row).

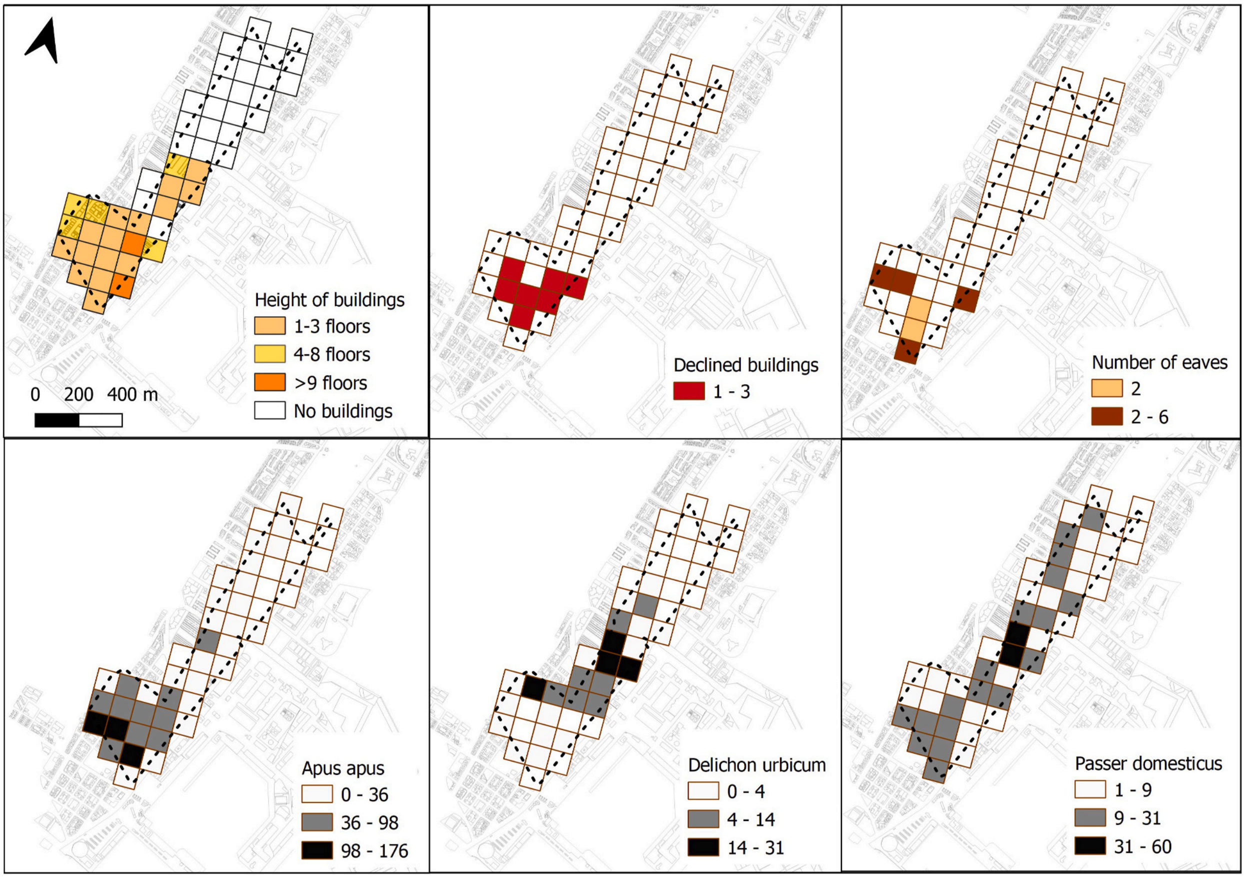


Fig. 5. Links between birds and building typology in the *Grao* district.

Fig. 6. Bird density in study areas.

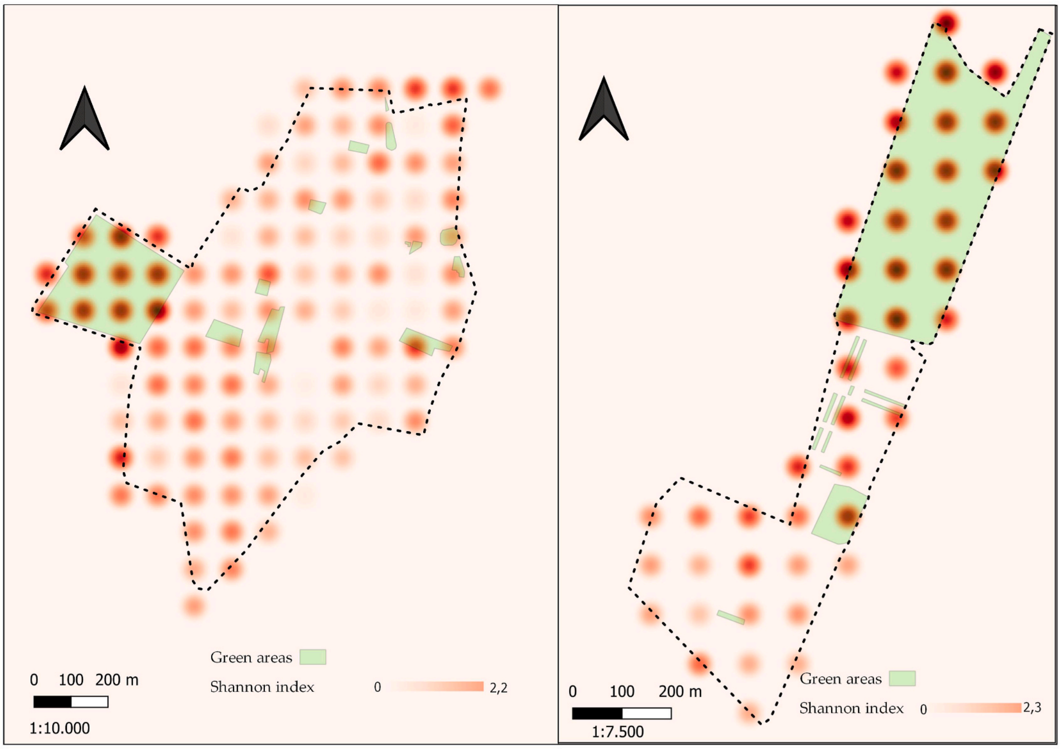


Fig. 7. Avian biodiversity and green areas.

3.4. Biodiversity indicators calculated

3.4.1. Calculation of the population

Many of the biodiversity indicators require the total number of inhabitants in order to establish per capita information. The population figures for the historic centre and the *Grao* are detailed in Table 5.

3.4.2. Indicator calculation

Table 6 contains summaries of the indicators obtained from the mapping and the calculations performed.

4. Discussion

The inventory and analysis of buildings serve as tools for detecting constructive features that favour biodiversity, also promoting the inclusion of these features in urbanization or urban regeneration processes. An example of this is height variability, which has been confirmed to benefit avifauna [14]. However, it also favours occupant comfort by respecting the lighting and ventilation received by most buildings in the urban fabric. The height most associated with the presence of birds in this study is three stories. The results of our study are consistent with recent research by Chen et al. [49] and Polak et al. [50], which indicate that a combination of building heights, especially from one to three stories, can increase avian biodiversity and improve the comfort of urban residents. The social benefits of green spaces and biodiversity are linked to the capacity for reflection, attachment, and a sense of identity through memories connected with the green space and its surroundings, which translates as well-being [51–53]. These findings suggest that urban planners and decision-makers should consider incorporating a variety of heights and green spaces into future urban regeneration projects to support biodiversity and improve the overall urban environment. These recommendations are also valid for urban development plans envisioned for the long term.

However, Castellón, as a bird habitat, presents some obstacles. One of these is the presence of tall buildings which do not allow fast and direct movement. This is supported by the finding that none of the species analysed appears near buildings of eight floors or more. A further drawback detected during the fieldwork is the presence of anti-bird spiking systems in some public and private buildings. These systems, which are more commonly used in renovated houses with accessible terraces, limit or prevent the presence of birds in strategic places as well as reducing disturbance to inhabitants and maintenance work.

The study demonstrates that the relationship between birds and building characteristics varies depending on the plot. Relationships in the historic centre are different from those observed in the *Grao* district. This may be due to the distribution of green areas, the size of the urban centres or the socio-spatial dynamics of the individual cases. According to the fieldwork data collected, the nesting requirements of birds confirm clear relationships. For nesting, both swifts and sparrows need hollows and crevices, spaces that are mostly found in older buildings. This point was also stressed in the analysis of swifts which breed in Indonesia and make use of specific built structures with thick walls and small hollows providing a cooler environment inside [54].

Previous research for specific urban areas in Lisbon found that 8% of urban ground is covered by a canopy of trees [20]. In the case of Castellón, considering the study area and the green places identified on the map, these figures stand at 12% for the historic centre and 44% for the *Grao* district. While it can be assumed that these figures are accurate and that the *Grao* has extensive green areas, this result is in fact due to the study area selected, which in both cases includes large parks and a small area with buildings. Something similar occurs with the green-concrete ratio as species diversity is strongly linked to green spaces. Therefore, the expansion and generation of parks, gardens and shrubs will always favour the life of migratory and non-migratory birds.

The World Health Organization (WHO) recommends between 10 and 15 m^2 of green space per inhabitant. In this study, only the *Grao* area meets this recommendation. The WHO recommendation would only be met if the rest of the area outside the study area maintained the same land cover. In Italy, the minimum urban green space requirement varies between 9 and 16 m^2 of green space per person, and in Bologna the green space requirement is 16 m^2 per inhabitant [55]. The green space per capita in the historic centre of Castellón de la Plana is insufficient compared to other reference cities with established regulatory frameworks. The shrubs found in areas identified in the historic centre leave a lot to be desired and hardly qualify these as consolidated areas for the promotion of biodiversity.

The number, diversity and distribution of bird species show that the *Grao* is better endowed than the historic centre. The new residential buildings in the *Grao* offer an advantage over the historic centre, as the garden strips found there allow birds to feed and may be one of the reasons why these are the quadrants with the highest number of individuals. The quadrants with the highest concentration of birds are those near parks and other small landscaped areas. In the case of the historic centre, the more populated quadrants are oriented towards the periphery. These findings are consistent with the relationship of bird abundance and the distance from the edge of the city [56].

The historic parks in the study area are the green areas with the most remarkable diversity of birds. Nesting facilities may be related to the age of the green infrastructure, including trees with larger diameter trunks which offering larger crevices for species to live in. In addition, migratory memory causes seasonally mobile birds to return. Maintaining heritage spaces in urban centres can mitigate the expected negative impacts of urbanization [7]. This result differs from that of Batáry et al. [41], where a wealth of species is not associated with public green spaces, but the authors found a higher presence of birds in the urban matrix. The results follow another study on the quality of the habitat, where authors state that the negative effects of urbanization on bird communities are mainly due to the decreased capacity of the landscape to provide appropriate feeding resources and nesting sites. This, combined with increased human disturbance, filters out certain species [42].

The building density of the historic centre of Castellón is higher than that of the *Grao*. In the historic centre, there are 13,000

Table 5
Estimation of population density of study areas.

Study area	Population density	Number of dwellings	Population
Historic centre	2.4	10,992	26,383
Grao district	2.6	2662	6921

Table 6
Calculation of selected indicators.

Indicator	Results for the historic centre	Results for the *Grao* district
Height of building	From 1 to 19 floors 18% 3-floors high	From 1 to 15 floors 35% 1-floor high
Building density	0.013 housing/m^2	0.008 housing/m^2
Use of building	Residential, commercial, industrial, public utilities, office, rental	Residential, commercial, industrial, public utilities, office, rental
Functionality	96% efficient	97% efficient
Proportion of green areas	12%	44%
Green-concrete proportion	1/8	4/9
Blue infrastructure	One lake	None
Green area per capita	3.94 m^2 per capita	20.51 m^2 per capita

dwellings per km^2, while in the *Grao*, there are 8000. Both densities are high compared to rural areas in the United States, where between 6 and 25 dwellings are found per km^2 [57]. These densities are also higher than in the Auckland Plan in New Zealand, where a medium-density development is considered to be between 2000 and 6000 dwellings per km^2 [58]. This indicator could help to correlate population density and avifauna, as some bird species are more closely linked to human activity than others. A particular weakness of the building density indicator is that definitions between studies often vary, making it ambiguous [59]. According to the results, the composition of bird colonies becomes increasingly impoverished by urban density, leading to the dominance of a few abundant species. Similarly, previous studies highlighted that anthropic-centred urban developments entail a reduction in biodiversity in the long term [41,42].

The virtual tour and the field visit only showed a lake in the historic centre, while there are no ponds or lagoons in the *Grao* district. This factor may be less crucial in the maritime zone given its proximity to the sea but the minimal presence of water bodies in the historic centre is a cause for concern. The proportion of the area covered by water is positively associated with the taxonomic diversity of urban birds [39,60]. Therefore, natural or artificial water bodies could benefit both human residents and urban fauna, while also counteracting the heat island phenomenon, a recurrent problem in cities today.

The use of biodiversity indicators depends on the behaviour of the species under assessment. Birds behave differently: while some are found in higher numbers in green areas, others prefer places with a high urban presence and the opportunity to feed on waste. Thanks to the indicators selected in this study it is possible to ascertain how many amenities the study areas could offer to biodiversity within the existing lay-out.

5. Conclusions

The assessment of the ecological role of historic centres in Castellón is the result of a four-stage methodology. The research demonstrates how it is possible to analyse the built environment through biodiversity indicators, correlate its density with the presence of the bird species. By analysing the information retrieved from cadastral sources and online applications such as Google Earth and regional cartographic viewers, the information is collected and evaluated with GIS software and statistical correlation.

The evaluation of district morphology includes the parameters of biodiversity indicators, such as the typology of buildings, the existence of green spaces, blue infraestructures and functionality. The findings of the study constitute a major contribution, expanding information on the enhancement of biodiversity in historic centres. Three of the bird species identified are selected to analyse their association with the built environment, mainly prompted by the population decline in recent years. Through the distribution mapping, the study finds that the three species rely on the most historic urban fabric and well-established green infrastructures. As a result, the authors have identified three types of habitats related to the basic needs of feeding and reproduction. One-to three-story buildings are those which most promote biodiversity while high-rise buildings do not appear to be associated with large concentrations of birds in this study. Elements such as eaves and balconies facilitate connectivity and movement of avifauna, as do wider streets and green areas nearby.

The statistical analysis correlating the density and distribution of all bird species found in the districts shows that the highest concentration of birds coincides with the grids found near parks and other peripheral natural areas. In terms of the implementation of indicators, the most notable weak point to be addressed in the areas of study is the lack of green spaces. While on the one hand efforts should focus on reaching the figure recommended by the WHO to promote the well-being of inhabitants, biodiversity connectivity should also be improved by providing blue infrastructure elements such as small ponds or fountains.

The results demonstrate how, when the management of the built environment is at stake, there is need for a better understanding of the availability of facilities, lay-outs and spaces to enhance biodiversity. As the preservation of historic urban structures can play an essential role in enhancing biodiversity we can conclude that historic buildings and green areas provide specific habitats for several species, while also promoting well-being and preserving the cultural identity of inhabitants. Accordingly, the present study generates new directions to respond to social and environmental challenges to be further developed in a future Green Plan for the city.

Some limitations in the study arose during the third stage of field data collection. The line transect method reflects potential structural biases intrinsic to the particularities of the urban environments, which is only to be expected when adopting the method at local level. As for the delimitation of areas, the study recommends, as far as possible, to assess complete urban nuclei, including more areas, in order to contrast the information, and to do so with several cities in similar climates. Another potential improvement could extend the selection of species to those with greater densities at the time of the census as well as to a more endangered species or one of greater conservation interest. A continuation of this study aims to contrast data to be obtained in other Spanish and European cities, further enabling the identification of strengths and weaknesses of built environments and biodiversity according to specific geographical regions.

Author contribution statement

Cristina del Pilar Buenaño: Performed the experiments; Analysed and interpreted the data; Wrote the paper. </p>
Juan A. García-Esparza: Conceived and designed the experiments; Wrote the paper. </p>
Antonio J. Castelló: Conceived and designed the experiments; Analysed and interpreted the data. </p>
Pablo Altaba:Contributed reagents, materials, analysis tools or data. </p>
Anna Valentín: Analysed and interpreted the data; Contributed reagents, materials, analysis tools or data. </p>

Data availability statement

Data will be made available on request.
No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors want to thank the reviewers for their invaluable comments which have enormously enhanced the quality of the article. We want to thank the work of Pepe Greño with the data collection and the advise of Mario Giménez in outlining the fieldwork approach.

References

[1] E. Sesana, A.S. Gagnon, C. Ciantelli, J. Cassar, J.J. Hughes, Climate change impacts on cultural heritage: a literature review, Wiley Interdiscip. Rev.-Clim. Chang. 12 (4) (2021), e710, https://doi.org/10.1002/wcc.710.
[2] M. Wang, M. Zhao, M. Lin, W. Cao, H. Zhu, N. An, Seeking Lost Memories: application of a new visual methodology for heritage protection, Geogr. Rev. 110 (4) (2020) 556–574, https://doi.org/10.1080/00167428.2020.1715800.
[3] A.N. Martins, A.A. Pereira, C. Forbes, J.L. de Lima, D. Matos, Risk to cultural heritage in Baixa Pombalina (Lisbon Downtown)-a transdisciplinary approach to exposure and drivers of vulnerability, Int. J. Archit. Herit. 15 (7) (2021) 1058–1108, https://doi.org/10.1080/15583058.2020.1745322.
[4] D. Feng, S.C. Chiou, F. Wang, On the sustainability of local cultural heritage based on the landscape narrative: a case study of historic site of qing yan yuan, China, Sustainability 13 (5) (2021) 2831, https://doi.org/10.3390/su13052831.
[5] Z. Deng, D. Chen, X. Qin, S. Wang, Comprehensive assessment to residents' perceptions to historic urban center in megacity: a case study of Yuexiu District, Guangzhou, China, J. Asian Archit. Build. Eng. 20 (5) (2021) 566–580, https://doi.org/10.1080/13467581.2021.1942000.
[6] K. Chapagain, H.T. Aboelnga, M.S. Babel, L. Ribbe, V.R. Shinde, D. Sharma, et al., Urban water security: a comparative assessment and policy analysis of five cities in diverse developing countries of Asia, Environ. Dev. 43 (2022), 100713, https://doi.org/10.1016/j.envdev.2022.100713.
[7] T. Bhakti, F. Rossi, P. de Oliveira Mafia, E.F. de Almeida, M.A.G. Fujaco, C.S. de Azevedo, Preservation of historical heritage increases bird biodiversity in urban centers, Environ. Dev. Sustain. 23 (6) (2021) 8758–8773, https://doi.org/10.1007/s10668-020-00993-7.
[8] J. Staes, S. Broekx, K. Van Der Biest, D. Vrebos, B. Olivier, L. De Nocker, et al., Quantification of the potential impact of nature conservation on ecosystem services supply in the Flemish Region: a cascade modelling approach, Ecosyst. Serv. 24 (2017) 124–137, https://doi.org/10.1016/j.ecoser.2017.02.020.
[9] C. Sun, S. Xu, W. Qi, C. Chen, Y. Deng, N. Pei, et al., Biodiversity constraint indicator establishment and its optimization for urban growth: framework and application, Environ. Res. Lett. 14 (12) (2019), 125006. https://iopscience.iop.org/article/10.1088/1748-9326/ab55aa.
[10] H. Lei, J. Koch, H. Shi, An analysis of spatio-temporal urbanization patterns in Northwest China, Land 9 (11) (2020) 411, https://doi.org/10.3390/land9110411.
[11] M. Salas, J.C. Hernandez-Hernandez, M. Iglesias, M.J. Corriale, Activity patterns and behavior of Myocastor coypus in a gated community in the metropolitan area of Buenos Aires (Argentina), J. Urban Ecol. 8 (1) (2022), https://doi.org/10.1093/jue/juab037 juab037.
[12] A.J. Felson, A.M. Ellison, Designing (for) urban food webs, Front. Ecol. Evol. 9 (2021), 582041, https://doi.org/10.3389/fevo.2021.582041.
[13] I. MacGregor-Fors, Winter thriving: on the role of a boreal city on bird communities, J. Urban Ecol. 8 (1) (2022), https://doi.org/10.1093/jue/juac010 juac010.
[14] V. Pellissier, M. Cohen, A. Boulay, P. Clergeau, Birds are also sensitive to landscape composition and configuration within the city centre, Landsc. Urban Plan. 104 (2) (2012) 181–188, https://doi.org/10.1016/j.landurbplan.2011.10.011.
[15] S. Giannakopoulou, E. Xypolitakou, D. Damigos, D. Kaliampakos, How visitors value traditional built environment? Evidence from a contingent valuation survey, J. Cult. Herit. 24 (2017) 157–164, https://doi.org/10.1016/j.culher.2016.11.004.

[16] D.T. Hayat, B. Ibrahim, Sustainable heritage management: a literature review, in: S. Grima, E. Özen, I. Romānova (Eds.), Managing Risk and Decision Making in Times of Economic Distress, Part A, 108A, Emerald Publishing Limited, 2022, pp. 181–194, https://doi.org/10.1108/S1569-37592022000108A040.
[17] L. Yongqi, Y. Ruixia, W. Pu, Y. Anlin, C. Guolong, A quantitative description of the spatial–temporal distribution and evolution pattern of world cultural heritage, Herit. Sci. 9 (1) (2021) 1–14, https://doi.org/10.1186/s40494-021-00549-6.
[18] G.N. Bratman, C.B. Anderson, M.G. Berman, B. Cochran, S. De Vries, J. Flanders, et al., Nature and mental health: an ecosystem service perspective, Sci. Adv. 5 (7) (2019), eaax0903, https://doi.org/10.1007/978-3-030-80975-1.
[19] A. Filazzola, N. Shrestha, J.S. MacIvor, The contribution of constructed green infrastructure to urban biodiversity: a synthesis and meta-analysis, J. Appl. Ecol. 56 (9) (2019) 2131–2143, https://doi.org/10.1111/1365-2664.13475.
[20] S.F. Franco, J.L. Macdonald, Measurement and valuation of urban greenness: remote sensing and hedonic applications to Lisbon, Portugal, Reg. Sci. Urban Econ. 72 (2018) 156–180, https://doi.org/10.1016/j.regsciurbeco.2017.03.002.
[21] A. Blanchart, G. Séré, C. Johan, W. Gilles, M. Stas, J. Consalès, et al., Towards an operational methodology to optimize ecosystem services provided by urban soils, Landsc. Urban Plan. 176 (2018) 1–9, https://doi.org/10.1016/j.landurbplan.2018.03.019.
[22] A. Azpeitia-Santander, A. Azkarate, A. De la Fuente, Historic urban landscapes: a review on trends and methodologies in the urban context of the 21st century, Sustainability 10 (8) (2018) 2603, https://doi.org/10.3390/su10082603.
[23] I.V. de Freitas, C. Sousa, M. Ramazanova, H. Albuquerque, Feeling a historic city: porto landscape through the eyes of residents and visitors, Int. J. Tour. Cities 8 (2) (2022) 529–545, https://doi.org/10.1108/IJTC-05-2021-0086.
[24] E. Paschalidou, C. Fafet, L. Milios, A strong sustainability framework for digital preservation of cultural heritage: introducing the eco-sufficiency perspective, Heritage 5 (2) (2022) 1066–1088, https://doi.org/10.3390/heritage5020058.
[25] J.M. Magre, M.B. Juncà, J.M. Campanera, A.B. Pagès, I.R. Mallén, R.M. Zaragoza, et al., How urban green management is influencing passerine birds' nesting in the Mediterranean: a case study in a Catalan city, Urban For. Urban Green. 41 (2019) 221–229, https://doi.org/10.1016/j.ufug.2019.03.012.
[26] M.J. Paulin, R.P. Remme, D.C.J. Van der Hoek, B. De Knegt, K.R. Koopman, Breure, et al., Towards nationally harmonized mapping and quantification of ecosystem services, Sci. Total Environ. 703 (2020), 134973, https://doi.org/10.1016/j.scitotenv.2019.134973.
[27] S.N. Alves, Water Infrastructure in a small west African city: situating sharing and volunteering in the making of urban infrastructures, Geoforum 132 (2022) 135–144, https://doi.org/10.1016/j.geoforum.2022.04.009.
[28] W. Xu, Y. Kong, D. Proverbs, Y. Zhang, Y. Zhang, J. Xu, A Water resilience evaluation model for urban cities, Water 14 (12) (2022) 1942, https://doi.org/10.3390/w14121942.
[29] Z. Tao, E. Neil, B. Si, Determining deep root water uptake patterns with tree age in the Chinese loess area, Agric. Water Manage. 249 (2021), 106810, https://doi.org/10.1016/j.agwat.2021.106810.
[30] N. Sloan, B. Doran, F. Markham, K. Pammer, Does base map size and imagery matter in sketch mapping? Appl. Geogr. 71 (2016) 24–31, https://doi.org/10.1016/j.apgeog.2016.04.001.
[31] D.R. Guilfoyle, G. Carey, A.J. Rogers, M. Bernard, R. Willoya-Williams, Empowering tribal youth in cultural heritage management: a case study from the kenai peninsula, Alaska, Archaeologies 15 (1) (2019) 42–63, https://doi.org/10.1007/s11759-019-09357-8.
[32] S. Grey, R. Kuokkanen, Indigenous governance of cultural heritage: searching for alternatives to co-management, Int. J. Herit. Stud. 26 (10) (2020) 919–941, https://doi.org/10.1080/13527258.2019.1703202.
[33] M.C. Kondo, J.M. Fluehr, T. McKeon, C.C. Branas, Urban green space and its impact on human health, Int. J. Environ. Res. Public Health 15 (3) (2018) 445, https://doi.org/10.3390/ijerph15030445.
[34] D. Schram-Bijkerk, P. Otte, L. Dirven, A.M. Breure, Indicators to support healthy urban gardening in urban management, Sci. Total Environ. 621 (2018) 863–871, https://doi.org/10.1016/j.scitotenv.2017.11.160.
[35] J.C. Doelman, E. Stehfest, A. Tabeau, H. van Meijl, L. Lassaletta, D.E. Gernaat, et al., Exploring SSP land-use dynamics using the IMAGE model: regional and gridded scenarios of land-use change and land-based climate change mitigation, Glob. Environ. Change 48 (2018) 119–135, https://doi.org/10.1016/j.gloenvcha.2017.11.014.
[36] H. Kim, I. Rosa, R. Alkemade, P. Leadley, G. Hurtt, A. Popp, et al., A protocol for an intercomparison of biodiversity and ecosystem services models using harmonized land-use and climate scenarios, 456, Geosci. Model Dev. (GMD) 11 (11) (2018) 4537, https://doi.org/10.5194/gmd-11-4537-2018, 2018.
[37] P. Vihervaara, A. Viinikka, L. Brander, F. Santos-Martín, L. Poikolainen, S. Nedkov, Methodological interlinkages for mapping ecosystem services–from data to analysis and decision-support, One Ecosyst. 4 (2019), e26368, https://doi.org/10.3897/oneeco.4.e26368.
[38] M.L. Sánchez, A.T. Cabrera, M.L.G. del Pulgar, The potential role of cultural ecosystem services in heritage research through a set of indicators, Ecol. Indic. 117 (2020), 106670, https://doi.org/10.1016/j.ecolind.2020.106670.
[39] J.D. Ibáñez-Álamo, F. Morelli, Y. Benedetti, E. Rubio, J. Jokimäki, T. Pérez-Contreras, et al., Biodiversity within the city: effects of land sharing and land sparing urban development on avian diversity, Sci. Total Environ. 707 (2020), 135477, https://doi.org/10.1016/j.scitotenv.2019.135477.
[40] B.L. Keeler, P. Hamel, T. McPhearson, M.H. Hamann, M.L. Donahue, K.A. Meza Prado, et al., Social-ecological and technological factors moderate the value of urban nature, Nat. Sustain. 2 (1) (2019) 29–38, https://doi.org/10.1038/s41893-018-0202-1.
[41] P. Batáry, K. Kurucz, M. Suarez-Rubio, D.E. Chamberlain, Non-linearities in bird responses across urbanization gradients: a meta-analysis, Glob. Change Biol. 24 (3) (2018) 1046–1054, https://doi.org/10.1111/gcb.13964.
[42] W. Sidemo-Holm, J. Ekroos, S. Reina García, B. Söderström, M. Hedblom, Urbanization causes biotic homogenization of woodland bird communities at multiple spatial scales, Glob. Change Biol. 28 (21) (2022) 6152–6164, https://doi.org/10.1111/gcb.16350.
[43] M.E. Becker, P.J. Weisberg, Synergistic effects of spring temperatures and land cover on nest survival of urban birds, Condor 117 (1) (2015) 18–30, https://doi.org/10.1650/CONDOR-14-1.1.
[44] J.W. Wang, C.H. Poh, C.Y.T. Tan, V.N. Lee, A. Jain, E.L. Webb, Building biodiversity: drivers of bird and butterfly diversity on tropical urban roof gardens, Ecosphere 8 (9) (2017), e01905, https://doi.org/10.1002/ecs2.1905.
[45] L.M. Leveau, I. Ibáñez, Nesting site and plumage color are the main traits associated with bird species presence in urban areas, Animals 12 (9) (2022) 1148, https://doi.org/10.3390/ani12091148.
[46] J.A. García-Esparza, C. Caballero Roig, Procedure for evaluating and refurbishing envelopes of obsolete buildings in warm regions, Adv. Build. Energy Res. 11 (2) (2017) 245–259, https://doi.org/10.1080/17512549.2016.123737.
[47] D.L. Prytherch, Urban planning and a Europe transformed: the landscape politics of scale in Valencia, Cities 20 (6) (2003) 421–428.
[48] A. Renau-Pruñonosa, O. García-Menéndez, M. Ibáñez, E. Vázquez-Suñé, C. Boix, B.B. Ballesteros, et al., Identification of aquifer recharge sources as the origin of emerging contaminants in intensive agricultural areas. La Plana de Castellón, Spain, Water 12 (3) (2020) 731, https://doi.org/10.3390/w12030731.
[49] Y. Chen, L. Li, X. Zhu, Y. Shen, A. Ma, X. Zhang, et al., Urban low-rise residential areas provide preferred song post sites for a resident songbird, Animals 12 (18) (2022) 2436, https://doi.org/10.3390/ani12182436.
[50] M. Polak, Relationship between traffic noise levels and song perch height in a common passerine bird, Transport. Res. Transport Environ. 30 (2014) 72–75, https://doi.org/10.1016/j.trd.2014.05.004.
[51] R.A. Fuller, K.N. Irvine, P. Devine-Wright, P.H. Warren, K.J. Gaston, Psychological benefits of greenspace increase with biodiversity, Biol. Lett. 3 (4) (2007) 390–394, https://doi.org/10.1098/rsbl.2007.0149.
[52] M. Dallimer, K.N. Irvine, A.M. Skinner, Z.G. Davies, J.R. Rouquette, L.L. Maltby, K.J. Gaston, Biodiversity and the feel-good factor: understanding associations between self-reported human well-being and species richness, Bioscience 62 (1) (2012) 47–55, https://doi.org/10.1525/bio.2012.62.1.9.
[53] J.A. García-Esparza, P. Altaba, J. Huerta, Examining urban polarization in five Spanish historic cities through online datasets and onsite stakeholders' perceptions, Habitat Int. 139 (2023), 102900, https://doi.org/10.1016/j.habitatint.2023.102900.
[54] Y. Ito, K.I. Matsumoto, A. Usup, Y. Yamamoto, A sustainable way of agricultural livelihood: edible bird's nests in Indonesia, Ecosys. Health Sustain. 7 (1) (2021), 1960200, https://doi.org/10.1080/20964129.2021.1960200.
[55] A. Kurvinen, A. Saari, Urban housing density and infrastructure costs, Sustainability 12 (2) (2020) 497, https://doi.org/10.3390/su12020497.

[56] I. MacGregor-Fors, R. Ortega-Álvarez, Fading from the forest: bird community shifts related to urban park site-specific and landscape traits, Urban For. Urban Green. 10 (3) (2011) 239–246, https://doi.org/10.1016/j.ufug.2011.03.004.
[57] C.M. Hamilton, M. Baumann, A.M. Pidgeon, D.P. Helmers, W.E. Thogmartin, P.J. Heglund, et al., Past and predicted future effects of housing growth on open space conservation opportunity areas and habitat connectivity around National Wildlife Refuges, Landsc. Ecol. 31 (9) (2016) 2175–2186, https://doi.org/10.1007/s10980-016-0392-8.
[58] E. Haarhoff, L. Beattie, A. Dupuis, Does higher density housing enhance liveability? Case studies of housing intensification in Auckland, Cogent Soc. Sci. 2 (1) (2016), 1243289, https://doi.org/10.1080/23311886.2016.1243289.56.
[59] M. Kuussaari, M. Toivonen, J. Heliölä, J. Pöyry, J. Mellado, J. Ekroos, et al., Butterfly species' responses to urbanization: differing effects of human population density and built-up area, Urban Ecosyst. 24 (3) (2021) 515–527, https://doi.org/10.1007/s11252-020-01055-6.
[60] F. Morelli, Y. Benedetti, T. Su, B. Zhou, D. Moravec, P. Šímová, et al., Taxonomic diversity, functional diversity and evolutionary uniqueness in bird communities of Beijing's urban parks: effects of land use and vegetation structure, Urban For. Urban Green. 23 (2017) 84–92, https://doi.org/10.1016/j.ufug.2017.03.009.

Glossary

Scientific name Common name

Aegithalos cauclatus: Long-tailed tit
Apus apus: Common swift
Bubulcus ibis: Cattle egret
Carduelis carduelis: Goldfinch
Columba livia: Rock dove
Columba palumbus: Common woodpigeon
Delichon urbicum: House martin
Egretta garzetta: Little egret
Erithaus rubecula: Robin redbreast
Falco eleonorae: Eleonora's falcon
Falco tinnunculus: Common kestrel
Hirundo rustica: Barn swallow
Ichthyaetus audouinii: Audouin's gull
Larus michahellis: Yellow-legged gull
Motacilla alba: White wagtail
Muscicapa striata: Spotted flycatcher
Otus scops: Eurasian scops owl
Parus major: Great tit
Passer domesticus: House sparrow
Periparus ater: Coal tit
Plegadis falcinellus: Glossy ibis
Pica pica: Common magpie
Psittacula krameri: Rose-ringed parakeet

Ptyonoprogne rupestris

Serinus serinus: Eurasian crag martin

European serin

Streptopelia decaocto: Eurasian collared dove
Sturnus unicolor: Spotless starling
Sylvia atricapilla: Blackcap
Turdus merula: Common blackbird
Unidentified columbida: Unidentified pigeon
Unidentified laridae: Unidentified laridae
Upopa epops: Eurasian hoopoe

Acronym Definition

GIS: Geographic information system (GIS)
QGIS: QGIS is a free and open source Geographic Information System for GNU/Linux, Unix, Mac OS, Microsoft Windows and Android platforms
WHO: World Health Organization