ASOCIACIÓN ESPAÑOLA DE ECOLOGÍA TERRESTRE

Ecosistemas 31(1):2354 [Enero-Abril 2022]
https://doi.org/10.7818/ECOS.2354

MONOGRAPHIC: Urban Ecology: A Growing Discipline

Editors: Juan Diego Ibáñez Álamo and Mercedes Molina Morales

REVIEW ARTICLE

ecosistemas
REVISTA CIENTÍFICA DE ECOLOGÍA Y MEDIO AMBIENTE

ISSN 1697-2473
Open access / CC BY-NC 3.0
disponible en www.revistaecosistemas.net

Changing urban bird diversity: how to manage adaptively our closest relation with wildlife

Mario Díaz[1], Anna Ramos[1], Elena D. Concepción[1]

(1) Department of Biogeography and Global Change (BGC–MNCN), Museo Nacional de Ciencias Naturales, CSIC, C/Serrano 115 bis, E-28006 Madrid, Spain.

* Corresponding author: Mario Díaz [Mario.Diaz@ccma.csic.es]

> Recibido el 09 de febrero de 2022 - Aceptado el 28 de febrero de 2022

How to cite: Díaz, M., Ramos, A., Concepción, E.D. 2022. Changing urban bird diversity: how to manage adaptively our closest relation with wildlife. *Eco-sistemas* 31(1): 2354. https://doi.org/10.7818/ECOS.2354

Changing urban bird diversity: how to manage adaptively our closest relation with wildlife

Abstract: We human beings are becoming urban citizens. More and more people spend their lives in urban environments, so that the conservation and improvement of urban biodiversity is an increasingly hot topic. On the one hand, as cities grow bigger and more populated they can become more hostile for some birds, but cities can also be safer than the surrounding rural environment for others. On the other hand, factors affecting negatively or positively wild birds may also influence human's health, either directly (e.g. pollution) or indirectly (enjoying wildlife diversity could contribute to improve our wellbeing). We review current state of knowledge on factors determining the abundance, diversity and health of urban birds, and derive methods for diagnosing what factors are acting in each particular case. Diagnoses are essential to design effective and efficient ways to manage urban bird diversity and improve it adaptively. We also address whether factors affecting birds could affect citizenship directly, so that urban birds can be used as indicators for healthy urban environments. Investigating and improving urban bird life can also improve human wellbeing through people's involvement on citizen science programs. Monitoring approaches taken by both authorities and NGOs are still too general and badly designed, but collaboration among scientist, volunteers and authorities will contribute to make them effective. Improving citizen involvement will in turn contribute to improve urban bird diversity, closing a win-win loop for both people and wildlife wellbeing.

Keywords: causes; citizen science; experiments; monitoring; wellness

El cambio en las comunidades de aves urbanas: cómo manejar de forma adaptativa nuestra más estrecha relación con la vida salvaje

Resumen: Los seres humanos nos estamos volviendo urbanitas, con lo que la conservación de la biodiversidad urbana es un tema cada vez más candente. A medida que las ciudades crecen, se vuelven más hostiles para algunas aves, mientras que para otras pueden resultar más seguras que los medios rurales periféricos. Por otro lado, los factores negativos o positivos para la avifauna pueden también serlo para la salud humana, ya sea directa (ej. contaminación) o indirectamente (el disfrute de la biodiversidad puede mejorar nuestro bienestar). Revisamos el conocimiento actual sobre los factores que determinan la abundancia, diversidad y salud de las aves urbanas, planteando métodos para diagnosticar cuáles de ellos actúan en cada caso particular. Dicho diagnóstico es esencial para un manejo efectivo y eficiente de la diversidad aviar urbana, y de su manejo adaptativo. Abordamos también si los factores que afectan a las aves podrían afectar directamente a la ciudadanía, en cuyo caso las aves podrían ser indicadoras de ambientes urbanos saludables. Aunque no ocurra ésto, la investigación y mejora de la vida de las aves podrían mejorar nuestro bienestar a través de la participación en programas de ciencia ciudadana. La colaboración entre científicos, voluntarios y autoridades mejoraría en gran medida las acciones de manejo y seguimiento realizadas por autoridades y ONGs, en la actualidad bastante preliminares, fomentando así la diversidad de las aves urbanas y, con ella, el bienestar de la gente y la vida salvaje en las ciudades.

Palabras clave: causas; ciencia ciudadana; experimentos; salud y bienestar; protocolos de monitorización

Introduction

More and more people are living in cities worldwide. Urban areas are growing much faster than any other land use to accommodate this increasing urban population (United Nations 2014), with future predictions estimating a 200% global urbanization increase by 2030 (Fragkias et al. 2013). Urbanization, defined as human-induced landscape changes during city development, is one of the most extreme anthropogenic impacts on the Earth's ecosystems (Foley et al. 2005). Besides producing drastic changes in habitat structure and ecosystem functioning (Grimm et al. 2008; Gaston 2010; Forman 2014), urbanization is also associated with global reductions in biodiversity (McKinney 2008; Seto et al. 2012; Newbold et al. 2015; Concepción et al. 2016; Ibáñez-Álamo et al. 2017). Hence, it is crucial to reconcile urban development with biodiversity conservation, as it was stated in the World Cities Report of the United Nations (United Nations 2016).

Bird communities are prominent components of ecosystems because birds play key roles for ecosystem function, such as seed dispersal or pest control (Şekercioğlu 2006), and birds are usually good indicators for other taxa (Rodrigues and Brooks 2007). This, together with commonness, high detectability and a resolved phylogeny (Jetz et al. 2012; Prum et al. 2015), make birds comparatively well-studied by urban ecologists (Marzluff et al. 2001; Lepczyk and Warren 2012; Gil and Brumm 2014). Several bird species have colonized urban environments from the very beginning of the urbanization process (Gaston 2010). A prime example is the house sparrow (*Passer domesticus*), the most widely distributed wild bird in the world (Johnston and Klitz 1977; Summers-Smith 1988). An increasing number of species followed, common swifts (*Apus apus*), common blackbirds (*Turdus merula*), great tits (*Parus major*) or woodpigeons (*Columba palumbus*) first, and more recently dozens of other bird species (Møller et al. 2012; Møller y Díaz 2018a, 2018b). Paradoxically, typical urban birds such as house sparrows are suffering important population declines (Inger et al. 2015; Isaksson et al. 2018). In fact, despite the apparent existence of benefits associated to urban environments, urban biodiversity is decreasing significantly worldwide (Ibáñez-Álamo et al. 2017).

Bird diversity loss in cities can have several detrimental effects for citizens. Ecosystem functions of pest control by insectivorous and granivorous birds and seed dispersal by frugivores (Şekercioğlu 2006) may be lost. Birds may also act as indicators of environmental quality if causes of its decline are also detrimental for human wellbeing, so that urban bird trends may be used to detect harmful environmental conditions for human health (Herrera-Dueñas et al. 2014, 2017). Finally, interaction with nature, or lack thereof, is essential for human mental health (Lee and Maheswaran 2011; Louv 2011). Increasing disconnection between humans and nature in low-diversity cities is called the “extinction of experience” (Soga and Gaston 2016), and implies the loss of a cultural ecosystem service provided by birds and other wildlife. Conciliation of urban development with biodiversity conservation is in fact one of the 17 Sustainable Development Goals of the EU H2020 Framework programme: Goal 11: To make cities inclusive, safe, resilient and sustainable (https://www.sdgfund.org/goal-11-sustainable-cities-and-communities).

Recent widespread success in bird conservation projects have been based on intensive management plans aiming at enhancing requirements of endangered species, often limiting or even excluding human uses (Donald et al. 2007; Pérez et al. 2012). This approach will not work, obviously, in man-made systems as cities are. Wildlife in cities depends on the maintenance of uses and human activities whose socioeconomic viability and social acceptance should be taken into account. The so-called socioecological approach to conservation (Mace 2014; Díaz, Demissew, et al. 2015), which integrates ecological and socioeconomic goals into management plans, is starting to be applied in agricultural and forestry settings with promising results (Fischer et al. 2012; Campos et al. 2013; Díaz and Concepción 2016; Brotons et al. 2018). Expanding this approach to urban systems requires sampling and analytical frameworks to diagnose causes of wildlife population changes, protocols to derive management proposals aimed at counteracting causes, and scientific monitoring of the performance of management actions to improve them following the principles of adaptive management (Díaz and Concepción 2016). Citizen implication on these frameworks though routine dissemination of results and development of citizen science programs will further improve both the success of conservation programs and the wellbeing of citizens, if properly designed and executed (Soga and Gaston 2016).

Here we review current knowledge on factors determining the abundance, diversity and health of urban birds, and derive methods for diagnosing what factors are acting in each particular case from basic principles of the scientific method and general protocols of bird sampling. Our primary aim is helping the development of science-based win-win protocols directed to preserve both urban bird diversity and citizen wellbeing. Guidance provided can be used by city authorities, NGOs and other citizen associations to improve, on a cost-effective basis, both people and wildlife wellbeing in our growing urban environment.

Factors affecting urban birds

Colonization, or persistence, of wild populations in cities depends on overcoming several selective pressures associated with urban environments (Johnsson and Munshi-South 2017). Disturbances, food, predation, competition, nesting sites, and different types of pollution (chemical, acoustic, light, and electromagnetic) may influence birds in cities according to recent reviews (**Fig. 1**; Gil and Brumm 2014; Murgui and Hedblom 2017; Isaksson et al. 2018). Effects of these factors on bird population trends are however much less known than what one could expect, and may considerably vary among bird species, as well as within and among cities. An increasing number of populations of numerous bird species such as common blackbirds, tits, woodpigeons or even black red-

Figure 1. *Main factors affecting birds in cities. From left to right, chemical, noise, and light pollution; availability of poor-quality food; disturbance by people and their pets; electromagnetic pollution (communication tower); feral predators; availability of high-quality food (insects) and nest sites (trees). Modified from Isaksson (2010) and Díaz et al. (2021a).*

Figura 1. *Factores principales que afectan a las aves urbanas. De izquierda a derecha, contaminación atmosférica, acústica y lumínica; disponibilidad de alimento de baja calidad (comida ultraprocesada); presencia de personas y sus mascotas; contaminación electromagnética (torre de comunicaciones); depredadores ligados al hombre; disponibilidad de alimento de alta calidad (insectos) y lugares para criar (árboles). Modificado de Isaksson (2010) y Díaz et al. (2021a).*

starts (*Phoenicurus ochruros*) are in fact responding positively to these pressures, increasing in numbers and range in urban settings (Møller et al. 2012; Møller and Díaz 2018a, 2018b), whereas others such as sparrows or house martins (*Delichon urbica*) are suffering significant declines (Isaksson 2010; Inger et al. 2015).

People and predators: disturbance levels and escape behaviour

In order to survive and reproduce, all organisms must eat and avoid being eaten. Flight initiation distance (FID), the distance at which animals flee from approaching potential predators, measures how animals weigh foraging needs against predation risk (Møller 2015). Most wild animals perceive humans as potential predators, so that measuring FIDs of birds when approached by humans under standardized conditions (Blumstein 2006; **Fig. 2**) also provided information on how birds deal with the high levels of disturbance caused by human presence in cities (Samia et al. 2015). Alert distances, the distances at which animals notice approaching potential predators (**Fig. 2**), and its relations to FIDs provide additional insights on antipredator behaviour of urban birds (Samia et al. 2017). FIDs are good predictors of bird abundance and population trends at several spatial and temporal scales, at least in Europe (Díaz et al. 2015; Møller and Díaz 2018a). Easy large-scale replication, direct link with key demographic and life-history traits (Sol et al. 2018) and close relation with population size and trends make analyses of bird scape behaviour a popular and powerful tool for analysing bird responses to urbanization and other related man-made factors (Díaz et al. 2013, 2021a, 2022).

Antipredator behaviour differs among bird species according to their life history strategies. Big size and slow pace of life (high adult survival, small clutch size and delayed reproduction) usually implies lower tolerance to predation risk and disturbance and larger escape distances than small size and fast pace of life, probably because of higher cost of predation for large and slow-living species (Sol et al. 2018). Gregariousness and flocking behaviour also influences FIDs, with larger distances in larger flocks of gregarious birds (Morelli et al. 2019). Life history and flocking effects occur during the breeding season mainly, when predation risk of adults involves extended costs to eggs or chicks (Mikula et al. 2018). Alert distances increase whereas escape distances decrease in urban as compared to surrounding rural areas (Díaz et al. 2013; Samia et al. 2017). Birds living in cities are more alert to disturbance but tolerate it more than those living in rural areas. Urbanization effects on scape behaviour are related to lower predation and nest parasitism risks in cities: predatory birds and brood parasites are larger than their victims. Consequently, they are less tolerant to disturbance and scarcer in cities, which are thus safer for other birds (Møller 2012; Møller et al. 2016). Predatory bird abundance also decreases northwards Europe, a fact that explains shorter escape distances of northern than of southern birds (Díaz et al. 2013). Shorter escape distances in low-risk environments enables more confident individuals to better exploit the food sources cities offer (Møller et al. 2015b), leading to a higher reproductive success and positive population trends (Díaz et al. 2015). Summing up, tolerant individuals and species able to reduce their escape distances are more suitable for colonizing urban environments and profit from the advantages they provide,

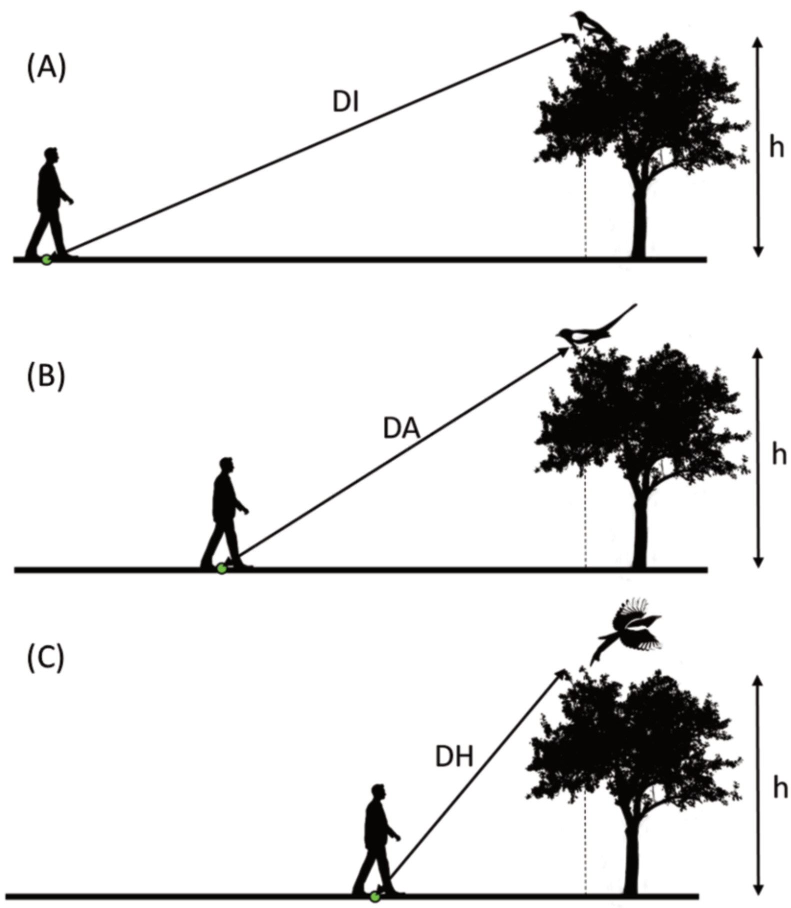

Figure 2. *Bird escape behaviour when a human observer is approaching (after Samia et al. 2017; Díaz et al. 2021a). The initial (ID), alert (AD) and escape (ED) distances are calculated from bird perch' height (h), and from horizontal distances among the observer and the bird when (**A**) the observer detects the bird and starts approaching it, (**B**) the bird detects the approaching observer and (**C**) the bird flies away, using the Pythagoras theorem.*

Figura 2. *Comportamiento de huida de las aves cuando se aproxima un observador humano (según Samia et al. 2017; Díaz et al. 2021a). Las distancias de inicio (DI), alerta (DA) y huida (DH) se calculan a partir de la altura sobre el suelo a la que está el ave (h), y las distancias horizontales entre el observador y el ave cuando (**A**) el observador detecta al ave, (**B**) cuando el ave detecta al observador que se aproxima, y (**C**) cuando el ave huye ante la aproximación del observador, respectivamente, usando el teorema de Pitágoras.*

mainly more food and less predators and nest parasites. Subtle behavioural responses to human presence in cities and to other global change drivers can lead to cascading effects at the species and community levels (Díaz et al. 2021b). Higher success of these birds are leading to the evolution of tolerant urban populations within species and to the assemblage of urban bird communities composed by species more tolerant to the human presence (Møller et al. 2015c; Møller and Díaz 2018b).

Noise, artificial light and heat island effects on bird city song

Human activities inside cities produce noise. Road traffic is the main source of such noise, which is low-frequency noise, highly variable in intensity along the day, the week and the year (Díaz et al. 2011). Noise interferes with bird acoustic communication (Brumm and Slabbekoorn 2005), especially for species with low-frequency songs that are most masked by urban noise (Francis et al. 2009; but see Moiron et al. 2015). Birds can cope with masking effects by changing the frequency or amplitude of songs when exposed to noise. For example, great tits *Parus major* sing more high-pitched in cities than in the surrounding countryside (Brumm and Slabbekoorn 2005). Changes in bird song are partially inherited and partially learned; in fact, urban bird singing is evolving by natural selection as so does escape behaviours (Johnson and Munshi-South 2017). Other strategy is to increase the amount of time devoted to singing, at least up to the level set by other conflicting demands such as predator avoidance or conspecific detection (Díaz et al. 2011). Alternatively, birds can also adjust the place and time of the day for singing in order to avoid noise. Quiet places such as large parks, located at a minimum distance from noise sources such as streets, roads and highways, may be preferred over noisy places (Francis et al. 2009).

Bird singing activity usually peaks at dawn ("dawn chorus"), when birds are less visible for their predators and have to spend the excess energy stores not used at night to reduce weight and increase manoeuvrability for efficient foraging (Marín-Gómez and MacGregor-Fors 2019). Rush hours in cities also occur at daybreak, though. Singing at night, when there is less noise, is another strategy followed by urban birds to cope with noise (Fuller et al. 2007). To do this, birds take advantage of the light pollution that also occurs in cities. Potential detrimental effects on birds (and humans; Navara and Nelson 2007) of light pollution are still poorly known, but could alter biological rhythms, physiology and hormonal levels (Jiang et al. 2020), even causing flight disorientation and higher rates of collisions with illuminated structures (Lao et al. 2020). Finally, urban birds start singing earlier in spring and sing for longer periods than in the surrounding rural areas, although this effect is not clearly related to increased temperatures inside cities (the so-called 'island heat' effect). Differences in duration of singing periods between paired urban and rural sites were as large as latitudinal differences between southern and northern Europe (Møller et al. 2015a). Bird singing and hence bird reproduction is altered in urban environments, as it is migratory behaviour, that is reduced or suppressed in many urban populations (Bonnet-Lebrun et al. 2020) Flight initiation distances (FIDs) also vary with increasing temperature, either because of heat island effects or due to climate warming. Herbivorous and insectivorous birds showed reduced FIDs with increasing temperature, whereas aerial feeders showed increased FIDs. Patterns found are consistent with temperature-related changes in food needs for the former and foraging efficiency changes in the latter (Díaz et al. 2021b). Overall, temperature changes in cities would have consequences in the structure and stability of food webs besides those due to expected changes in specie's distributions (Díaz et al. 2021b).

Air quality, diet, parasites: effects on urban bird health

Air pollution, mainly produced by road traffic, is the type of city pollution citizens are most worried about (Borge et al. 2018). Knowledge on the effects of the different chemicals that pollute city air on people's health and mortality are improving rapidly, but effects on wildlife are much less known and seem to be more complex than expected at first sight. Exposure to urban pollution produces cardiovascular illnesses in addition to several types of cancer in humans (Lodovici and Bigagli 2011), whereas birds are seldom affected directly by pollutants, probably because the bird respiratory system is very efficient due to pressures associated to the evolution of active flight (Kardong 1999). Indirect effects of main pollutants (nitrogen oxides –NO_x- and particles) on birds seem to be mediated by pollutant induction of inflammatory and oxidative stress mechanisms (Lodovici and Bigagli 2011; Kekkonen 2017). This induction increases production of free radicals, and hence the consumption of the antioxidants which are employed in the normal aerobic metabolism (Limón-Pacheco and Gonsebatt 2009). Excess free radicals oxidize key organic molecules as lipids of the cellular membrane, proteins and even the genetic material (Herrera-Dueñas et al. 2017; Ibáñez-Álamo et al. 2018). Birds exposed to pollutants show physiological signals in blood and other tissues consistent with these mechanisms, although direct relations between associated potential health problems and bird abundances or trends have seldom been proved (Herrera-Dueñas et al. 2014, 2017). An indirect relationship between health status and population trends mediated by avian malaria has been recently demonstrated for house sparrows in London. Less healthy individuals more exposed to pollution were more prone to suffer malaria because of a shortage of the antioxidants needed to fend off malaria parasites, and malaria infection increases bird mortality causing negative population trends (Dadam et al. 2019). Differences in avian malaria prevalence among urban and rural house sparrows have been reported for other cities, but the link between health condition, antioxidant levels, pollution and population trends has not been accurately established in these cases yet (Jiménez-Peñuela et al. 2019).

Elimination of free radicals requires antioxidants, which are obtained from the diet in most animals, including humans and birds. Some of these (i.e. carotenoids), are also used by birds to display honest signals of health and genetic quality based on plumage coloration (Møller et al. 2000). Pollutants reduce the main source of carotenoids for birds, insect food, causing decreasing availability for plumage colouration and, hence, paler plumages and reduced reproductive success, in more polluted areas (Eeva et al. 1998). Abundant ultra-processed food, present almost everywhere in cities (Tryjanowski et al. 2015), is poor in carotenoids and other antioxidants such as vitamins (Bowman and Vinyard 2004), so that using it cannot compensate for decreased high-quality insect food. Worse, birds feed with ultra-processed food get worse levels of physiological health indicators, especially if they came from urban environments exposed to pollutants (Herrera-Dueñas et al. 2017). Low availability of healthy food would thus prevent birds from balancing out negative pollutants' effects on their health and, potentially, on population size and trends.

Urban landscapes and bird diversity

Biodiversity in the cities is assumed to be largely determined by the amount of green areas, more hospitable to a varied wildlife than buildings and paved surfaces (Ibáñez-Álamo et al. 2020b). Green areas can be distributed in the urban landscape following two designs, which are extremes of a continuum. Land-sparing designs consists of large (or as large as possible) urban parks surrounded by paved and built areas, whereas land-sharing designs mix built areas with smaller gardens and streets with trees (Lin and Fuller 2013). Contrarily to initial expectations, land-sharing urban designs harbour more diverse bird communities than large parks surrounded by streets and buildings without vegetation, at least in Europe (Ibáñez-Álamo et al. 2020b). Reasons for this finding are still unknown, as classical fragmentation models used for the design of biological reserves predict in fact the opposite pattern (Ibáñez-Álamo et al. 2020b). New models are required to account for these results, which are however in line with those found in recent reviews (Fahrig 2020). New approaches based on the knowledge of mechanistic causes of bird declines are thus needed (Díaz et al. 2021b; Jokimäki et al. 2020). Nevertheless, effects of urban landscape designs on wildlife would act though multiple causes, a fact that make mechanistic approaches difficult. For instance, both noise and air pollution are mostly produced by road traffic, that in turns depends closely on urban landscape design, such as street width and street density (Page and Díaz, unpublished). Relationships between urban landscape structure and bird diversity, population size or trends may thus be mediated by noise effects (Brumm and Slabbekoorn 2005), pollution effects (Borge et al. 2018), food availability (Fernández Cañero and González Redondo 2010), or even predation (Jokimäki et al. 2020). Experimental designs aimed at disentangling relative effects of multiple potential causes at its spatial and temporal variation are thus required to ensure the conservation of urban biodiversity (Scheiner and Gurevitch 2001).

Establishing the local causes of urban bird trends

Monitoring bird trends

Long-term surveys of bird populations are available for some sites and countries as back as 1928, making birds almost ideal organisms to study causes of wildlife population trends. Nevertheless, short time series for most sites, strong spatial variation of sampling effort, and methodological and inter-observer variability are common sources of errors and bias that should be taken into account just for comparing trends for different localities (Møller and Hochachka 2019; Carrascal and del Moral 2020). In Spain, standardized bird surveys started in 1998 (SACRE project, coordinated by the Spanish Society of Ornithology; https://www.seo.org/sacre/) and 2001 (SOCC project, coordinated by the Catalonian Institute of Ornithology (http://www.ornitologia.org/ca/quefem/monitoratge/seguiment/socc/index.html). Volunteers sample every year birds by sight and sound in permanent point counts (SACRE) or line transect (SOCC) distributed in the territory to sample all common bird species in all main habitat types. Survey protocols have proven to be robust enough to estimate population trends of most common birds at national or even regional scales (Carrascal and del Moral 2020 and references therein). Nevertheless, these large-scale protocols are not generally useful for comparisons at lower scales, such as among nearby cities or among neighbourhoods within cities (Díaz et al. 2021a), because typical sampling density of these schemes are in the order of tens of samples per 100 km^2 only. Specific monitoring protocols for some Spanish cities (Valencia, Barcelona, Vitoria, Madrid, Toledo and Granada) are ongoing, most from 2010 onwards or later on (E. Murgui, S. Herrando, J. Quesada and B. Sánchez, com. pers.). Samples of spring and winter bird densities taken in 1984-1986 in 19 cities and 136 smaller towns and 7 neighbourhoods and 7 large urban parks in Madrid are also available (Bernis 1988). Differences in methodologies preclude direct comparisons among these data sources however (Møller and Hochachka 2019).

Relating trends to potential causes

Local bird densities may vary one order of magnitude or more among urban count samples both in space and time (e.g. Ibáñez-Álamo et al. 2020b; Díaz et al. 2021a; **Fig. 3**). Relating variation of bird counts with variation of relevant variables is the usual first step for diagnosing the causes of population change, either in space, when counts are compared among samples or sites differing in environmental conditions, or in time, when bird time series are related to changing environmental conditions. For instance, coincidence of house sparrow population declines with more or less abrupt changes in food abundance (Murgui and Macias 2010; Peach et al. 2013), availability of nesting sites (Summers-Smith 1988), activity of wild or domestic predators (Bell et al. 2010), stress (Chávez-Zichinelli et al. 2010), pollution (Balmori and Hallberg 2007; Kekkonen 2017; Riyahi et al. 2017) or parasitism (Dadam et al. 2019) have led to propose food, nesting sites, predators, disturbance, pollution or parasites as the causes of the widespread house sparrow declines observed in the last decades in Europe (De Laet and Summers-Smith 2007; Moudrá et al. 2018; Dadam et al. 2019). Other proposals are based on spatial associations between rates of parasitism, physical condition or local behaviour with factors such as those indicated above (e.g. Herrera-Dueñas et al. 2014, 2017; Jiménez-Peñuela et al. 2019; Moudrá et al. 2018), or on associations between local abundance and characteristics of the urban habitat such as the density of buildings or the presence of parks (Bernis 1989), assuming that these associations would also be responsible for trends over time. In general, a single cause or general set of causes has not yet been found to explain the observed declines even within the same country (Dadam et al. 2019), which probably indicates that different processes are at work in each local case.

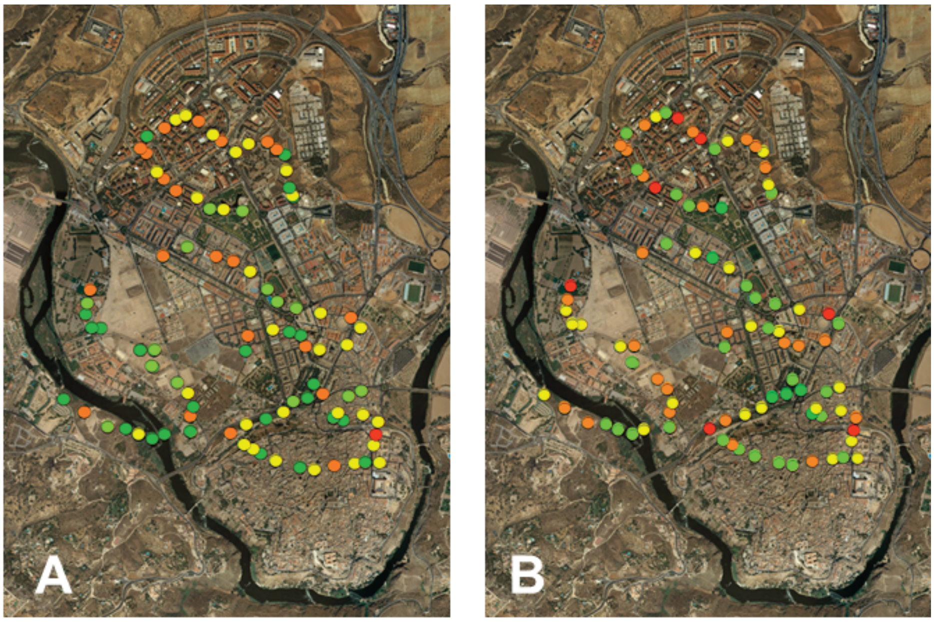

Figure 3. *Results of house sparrow (Passer domesticus) 5-min point counts carried out in Toledo in 2018 (**A**) and abundance change between 2018 and 2019 in relation to the mean annual abundance (**B**). Abundance ranged from 0-8 birds/count (light green) to 33-40 birds/count (red) and change between 120-200% increase (light green) and 120-200% (red) decrease (M. Díaz, unpublished; Díaz et al. 2021a).*

Figura 3. *Resultados de estaciones de escucha de 5 minutos de duración y radio ilimitado realizadas en Toledo en las primaveras de 2018 y 2019. (**A**) abundancia de gorriones comunes (Passer domesticus) en 2018 y (**B**) cambio de abundancia entre 2018 y 2019, en relación a la abundancia media interanual. Los valores de abundancia oscilaron entre 0-8 aves/conteo (verde claro) hasta 33-40 aves/conteo (rojo), y los de cambio interanual entre 120-200% de aumento (verde claro) y 120-200% de disminución (rojo) (M. Díaz, datos propios no publicados; Díaz et al. 2021a).*

Rather than relating single factors with variations in population size or trends, multiple comparisons with potential causal factors should be made. Food (quantity and quality), refuge availability, disturbance by pedestrians, abundance of predators and potential competitors, and several sources of pollution can be estimated directly (e.g. Díaz et al. 2013; Ibáñez-Álamo et al. 2020b). Other sources of pollution (e.g. light, electromagnetic fields or air pollutants), climatic variables or details of urban landscape structure can be obtained from thematic cartography (e.g. Concepción et al. 2016; Morelli et al. 2020, 2021; Page and Díaz, unpublished). Available sources can be either local (e.g. the official city web pages) or derived from European-scale monitoring projects (Copernicus Land Monitoring Service; https://land.copernicus.eu/). Number and type of samples (i.e. point, transect or plot counts), independent variables to be estimated directly and from available sources, and spatial scale of independent samples (e.g. entire cities or landscape blocks within cities) should ideally be defined before sampling (e.g. Ibáñez-Álamo et al. 2020b). The information reviewed above on both bird distribution and trends, and on potential causes of their spatiotemporal variation, should then be the basis for study designs (see also Gil and Brumm 2014; Isaksson et al. 2018; Felappi et al. 2020; Yang 2020 for recent reviews).

Testing causes of population variation

Relationships among bird abundance or trends and potential causal factors can be analysed by fitting statistical models to databases gathered by scientists and, increasingly, by volunteers (Yang 2020). Methods developed to analyse effects of climate change on bird populations (Møller and Dunn 2019) can be also used to analyse potential effects of factors driving change in urban environments (e.g. Morelli et al. 2020). Nevertheless, it should be borne in mind that the statistical patterns found are not true tests of causal factors, but just hypotheses derived from inductive methods about the factors determining the decline, stability, or increase of the bird populations sampled. True hypotheses testing should involve experiments with proper controls, where the involved factors are manipulated and changes of bird abundance are monitored (Hurlbert 1984; Scheiner and Gurevitch 2001). Parallel measurements of relevant physiological or behavioural variables linked to how the factor(s) addressed condition bird population parameters will further provide a mechanistic basis for the patterns found (e.g. Herrera-Dueñas et al. 2014, 2017; Dadam et al. 2019; Jokimäki et al. 2020).

Environmental factors, such as food or nest site availability, can be manipulated by supplementary feeding or by the addition of different types of nest-boxes (e.g. Corsini et al. 2020). Population size should be measured afterwards both in manipulated sites and in proper controls. BACI (before-after-control-impact) experimental designs, where measurements of relevant variables are taken before the manipulation in both the manipulated and control sites, further increase the strength of inference from results obtained (Christie et al. 2019). Other factors such as pollution, predators or potential competitors can be addressed using campaigns for controlling feral pets, invasive species or pollution levels, as far as measurements are available before campaign application and/or in proper controls. In fact, the drastic decrease of human activities in cities during the spring of 2020 due to the Covid-19 disease is now being used as such a kind of unplanned experiment (Rutz et al. 2020; Page and Díaz, unpublished). Physiological or behavioural variables potentially explaining population responses vary from nest predation rates and antipredator behaviours to levels of antioxidants or hormones in blood or feathers, or parasite and/or vector abundances or prevalences (Herrera-Dueñas et al. 2014, 2017; Samia et al. 2017; Dadam et al. 2019; Ibáñez-Álamo et al. 2020a; Jokimäki et al. 2020). Few studies address explicitly, however, whether, how, and why physiological and behavioural traits are responsible for population trends (Díaz et al. 2015; Dadam et al. 2019).

Adaptive monitoring of urban management actions: a role for citizen science

Manipulation, either deliberate or not, of potential causes of bird population trends is commonplace in cities due to its high ecological dynamism. Monitoring the effects of these manipulations by extending BACI designs from pilot experiments will be the best way of diagnosing causes of change and develop efficient ways to manage them. This procedure has long been claimed for European agricultural systems in order to improve environmental goals of the Common Agricultural Policy (Díaz and Concepción 2016), although its success has still been moderate at best (Pe'er et al. 2020).

Monitoring costs are usually claimed as prime reasons for relying on proxy indicators and sampling rather than on direct measurements when evaluating management action (Lindemayer et al. 2012). Citizen science monitoring (Bonney et al. 2009) may greatly overcome these costs enabling adequate spatial and temporal coverage of monitoring programs, as long as programs are successful to attract dedicated and competent volunteers (Torre et al. 2019). Design of bird citizen science programs has in fact been focused on attracting as many volunteers as possible by means of flexible protocols to tackle general, large scale bird monitoring goals (e.g. seo.org/urbano-sacre or celebrateurbanbirds.org/cub/maps/participants). It is increasingly evident, however, that this flexibility involves several biases (Sparks et al. 2008; Tullock and Szabo 2012). Apart from ensuring volunteers' performance to apply monitoring methods (Torre et al. 2019), it is essential to develop sampling schemes aimed at testing hypotheses on causes of trends rather than just document such trends to infer potential causes (Møller and Hochachka 2019). The state of knowledge on what these potential causes is fairly complete nowadays (see references above). Contrastingly, almost nothing is known on the fine-scale spatial and temporal variation of their patterns of change, typical of urban systems (see above and **Fig. 3**), and on whether conservation actions such as feeder or nest box provisioning are effective or not. Monitoring programs maintained by the corresponding authorities and citizen science programs not only differ in whether participants are paid for or not; citizen science implies collaboration among professional scientists, who design and supervise protocols, and skilled volunteers who execute them (Dickinson et al. 2010). Science aims at answering relevant, and unsolved questions and formulating new ones. Citizen science programs will thus go a step beyond of just involving as many people as possible in just counting birds (Møller and Hochachka 2019).

Urban bird trends and human wellbeing

Mechanisms responsible for urban bird population trends could be the same or similar to those that could be directly affecting citizen's health. If this is the case for a given city or neighbourhood, then bird population trends can also indicate environmental quality for human citizens, and bird monitoring can also be used as an integrative indicator of conditions for human health (e.g. Herrera-Dueñas et al. 2014), following the so-called 'one health' approach. This approach consists in the integrated management of all factors affecting human health, from classical diseases and zoonosis to the multifunctional influences of environmental conditions though biodiversity roles on human wellbeing (Zinnstag et al. 2020). A recent review on the characteristics of urban green infrastructure (urban parks) influencing mental health and urban wildlife (Felappi et al. 2020) identifies several traits, such as peri-urban location of parks, vegetation complexity or noise levels, that benefits both humans and wildlife. Nevertheless, others traits, such as flat topography, management intensity or presence of pets were good for mental health though safety perception but not for maintaining high levels of biodiversity.

Factors such as predation by feral pets or disturbance by human management can cause local bird population declines (references above) but have no direct effects on human wellbeing. If this is the case, bird population trends cannot be used to monitor environmental quality for humans. Nevertheless, recent work has shown that bird richness can provide non-material ecosystem services, whose estimated effect on wellbeing can be similar in magnitude to effect of income (Methorst et al. 2021). Bird richness effects on wellbeing can be direct, when birds themselves promote life-satisfaction by means of their visual and auditory perception, or indirect, when life-satisfaction is fostered by experiencing landscapes with characteristics which are beneficial both for bird species richness and human wellbeing. If, and only if, positive effects of birds on people are indirect, bird monitoring, and management of causes of bird trends, can be used to indicate and manage environmental quality for citizens (the 'canary in the coal mine' approach). Otherwise, management of urban birds cannot be said to improve citizen's environment but just bird abundance. Well-designed monitoring programs for urban bird populations are key to answer these questions to improve efficiently both birds' and citizen's wellbeing.

Concluding remarks

Intensive research in the last decades has provided the basis for a fairly good knowledge on the factors that could potentially affect bird abundance and trends in cities. Contrastingly, few attempts have been made to diagnose what factor(s) are acting at each particular case. This diagnosis and its effective monitoring over time, including the evaluation of management actions, are however essential to derive effective and efficient ways to manage urban bird diversity and improve them adaptively.

Citizen science programs for urban bird monitoring have a potential key role for this urgently-needed fine-scale diagnosis and monitoring. Nevertheless, current monitoring approaches taken by both authorities and NGOs are usually too general and poorly designed to be effective. Good knowledge by scientists on potential causes, as well as a stricter application of the scientific method, will largely improve monitoring programs to make them true citizen science rather than just data gathering exercises. Collaboration among scientists, volunteers and authorities responsible for the monitoring of human wellbeing in cities is key to tackle this goal.

Recent research is also showing how people's involvement on citizen science programs aimed at diagnosing and halting causes of biodiversity loss in cities have positive consequences on their health and wellbeing. Improving citizen involvement in well-designed and executed citizen science programs will thus contribute to improve both urban bird diversity and citizen heath, closing a win-win loop for both people and wildlife wellbeing.

Acknowledgments

We thank J.D. Ibáñez-Álamo and A. Herrera-Dueñas for their kind invitation to write this review. Part of the material reviewed comes from a research project submitted to the last call by the BBVA Foundation, leaded by M. Díaz and participated by E.D. Concepción and L. Amo (MNCN-CSIC), J.D. Ibáñez-Álamo, F. González and J. Guardiola (Univ. Granada), M.B. Morales (Univ. Autónoma de Madrid), J.C. Senar and J. Quesada (Museu de Ciències Naturals de Barcelona), A. Marzal (Univ. Extremadura), Ll. Brotons (CREAF-CTFC-CSIC), S. Herrando (Institut Catala d'Ornitologia), A. Herrera-Dueñas (SEO/BirdLife) and E. Murgui (Grupo para el Estudio de la Avifauna); we hope next time the Project will be granted. This paper is a contribution to the project URBILAND (PID2019-107423GA-I00), funded by the Spanish Research Agency. A. Ramos was supported by a JAE intro contract form the Spanish CSIC, and E.D. Concepción by a Juan de la Cierva contract of the Spanish Research Agency (IJCI-2016-30964).

Author's contributions

Mario Díaz: conceptualization, research, literature review, writing - first draft, review and edition; Anna Ramos: research, literature review, writing -review and edition, validation; Elena D. Concepción: conceptualization, research, literature review, writing - review and edition, validation.

References

Balmori, A., Hallberg, Ö. 2007. The urban decline of the house sparrow (*Passer domesticus*): a possible link with electromagnetic radiation. *Electromagnetic biology and medicine* 26(2):141-151.

Bell, C.P., Baker, S.W., Parkes, N.G., Brooke, M.D.L., Chamberlain, D.E. 2010. The role of the Eurasian Sparrowhawk (*Accipiter nisus*) in the decline of the House Sparrow (*Passer domesticus*) in Britain. *The Auk* 127(2):411-420.

Bernis, F. 1988. Avifauna urbana de las mesetas. In: Bernis, F. (ed.), *Aves de los medios urbano y agrícola de las mesetas españolas*, pp. 27-171. Sociedad Española de Ornitología (SEO), Madrid, Spain.

Bernis, F., 1989. *Los gorriones: con especial referencia a su distribución y eto-ecología en las mesetas españolas*. Instituto Nacional de Investigaciones Agrarias (INIA), Madrid, Spain.

Blumstein, D.T. 2006. Developing an evolutionary ecology of fear: How life history and natural history traits affect disturbance tolerance in birds. *Animal Behaviour* 71(2):389–399.

Bonnet-Lebrun, A.S., Manica, A., Rodrigues, A.S. 2020. Effects of urbanization on bird migration. *Biological Conservation* 244: 108423.

Bonney, R., Cooper, C.B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K.V., et al. 2009. Citizen science: A developing tool for expanding science knowledge and scientific literacy. *BioScience* 59(11):977–984.

Borge, R., Artíñano, B., Yagüe, C., Gomez-Moreno, F.J., Saiz-Lopez, A., Sastre, M., et al. 2018. Application of a short term air quality action plan in Madrid (Spain) under a high-pollution episode - Part I: Diagnostic and analysis from observations. *The Science of the Total Environment* 635:1561-1573.

Bowman, S.A., Vinyard, B.T. 2004. Fast food consumption of U.S. adults: impact on energy and nutrient intakes and overweight status. *Journal of the American College of Nutrition* 23(2): 163–168.

Brotons, L., Herrando, S., Sirami, C., Kati, V., Díaz, M. 2018. Mediterranean forest bird communities and the role of landscape heterogeneity in space and time. In: Mikusinski, G., Roberge, J.-M., Fuller, R.J. (eds.), *Ecology and Conservation of Forest Birds*, pp. 318-349. Cambridge University Press. Cambridge, UK.

Brumm, H., Slabbekoorn, H. 2005. Acoustic communication in noise. *Advances in the Study of Behavior* 35:151–209.

Campos, P., Huntsinger, L., Oviedo, J.L., Díaz, M., Starrs, P., Standiford, R.B., et al. (eds.). 2013. *Mediterranean Oak Woodland Working Landscapes: Dehesas of Spain and Ranchlans of California*. Springer, New York, USA.

Carrascal, L.M., Del Moral, J.C. 2020. Two surveys per spring are enough to obtain robust population trends of common and widespread birds in yearly monitoring programmes. *Ardeola* 68(1):33-51.

Chávez-Zichinelli, C.A., MacGregor-Fors, I., Rohana, P.T., Valdéz, R., Romano, M.C., Schondube, J.E. 2010. Stress responses of the House Sparrow (*Passer domesticus*) to different urban land uses. *Landscape and Urban Planning* 98(3-4):183-189.

Christie, A.P., Amano, T., Martin, P.A., Shackelford, G.E., Simmons, B.I., Sutherland, W.J. 2019. Simple study designs in ecology produce inaccurate estimates of biodiversity responses. *Journal of Applied Ecology* 56:2742-2754.

Concepción, E.D., Obrist, M.K., Moretti, M., Altermatt, F., Baur, B., Nobis, M.P. 2016. Impacts of urban sprawl on species richness of plants, butterflies, gastropods and birds: not only built-up area matters. *Urban Ecosystems* 19:225–242.

Corsini, M., Schöll, E.M., Di Lecce, I., Chatelain, M., Dubiec, A., Szulkin, M. 2020. Growing in the city: Urban evolutionary ecology of avian growth rates. *Evolutionary Applications* 00:1-16.

Dadam, D., Robinson, R.A., Clements, A., Peach, W.J., Bennett, M., Rowcliffe, J.M., et al. 2019. Avian malaria-mediated population decline of a widespread iconic bird species. *Royal Society open science* 6(7):182197.

De Laet, J., Summers-Smith, J.D. 2007. The status of the urban house sparrow *Passer domesticus* in north-western Europe: a review. *Journal of Ornithology* 148(2): 275-278.

Díaz, M., Concepción, E.D. 2016. Enhancing the effectiveness of CAP greening as a conservation tool: a plea for regional targeting considering landscape constraints. *Current Landscape Ecology Reports* 1:168-177.

Díaz, M., Parra, A., Gallardo, C. 2011. Serins respond to anthropogenic noise by increasing vocal activity. *Behavioral Ecology* 22(2):332-336.

Díaz, M., Møller, A.P., Flensted-Jensen, E., Grim, T., Ibáñez-Álamo, J.D., Jokimäki, J., et al. 2013. The geography of fear: a latitudinal gradient in anti-predator escape distances of birds across Europe. *PloS one* 8(5).

Díaz, M., Cuervo, J.J., Grim, T., Flensted-Jensen, E., Ibáñez-Álamo, J.D., Jokimäki, J., et al. 2015. Interactive effects of fearfulness and geographical location on bird population trends. *Behavioral Ecology* 26(3):716–721.

Díaz, M., Concepción E.D., Herrera-Dueñas, A., Page, A., Sánchez, B. 2021a. Contaminación y biodiversidad de aves urbanas: ¿Indicadores ambientales, o fuente de salud para los seres humanos? In: (Simón, C., Nogueira, J.J. coord.), *Contaminación, Salud, Biodiversidad y Zonas de Bajas Emisiones*. Respira Madrid, Madrid, libro electrónico. https://www.respiramadrid.org/post/biodiversidad

Díaz, M., Grim, T., Markó, G., Morelli, F., Ibáñez-Alamo, J.D., Jokimäki, J., et al. 2021b. Changing interspecific interactions: Differential effects of spatiotemporal variation in climate on flight initiation distances by birds across Europe. *Scientific Reports* 11: 12826.

Díaz, M., Fernández, J., Page, A. 2022. Cat colonies and flight initiation distances of urban birds: Dealing with conflicting sources of citizen wellbeing. *Science of the Total Environment* 828: 154401.

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., et al. 2015. The IPBES Conceptual Framework—connecting nature and people. *Current Opinion in Environmental Sustainability* 14:1-16.

Dickinson, J.L., Zuckerberg, B., Bonter, D.N. 2010. Citizen science as an ecological research tool: challenges and benefits. *Annual review of ecology, evolution, and systematics* 41:149-172.

Donald, P.F., Sanderson, F.J., Burfield, I.J., Bierman, S.M., Gregory, R.D., Waliczky, Z. 2007. International conservation policy delivers benefits for birds in Europe. *Science*, 317(5839):810-813.

Eeva, T., Lehikoinen, E., Rönkä, M. 1998. Air pollution fades the plumage of the Great Tit. *Functional Ecology* 12(4):607-612.

Fahrig, L. 2020. Why do several small patches hold more species than few large patches? *Global Ecology and Biogeography* 29(4):615-628.

Felappi, J.F., Sommer, J.H., Falkenberg, T., Terlau, W., Kötter, T. 2020. Green infrastructure through the lens of "One Health": A systematic review and integrative framework uncovering synergies and trade-offs between mental health and wildlife support in cities. *Science of the Total Environment* 748:141589.

Fernández Cañero, R., González Redondo, P. 2010. Green roofs as a habitat for birds: a review. *Journal of Animal and Veterinary Advances* 9(15):2041-2052.

Fischer, J., Hartel, T., Kuemmerle, T. 2012. Conservation policy in traditional farming landscapes. *Conservation Letters* 5:167–175.

Foley, J.A., Defries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., et al. 2005. Global consequences of land use. *Science*, 309:570–574.

Forman, R. 2014. *Urban Ecology: Science of Cities*. Cambridge University Press, Cambridge, UK.

Fragkias, M., Güneralp, B., Seto, K.C., Goodness, J. 2013. A Synthesis of Global Urbanization Projections. In: Elmqvist, T., et al. (eds), *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities*, pp. 409-435. Springer, Dordrecht, Netherlands.

Francis, C.D., Ortega, C.P., Cruz, A. 2009. Noise pollution changes avian communities and species interactions. *Current biology: CB* 19(16):1415–1419.

Fuller, R.A., Warren, P.H., Gaston, K.J. 2007. Daytime noise predicts nocturnal singing in urban robins. *Biology letters* 3(4):368-370.

Gaston, K. 2010. *Urban Ecology*. Cambridge University Press, Cambridge, UK.

Gil, D., Brumm, H. 2014. *Avian Urban Ecology: Behavioural and Physiological Adaptations*. Oxford University Press, Oxford, UK.

Grimm, N.B., Faeth, S.H., Golubiewski, N.E., Redman, C.L., Wu, J., Bal, X., et al. 2008. Global change and the ecology of cities. *Science* 319:756–760(5864).

Herrera-Dueñas, A., Pineda, J., Antonio, M.T., Aguirre, J.I. 2014. Oxidative stress of House Sparrow as bioindicator of urban pollution. *Ecological Indicators* 42:6-9.

Herrera-Dueñas, A., Pineda-Pampliega, J., Antonio-García, M.T., Aguirre de Miguel, J.I. 2017. The Influence of Urban Environments on Oxidative Stress Balance: A Case Study on the House Sparrow in the Iberian Peninsula. *Frontiers in Ecology and Evolution* 5(106):1-10.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. *Ecological Monographs* 54:187-211.

Ibáñez-Álamo, J.D., Rubio, E., Benedetti, Y., Morelli, F. 2017. Global loss of avian evolutionary uniqueness in urban areas. *Global change biology* 23(8):2990–2998.

Ibáñez-Álamo, J.D., Pineda-Pampliega, J., Thomson, R.L., Aguirre, J.I., Díez-Fernández, A., Faivre, B., et al. 2018. Urban blackbirds have shorter telomeres. *Biology Letters* 14(3):20180083.

Ibáñez-Álamo, J.D., Jimeno, B., Gil, D., Thomson, R.L., Aguirre, J. I., Díez-Fernández, A., et al. 2020a. Physiological stress does not increase with urbanization in European blackbirds: Evidence from hormonal, immunological and cellular indicators. *Science of The Total Environment* 721:137332.

Ibáñez-Álamo, J.D., Morelli, F., Benedetti, Y., Rubio, E., Jokimäki, J., Pérez-Contreras, et al. 2020b. Biodiversity within the city: Effects of land sharing and land sparing urban development on avian diversity. *Science of The Total Environment* 707:135477.

Inger, R., Gregory, R., Duffy, J.P., Stott, I., Voříšek, P., Gaston, K.J. 2015. Common European birds are declining rapidly while less abundant species' numbers are rising. *Ecology letters* 18(1):28-36.

Isaksson, C. 2010. Pollution and its impact on wild animals: A meta-analysis on oxidative stress. *EcoHealth* 7(3):342–350.

Isaksson, C., Rodewald, A.D., Gil, D. (eds.) 2018. *Behavioural and ecological consequences of urban life in birds*. Frontiers Media, Lausanne, Switzerland.

Jetz, W., Thomas, G.H., Joy, J.B., Hartmann, K., Mooers, A.O. 2012. The global diversity of birds in space and time. *Nature* 491:444–448.

Jiang, J., He, Y., Kou, H., Ju, Z., Gao, X., Zhao, H. 2020. The effects of artificial light at night on Eurasian tree sparrow (*Passer montanus*): Behavioral rhythm disruption, melatonin suppression and intestinal microbiota alterations. *Ecological Indicators* 108(105702).

Jiménez-Peñuela, J., Ferraguti, M., Martínez-de la Puente, J., Soriguer, R., Figuerola, J. 2019. Urbanization and blood parasite infections affect the body condition of wild birds. *The Science of the total environment* 651 (Pt 2):3015–3022.

Johnson, M., Munshi-South, J. 2017. Evolution of life in urban environments. *Science* 358(6363): eaam8327.

Johnston, R.F., Klitz, W.J. 1977. Variation and evolution in a granivorous bird: the house sparrow. In: Pinowski, J., Kendeigh, S.C. (eds.), *Granivorous birds in ecosystems*, pp. 15-53. Cambridge University Press, Cambridge, UK.

Jokimäki, J., Suhonen, J., Benedetti, Y., Díaz, M., Kaisanlahti□Jokimäki, M.L., Morelli, F., et al. 2020. Land-sharing vs. land-sparing urban development modulate predator-prey interactions in Europe. *Ecological Applications* 30(3):e02049.

Kardong, K. 1999. *Vertebrados. Anatomía Comparada, función, evolución*. (2nd ed.). McGraw-Hill Interamericana, Madrid, Spain.

Kekkonen, J. 2017. Pollutants in Urbanized Areas: Direct and Indirect Effects on Bird Populations. In: Murgui, E., Hedblom, M. (eds.), *Ecology and Conservation of Birds in Urban Environments*, pp. 227–250. Springer, Cham, Switzerland.

Lao, S., Robertson, B.A., Anderson, A.W., Blair, R.B., Eckles, J.W., Turner, R.J., et al. 2020. The influence of artificial night at night and polarized light on bird-building collisions. *Biological Conservation* 241:108358.

Lee, A.C., Maheswaran, R. 2011. The health benefits of urban green spaces: a review of the evidence. *Journal of public health* 33(2):212–222.

Lepczyk, C., Warren, P. 2012. *Urban Bird Ecology and Conservation*. University of California Press, California, USA.

Limón-Pacheco, J., Gonsebatt, M.E. 2009. The role of antioxidants and antioxidant-related enzymes in protective responses to environmentally induced oxidative stress. *Mutation research* 674(1-2):137–147.

Lin, B.B., Fuller, R.A. 2013. Sharing or sparing? How should we grow the world's cities? *Journal of Applied Ecology* 50(5):1161–1168.

Lindenmayer, D.B., Gibbons, P., Bourke, M.A.X., Burgman, M., Dickman, C.R., Ferrier, S., et al. 2012. Improving biodiversity monitoring. *Austral Ecology* 37(3):285-294.

Lodovici, M., Bigagli, E. 2011. Oxidative stress and air pollution exposure. *Journal of toxicology* 2011:487074.

Louv, R. 2011. *The nature principle: Human restoration and the end of nature-deficit disorder*. Algonquin Books of Chapel Hill, Chapel Hill, USA.

Mace, G.M. 2014. Whose conservation? *Science*, 345(6204):1558-1560.

Marín-Gómez, O.H., MacGregor-Fors, I. 2019. How Early Do Birds Start Chirping? Dawn Chorus Onset and Peak Times in a Neotropical City. *Ardeola* 66(2):327-341.

Marzluff, J., Bowman, R., Donnelly, R. 2001. *Avian Ecology and Conservation in an Urbanizing World*. Springer Science, USA.

McKinney, M. 2008. Effects of urbanization on species richness: A review of plants and animals. *Urban Ecosystems* 11:161-176.

Methorst, J., Rehdanz, K., Mueller, T., Hansjürgens, B., Bonn, A., Böhning-Gaese, K. 2021. The importance of species diversity for human well-being in Europe. *Ecological Economics* 181(106917).

Mikula, P., Díaz, M., Albrecht, T., Jokimäki, J., Kaisanlahti-Jokimäki, M.L., Kroitero, G., et al. 2018. Adjusting risk-taking to the annual cycle of long-distance migratory birds. *Scientific Reports* 8(13989).

Moiron, M., González-Lagos, C., Slabbekoorn, H., Sol, D. 2015. Singing in the city: high song frequencies are no guarantee for urban success in birds. *Behavioral Ecology* 26(3):843-850.

Møller, A.P. 2012. Urban areas as refuges from predators and flight distance of prey. Behavioral Ecology 23(5):1030–1035.

Møller, A.P. 2015. The value of a mouthful: flight initiation distance as an opportunity cost. *European Journal of Ecology* 1(1):43-51.

Møller, A.P., Díaz, M. 2018a. Avian preference for close proximity to human habitation and its ecological consequences. *Current Zoology* 64(5):623-630.

Møller, A.P., Díaz, M. 2018b. Niche segregation, competition, and urbanization. *Current Zoology* 64(2):145–152.

Møller, A.P., Dunn, P.O. (eds.) 2019. *Effects of Climate Change on Birds*. (2nd ed.). Oxford University Press, Oxford, UK.

Møller, A.P., Hochachka, W.M. 2019. Long-term time series of ornithological data. In: Dunn, P.O., Møller, A.P. (eds.), *Effects of Climate Change on Birds*, pp. 37-43. Oxford University Press, Oxford, UK.

Møller, A.P., Biard, C., Blount, J.D., Houston, D.C., Ninni, P., Saino, N., et al. 2000. Carotenoid-dependent signals: indicators of foraging efficiency, immunocompetence or detoxification ability? *Avian and Poultry Biology Reviews* 11(3):137-159.

Møller, A.P., Díaz, M., Flensted-Jensen, E., Grim, T., Ibáñez-Álamo, J.D., Jokimäki, J., et al. 2012. High urban population density of birds reflects their timing of urbanization. *Oecologia* 170(3):867-875.

Møller, A.P., Díaz, M., Grim, T., Dvorská, A., Flensted-Jensen, E, Ibáñez-Alamo, et al. 2015a. Effects of urbanization on animal phenology: A continental study of paired urban and rural avian populations. *Climate Research* 66(3):185–199.

Møller, A.P., Díaz, M., Flensted-Jensen, E., Grim, T., Ibáñez-Álamo, J.D., Jokimäki, J., et al. 2015b. Urbanized birds have superior establishment success in novel environments. *Oecologia* 178(3):943–950.

Møller, A.P., Tryjanowski, P., Díaz, M., Kwieciński, Z., Indykiewicz, P., Mitrus, C., et al. 2015c. Urban habitats and feeders both contribute to flight initiation distance reduction in birds. *Behavioral Ecology* 26(3):861–865.

Møller, A.P., Díaz, M., Liang, W. 2016. Brood parasitism and proximity to human habitation. *Behavioral Ecology* 27(5):1314-1319.

Morelli, F., Benedetti, Y., Su, T., Zhou, B., Moravec, D., Šímová, P., et al. 2017. Taxonomic diversity, functional diversity and evolutionary uniqueness in bird communities of Beijing's urban parks: effects of land use and vegetation structure. *Urban Forestry and Urban Greening* 23:84–92.

Morelli, F., Benedetti, Y., Díaz, M., Grim, T., Ibáñez-Álamo, J.D., Jokimäki, J., et al. 2019. Contagious fear: Escape behavior increases with flock size in European gregarious birds. *Ecology and Evolution* 9(10):6096-6104.

Morelli, F., Benedetti, Y., Ibáñez-Álamo, J.D., Tryjanowski, P., Jokimäki, J., Kaisanlahti-Jokimäki, M.L., et al. 2020. Insurance for the future? Potential avian community resilience in cities across Europe. *Climatic Change* 159:195-214.

Morelli, F., Reif, J., Díaz, M., Tryjanowski, P., Ibáñez-Álamo, J.D., Suhonen, J., et al. 2021. Top ten birds indicators of high environmental quality in European cities. *Ecological Indicators* 133: 108397.

Moudrá, L., Zasadil, P., Moudrý, V., Šálek, M. 2018. What makes new housing development unsuitable for house sparrows (*Passer domesticus*)? *Landscape and Urban Planning* 169:124-130.

Murgui, E., Macias, A. 2010. Changes in the House Sparrow *Passer domesticus* population in Valencia (Spain) from 1998 to 2008. *Bird Study* 57(3):281-288.

Murgui, E., Hedblom, M. 2017. *Ecology and Conservation of Birds in Urban Environments*. Springer, New York, USA.

Navara, K.J., Nelson, R.J. 2007. The dark side of light at night: physiological, epidemiological, and ecological consequences. *Journal of Pineal Research* 43(3):215–224.

Newbold, T., Hudson, L.N., Hill, S.L.L., Contu, S., Lysenko, I., Senior, R.A., et al. 2015. Global effects of land use on local terrestrial biodiversity. *Nature* 520:45–50.

Pe'er G., Lakner S., Seppelt R., Baumann F., Bezák P., Bonn, A., et al. 2020. The EU's Common Agriculture Policy and Sustainable Farming: A statement by scientists. *Zenodo*.

Peach, W.J., Mallord, J.W., Orsman, C.J., Ockendon, N., Haines, W.G. 2013. Testing assumptions of a supplementary feeding experiment aimed at suburban House Sparrows *Passer domesticus*. *Bird Study* 60(3):308-320.

Pérez, I., Anadón, J.D., Díaz, M., Nicola, G.G., Tella, J.L., Giménez, A. 2012. What is wrong with current translocations? A review and a decision-making proposal. *Frontiers in Ecology and the Environment* 10(9):494-501.

Prum, R.O., Berv, J.S., Dornburg, A., Field, D.J., Townsend, J.P., Moriarty Lemmon, E., et al. 2015. A comprehensive phylogeny of birds (Aves) using targeted next-generation DNA sequencing. *Nature* 526:569–573.

Riyahi, S., Vilatersana, R., Schrey, A.W., Node, H.G., Aliabadian, M., Senar, J.C. 2017. Natural epigenetic variation within and among six subspecies of the house sparrow, *Passer domesticus*. *Journal of Experimental Biology* 220(21):4016-4023.

Rodrigues, A.S.L., Brooks, T.M. 2007. Shortcuts for Biodiversity Conservation Planning: The Effectiveness of Surrogates. *Annual Review of Ecology, Evolution, and Systematics*, 38(1):713-737.

Rutz, C., Loretto, M.C., Bates, A.E., Davidson, S.C., Duarte, C.M., Jetz, W., et al. 2020. COVID-19 lockdown allows researchers to quantify the effects of human activity on wildlife. *Nature Ecology and Evolution* 4:1156-1159.

Samia, D.S., Nakagawa, S., Nomura, F., Rangel, T.F., Blumstein, D.T. 2015. Increased tolerance to humans among disturbed wildlife. *Nature communications* 6(1):1-8.

Samia, D.S.M., Blumstein, D.T., Díaz, M., Grim, T., Ibáñez-Álamo, J.D., Jokimäki, J., et al. 2017. Rural-Urban Differences in Escape Behavior of European Birds across a Latitudinal Gradient. *Frontiers in Ecology and Evolution* 5:1-66.

Scheiner, S.M., Gurevitch, J. (eds.) 2001. *Design and analysis of ecological experiments.* Oxford University Press, Oxford, UK.

Şekercioğlu, C.H. 2006. Increasing awareness of avian ecological function. *Trends in Ecology & Evolution* 21(8):464–471.

Seto, K.C., Güneralp, B., Hutyra, L.R. 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences of the United States of America* 109(40):16083–16088.

Soga, M., Gaston, K.J. 2016. Extinction of experience: The loss of human-nature interactions. *Frontiers in Ecology and the Environment* 14(2):94-101.

Sol, D., Maspons, J., Gonzalez-Voyer, A., Morales-Castilla, I., Zsolt Garamszegi, L., Møller, A.P. 2018. Risk-taking behavior, urbanization and the pace of life in birds. *Behavioral Ecology and Sociobiology* 72(59):1-9.

Sparks, T.H., Huber, K., Tryjanowski, P. 2008. Something for the weekend? Examining the bias in avian phenological recording. *International journal of biometeorology* 52(6):505-510.

Summers-Smith, J.D. 1988. *The Sparrows: a study of the genus Passer*. A & C Black Publishers Ltd., London, UK.

Torre, I., Raspall, A., Arrizabalaga, A., Díaz, M. 2019. Evaluating trap performance and volunteers' experience in small mammal monitoring programs based on citizen science: The SEMICE case study. *Mammalian Biology* 95:26–30.

Tryjanowski, P., Skórka, P., Sparks, T.H., Biaduń, W., Brauze, T., Hetmański, T., et al. 2015. Urban and rural habitats differ in number and type of bird feeders and in bird species consuming supplementary food. *Environmental science and pollution research international* 22(19):15097–15103.

Tulloch, A.I., Szabo, J.K. 2012. A behavioural ecology approach to understand volunteer surveying for citizen science datasets. *Emu-Austral Ornithology* 112(4):313-325.

United Nations 2016. *Urbanization and Development: Emerging Futures. World Cities Report 2016*. United Nations.

United Nations, Department of Economic and Social Affairs, Population Division 2014. *World Urbanization Prospects: The 2014 Revision, Methodology. Working Paper* No. ESA/P/WP.238

Yang, J. 2020. Big data and the future of urban ecology: From the concept to results. *Science China Earth Sciences* 63:1-14.

Zinsstag, J., Schelling, E., Crump, L., Whittaker, M., Tanner, M., Stephen, C. (eds.) 2020. *One Health: the theory and practice of integrated health approaches*. CABI, Wallingford, UK.