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Short Communication

Disease prevalence in an urban raptor related to pest species: The case of Eurasian Scops Owl *Otus scops* infection by *Gongylonema* sp.

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Urbanization is often associated with homogenization, including the homogenization of biodiversity and overpopulation by generalist species that can change community and disease dynamics. In Madrid, nestlings of Eurasian Scops Owl *Otus scops* frequently suffer necrotic oropharyngeal disease as a result of infection by *Gongylonema* sp., a parasitic nematode transmitted by adult owls to their offspring through the diet, more specifically through consumption of a pest species: the oriental cockroach *Blatta orientalis*. We studied how the presence of cockroaches and owl infection rates are affected by urban features such as green areas. We found that a higher number of birds were affected by the parasite in the initial period of the breeding season and in areas with greater surface area of green spaces. We suggest that urban management should promote the diversity of insects in green areas so that the owls diversify their dietary offer to their offspring, to reduce the prevalence of the disease and improve their breeding success in the city of Madrid, as this problem has not yet been described in other cities.

Keywords: disease ecology, pathogens, urban ecology vector management, urban green area management.

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Large metropolitan areas are currently undergoing rapid growth associated with numerous negative effects on species richness, which may be caused by pollution, habitat fragmentation, loss of primary habitats or loss of resources (Palomino & Carrascal 2006). Although living in a city can have positive effects for different species (Aronson *et al.* 2014, Rebolo-Ifrán *et al.* 2017, Seitz *et al.* 2022), urbanization is now considered one of the main drivers of biodiversity change that may cause species loss and homogenization (McKinney 2002, Pauchard *et al.* 2006). Studies focusing on the direct or indirect effects of urbanization on species are particularly needed to detect selective pressures on populations in large urban areas and to assess their adaptation (Fernández-Juricic & Tellería 2000, Fernández-Juricic *et al.* 2001). In this context, we have selected the Eurasian Scops Owl *Otus scops* Linnaeus, 1758, hereafter referred to as Scops Owl, as a model species in the city of Madrid. In Spain, this species suffered a population decline of 32.4% between 2006 and 2018, and is listed as Vulnerable (SEO/BirdLife 2021). In Madrid, Scops Owl chicks infected with undescribed species of *Gongylonema* (Nematoda) can develop a disease called necrotic oropharyngeal disease (NOD; Esperón *et al.* 2013). Since 1997, 90% of nestlings and fledglings have annually shown severe proliferative necrotic lesions in their oral cavities, which can lead to death by starvation (Lopes *et al.* 2022). It has only been detected in chicks less than 3 weeks of age. Therefore, it may be associated with reduced productivity and a significant decline of Scops Owls in Madrid (I. Hernández-Téllez *et al.* unpubl. data). This disease has not been detected in owls in other large cities.

Gongylonema has indirect life cycles associated with coprophagous arthropods, such as dung beetles or cockroaches, which act as intermediate hosts (Illescas-Gómez *et al.* 1988, Jelinek & Löscher 1994). The oriental cockroach (*Blatta orientalis* Linnaeus, 1758; Arthropoda: Blattodea) has recently been identified as the intermediary host for the *Gongylonema* sp. of Scops Owl in

Madrid. Almost 67% of analysed cockroaches in this city were infected, and cockroaches are the most common prey that adults provide to the chicks in this area (Lopes *et al.* 2022). In Madrid, this cockroach is considered a common and annual pest, even causing public health concerns (Madrid Salud 2016). In general, arthropods are negatively impacted by urbanization, which may cause a drastic decrease in species richness (McIntyre 2000, Lagucki *et al.* 2017, Fenoglio *et al.* 2020) and arthropod communities dominated by a few generalist and opportunistic species, such as cockroaches (Penone *et al.* 2012).

Because of the potential impact that NOD could be having on the Scops Owl population in Madrid, the aim of this study was to evaluate the environmental factors that determine chick infection by *Gongylonema* sp. As the oriental cockroach is the only known vector for *Gongylonema* sp., it is hypothesized that a higher NOD prevalence will be temporally and spatially associated with these insects, such that a higher incidence of infection in Scops Owls during their breeding season would be expected. These data will be critical to identify and implement appropriate management activities in the cities.

MATERIAL AND METHODS

Study area

The study was carried out in the city of Madrid (Fig. 1), the most populated city in Spain, with over 3.2 million inhabitants (INE 2022). Madrid is highly urbanized with an extensive network of buildings, sanitation and sewage systems but it has a high density of green spaces, representing 9% of the municipality's surface area (according to data from the latest Municipal Barometer of Urban Economy of the Madrid City Council).

Data collection

Between 1997 and 2015, data were collected from all Scops Owls admitted to the Brinzal Night Raptors Recovery Centre. For each case, the presence or absence of NOD, the georeferenced location where the individual was found and the admission date to the Centre (ADC) was recorded. The breeding season was classified from June to September (Mikkola 1983, Alonso *et al.* 2003). As the lesions caused by the parasite were only detected in 2- to 3-week-old chicks, data from adult individuals were discarded (Fig. 1a).

Variable selection

Although Scops Owl chicks of this age are mobile, they cannot fly, and so it is assumed that the location in which they were found is near their nest. To represent the feeding area of each breeding pair, a 150-m buffer was established. This was the maximum distance that parents move away from the nest to hunt, based on movement of individuals tracked with radio-transmitters (Lopes *et al.* 2022).

Areas with higher presence of oriental cockroaches in Madrid were identified from the year 2010 to 2015, using reports of cockroach sightings in public areas, provided by the Technical Unit of Vector Control of the Department of Environmental Health of Madrid (Madrid Salud). Only reports between June and November were selected, representing the highest interaction among the phenology of cockroaches and the Scops Owl chick-feeding period. A total of 6800 oriental cockroach presence reports were provided (Fig. 1b).

To understand the factors that determine the presence of cockroaches, a series of variables were selected considering the biology and habitat requirements of the oriental cockroach. These variables included seasonal humidity (average monthly relative humidity as a percentage, also related to precipitation variables); minimum temperature (average monthly minimum temperature in °C) and distance to the nearest sewer. To correct possible bias of higher presence of cockroaches in the vicinity of the sewage system, the Sewage Unit of the City of Madrid provided a map with a total of 14 568 gratings and registration lids throughout the study area. In addition to such traits, cockroaches are expected to favour areas near rivers; consequently, the distance to the nearest watercourse was considered.

Statistical analysis

To determine whether NOD prevalence among administered owls varied among years, we constructed a general linear model (GLM) including year as a covariate. An additional analysis of variance (ANOVA) test was used to compare the observation dates of infected and non-infected chicks throughout the year.

The progression of the number of cockroach reports over the years was analysed with univariate linear regression. To consider the biology and habitat preferences of the cockroaches, we assessed the variation in the number of cockroach presence alerts in relation to the date (during the breeding season of the owls), humidity, minimum temperature and distance to the sewers with regressions.

To predict the environmental variables that influence NOD presence in Scops Owls, we constructed a binomial GLM with the presence/absence of lesions as a binomial dependent variable. The time of the year in which the chicks were reported as ADC (including the quadratic term), the proportion of green areas (% green area) and the number of sewers in each home-range (distance to sewer), humidity, minimum and maximum

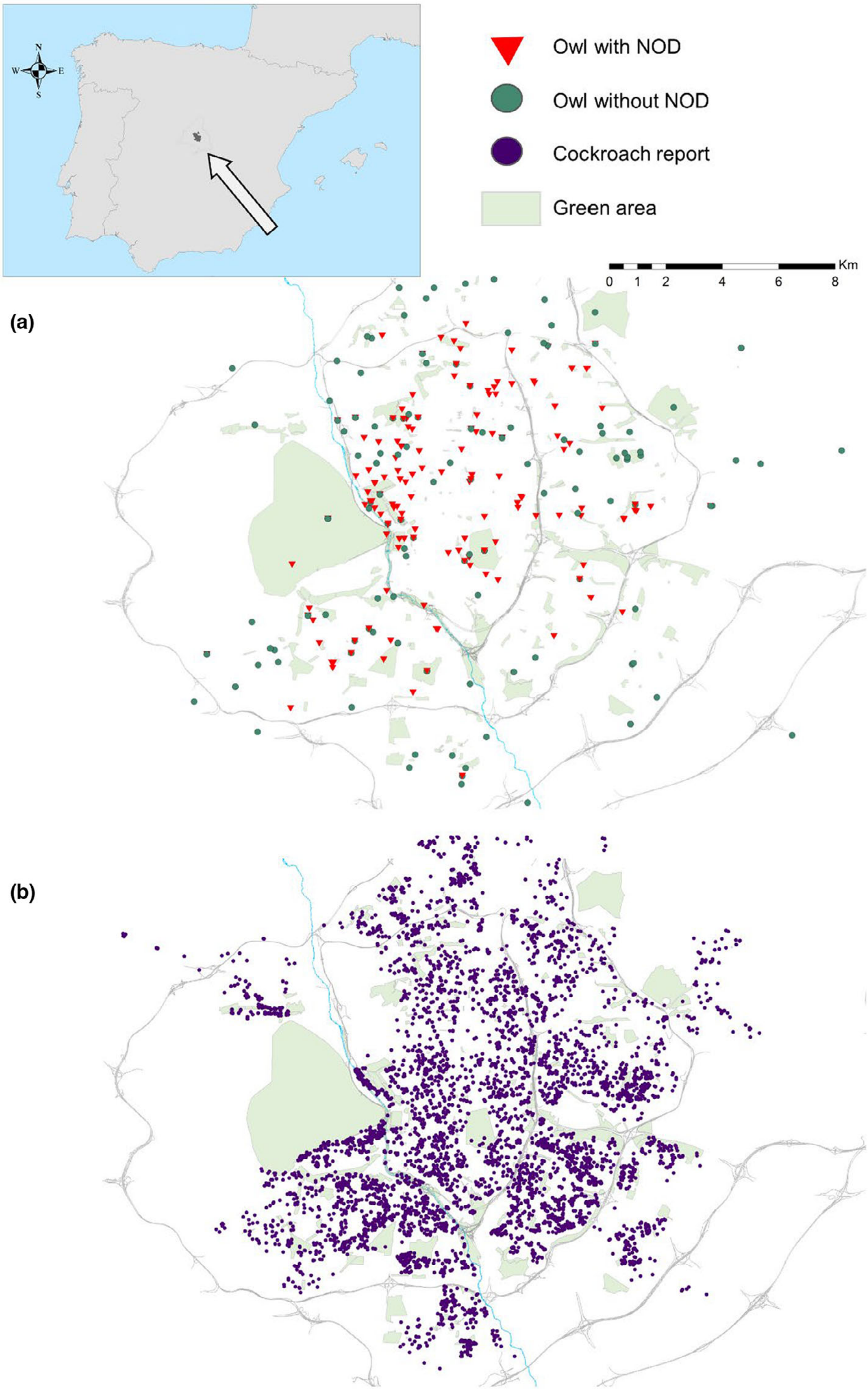

Figure 1. Locations of (a) Scops Owl chicks infected and not infected with necrotic oropharyngeal disease (NOD) in the city of Madrid (Spain) from 1997 to 2015 and (b) oriental cockroach reports in the city of Madrid from 2010 to 2015. The blue line indicates the Manzanares River and grey lines indicate the city's ring roads, marking the urban centre in the middle of them.

monthly temperature, and distance to the river were used as exploratory variables.

Initially, a preliminary study of all the variables was carried out through an array of correlations. We simplified this model by selection of variables based on the Akaike information criterion (AIC).

All statistical analyses were performed in the R software environment (R Core Team 2022) with the *lme4* (Bates *et al.* 2015) and *multcomp* packages (Hothorn *et al.* 2008). Graphs were produced with the *ggplot2* package (Wickham 2016). Maps and GIS analyses were made with ArcGIS 10.8 (Environmental Systems Research Institute, West Redlands, CA, USA).

RESULTS

From 1997 to 2015, of the 477 owl chicks under study, 286 (60%) showed necrotic plaques in their oral cavities consistent with NOD. The distribution of admitted chicks and disease status is shown in Figure 1a.

The number of owls administered increased between 1997 and 2015 (Wald = 5.954; $P < 0.001$; Fig. 2a). However, NOD prevalence has not fluctuated significantly among years (Wald = 19.705; $P = 0.35$; Fig. 2a) and only two years differed significantly from the rest, the highest prevalence being in 1998 (Wald = 3.95, $P = 0.047$) and the lowest in 2013 (Wald = 10.51, $P = 0.001$). Thus, data from all years were combined for the rest of the analyses.

There was a significant difference in the date of admission of infected and non-infected chicks in each year ($F_{1,475} = 14.091$, $P = 0.0002$; Fig. 2b), with infected owls found earlier (mean Julian day = 190.06 = 9 July; sd = 17.15) than non-infected ones (mean Julian day = 197.62 = 16 July; sd = 26.87). Cases of NOD were more frequent early in the season and in areas with a higher percentage cover of green areas (Table 2). The number of sewers within each breeding pair's home-range, humidity, maximum temperature and proximity to the river did not have a significant effect on NOD infections. The number of cockroach reports declined significantly between 2010 and 2015 ($r^2 = 0.82$, $P = 0.013$, Supporting Information Fig. S1). The regressions revealed a negative relationship between the time of the year and the number of cockroaches (within the Scops Owl breeding season, the earlier the date, the more cockroaches there will be and vice versa), as well as with humidity and distance to the sewers, and a positive relationship with temperatures (the higher the temperature, the more cockroaches; Table 1). Additionally, cockroaches were detected more frequently in the green areas closer to sewers ($r^2 = 0.852$, $P = 0.009$).

We also analysed the frequencies of cockroach occurrence throughout the breeding season of the Scops Owl (June to November) to determine the period in which the highest number of oriental cockroaches occurs. Cockroach activity peaked from mid-June to mid-July (Julian day 160–200) and gradually decreased throughout the rest of the breeding season, which is partially in line with the peak in NOD prevalence in the Scops Owls (Fig. 2c), with a difference of a few days (Supporting Information Table S1).

DISCUSSION

This study highlights the importance of urbanization processes in biological communities involving not only predators (*Otus scops*) but also their prey (*Blatta orientalis*). Oriental cockroaches are known to be the main prey of Scops Owls breeding in the urban environment of Madrid, and act as vectors of *Gongylonema* sp., causing lethal infections in Scops Owl chicks. Here we studied the seasonal and long-term dynamics and environmental correlates of *Gongylonema* infections in Scops Owl chicks. The results show that the breeding period of the Scops Owl in Madrid has a temporal relationship with the peak of cockroach abundance, which increases the risk of infection of chicks by *Gongylonema* sp.

We found that in the city of Madrid, cockroaches can be found in greater numbers at the beginning of summer (Fig. 2c), when minimum temperatures are higher (Robinson 2005). Under natural conditions, Scops Owls show a very diverse insectivorous diet, dominated by large Orthoptera and nocturnal Lepidoptera (Bavoux *et al.* 1993, Mori *et al.* 2016). The diet of this species in Madrid seems to differ from that of their non-urban conspecifics, as they frequently prey on cockroaches. Lopes *et al.* (2022) describe cockroaches in Madrid's parks as the most abundant prey, representing 51% of the potential prey for the Scops Owl, and being one of the few available prey species with nocturnal habits. This issue makes cockroaches abundant, conspicuous and available. In urban ecosystems, parks that represent islands of natural habitat immersed in a large urban matrix (Fernández-Juricic & Jokimäki 2001) become essential elements for the maintenance of biodiversity in cities (Savard *et al.* 2000). The problem arises when these green spaces are landscaped and the environmental management strategies for parks are not adequate (i.e. use of biocides), resulting in limited arthropod diversity (Penone *et al.* 2012).

Our results showed a highly significant spatial influence related to green areas within Madrid, as more owl individuals were infected with *Gongylonema* sp. in locations with a higher proportion of green spaces within the home-range of the breeders (Table 2). Scops Owls in the city use green areas as nesting and breeding sites (Lopes *et al.* 2022). Oriental cockroach reports (see

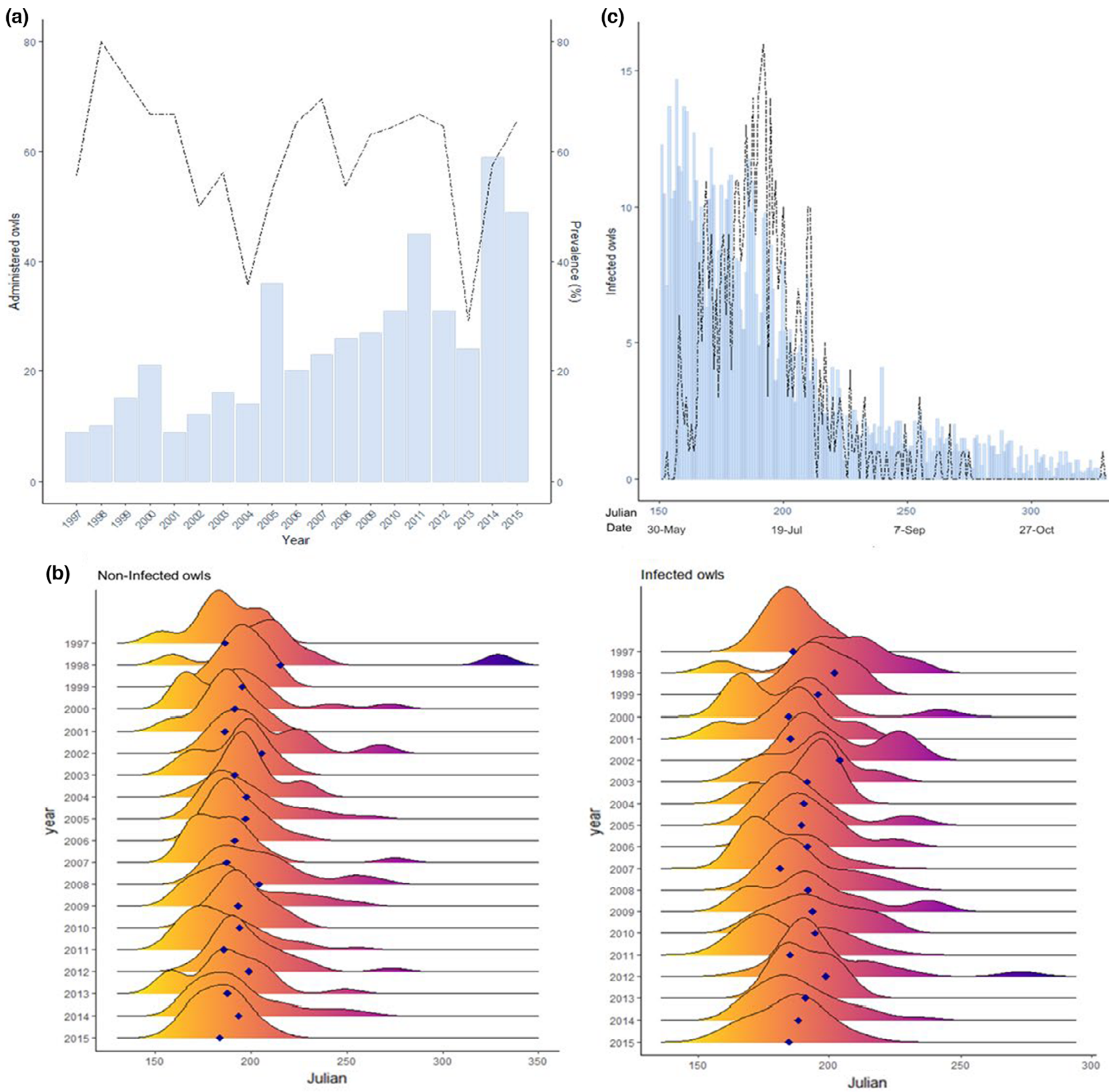

Figure 2. Prevalence of necrotic oropharyngeal disease in Scops Owls from Madrid, Spain, from 1997 to 2015. (a) Annual variation in number of owl chicks admitted to the centre (blue bars) and the percentage infected with necrotic oropharyngeal disease (NOD; dashed line). (b) Daily number of non-infected (left) and infected (right) owl chicks in each year from 2010 to 2015. (c) Daily number (pooled data from 2010 to 2015) of oriental cockroach *Blatta orientalis* reports during the Scops Owl breeding season (blue bars) and owl chicks with NOD throughout the year from 1997 to 2015 (black dashed line). Days of the year are shown in the Julian calendar.

Fig. 1b) mainly refer to strictly urban areas, yet green areas such as city parks in Madrid show very high cockroach abundance and density (Lopes *et al.* 2022). The Scops Owls use urban habitats with abundant food but where there is a risk of parasites (Delibes *et al.* 2001). Therefore, in the urban context of Madrid, changes in habitat management should be promoted to counteract the detrimental effects on biodiversity (Sattler *et al.* 2010). In particular, by managing parks and green areas to maintain a high diversity of arthropods, exploitation of cockroaches by the Scops Owl and transmission of the parasite could potentially be reduced.

The prevalence of NOD in chicks from Madrid has remained nearly constant during this 19-year study

Table 1. Results of regression analyses of the influence of abiotic variables (distance to sewers, relative humidity, time of year and minimum temperature) on the presence of cockroach reports (*Blatta orientalis*) in the city of Madrid.

Variable	Estimate	se	*t* value	Pr(> |*t*|)	R^2
Distance to nearest sewer (m)	−2.112	0.615	−3.433	0.0007***	0.063
Monthly relative humidity (%)	−1.854	0.189	−9.789	<0.0001***	0.353
Date (Julian day)	−0.641	0.028	−23.160	<0.0001***	0.753
Minimum temperature (°C)	4.132	0.545	7.575	<0.0001***	0.246

***$P < 0.001$.

Table 2. Results of the final GLM of the environmental variables influencing NOD presence in Scops Owls in the city of Madrid.

Variable	Estimate	se	*z*-value	Pr(> |*z*|)
Distance to river (m)	−7.143e-05	4.319e-05	1.654	0.09813
ADC (Julian day)	0.1757	0.06.799	2.585	0.00974**
ADC^2	−4.597e-04	1.696e-04	−2.711	0.00671**
% green area (%)	0.021251	0.003674	4.321	1.56e-05***

Distance to the river is the distance in metres between the Scops Owl occurrence and the nearest river, admission date to the centre (ADC) is the Julian day when the Scops Owls were found and admitted to Brinzal Night Raptor Recovery Centre, ADC^2 is quadratic Julian day, and % green area is the percentage of green and vegetated areas around the Scops Owl occurrence. **$P < 0.01$; ***$P < 0.001$.

period and, given that cockroaches act as a vector, a higher incidence of the infection in the Scops Owl would be expected during the breeding season. In fact, our results show more owl individuals infected with *Gongylonema* sp. at the beginning of the breeding season, around the first half of July (Fig. 2b), which partially overlaps with the phenology of the cockroach. The non-complete overlap could be due to the delayed onset of symptoms in the chicks after parental feeding. In addition, our results show a significant relationship between the proximity to the peak of cockroach abundance and the number of chicks infected with *Gongylonema* sp., due to a higher intake of infected oriental cockroaches as the most available resource at the beginning of the season. Consequently, if owls schedule their breeding season to coincide with the availability of cockroaches, this could lead to a higher rate of NOD prevalence in Madrid.

Among the possible hypotheses concerning the *Gongylonema* life cycle, we propose that Scops Owls are dead-end accidental hosts involved in a vectorial cycle of the *Gongylonema* life cycle, in which cockroaches are vectors and another vertebrate species the definitive host. Due to high abundance of cockroaches in urban areas of Madrid (Lopes *et al.* 2022), Scops Owls are forced to feed their chicks with infected cockroaches, resulting in inter-animal zoonosis, without affecting the adult owls. Considering that there must be a definitive host with an abundant population settled in the city to complete the life cycle of *Gongylonema* sp., it is most likely that an urban mammal (*Rattus* sp.) can play this role (Setsuda *et al.* 2016). This cycle would be completed through the organic residues of the definitive hosts, whose carcasses would be ingested by the cockroaches during their feeding activities.

This study highlights the cost of living in urban areas and reaffirms the importance of developed maintenance programmes in urban green spaces to increase arthropod richness and feeding resources for Scops Owls, as well as adequate cleaning services and garbage management to control pest species. Higher prey diversity enhances the dilution effect and reduces infection risks (Johnson & Thieltges 2010). As the parasitic cycle is still unknown, studies should be conducted to detail its development and transmission to hosts.

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AUTHOR CONTRIBUTIONS

Irene Hernández Téllez: Conceptualization; data curation; formal analysis; investigation; methodology; supervision; validation; visualization; writing – original draft; writing – review and editing. **Beatriz Martínez-Miranzo:** Conceptualization; data curation; formal analysis; methodology; supervision; validation; writing – review and editing. **Diego Gil-Tapetado:** Formal analysis; validation; visualization; writing – review and editing. **Francisca Lopes:** Resources; validation; writing – review and editing. **Frenando Esperón:** Validation; writing – review and editing. **Francisco J. Cabrero-Sañudo:** Validation; writing – review and editing. **José Ignacio Aguirre:** Conceptualization; formal analysis; investigation; supervision; validation; writing – review and editing.

ETHICAL NOTE

None.

FUNDING

None.

CONFLICT OF INTEREST STATEMENT

There are no conflicts of interest for this article.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Figure S1. Result of the regression analysis of the variation in the number of cockroach reports from 2010 to 2015.

Table S1. Seasonal variation in the number of cockroach reports and reports of Scops Owl chicks with NOD.