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Research paper

Citizen science in action—Evidence for long-term, region-wide House Sparrow declines in Flanders, Belgium

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HIGHLIGHTS

- We studied the status of the House Sparrow in Flanders.
- The data was collected by volunteers during ten years.
- Sparrows were less recorded in more densely populated, urban areas.
- House Sparrow abundances declined over time.
- Results suggest that House Sparrows decreased due to advancing urbanization.

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ABSTRACT

Urban expansion is detrimental for many species. While the House Sparrow (*Passer domesticus*) initially flourished in the vicinity of men, a decline in House Sparrow numbers has been observed in several European cities during the last decades. A lack of systematic data on the status of this species in the highly urbanized Flanders (Belgium) has been the reason why since 2002, the Flemish population has been called annually to count House Sparrows during the breeding season. Here, we describe the results of the first ten years of sparrow counting. While inhabitants from 99% of the municipalities participated at least once, large differences in numbers of participants were observed among municipalities: the larger the population size, the more people counted sparrows. Results indicated that House Sparrow abundances have been decreasing in Flanders over the past decade. Contrary to several other European regions, the decline appears equally strong in rural and urban areas. However, average numbers of House Sparrows were lower in more densely populated, urban areas, and where less cropland, grassland and parks surrounded the sampling location. House Sparrow abundances also decreased significantly over time at locations where predator pressure increased. These results suggest that the House Sparrow decline in Flanders is due to the ever encroaching urbanization and the reduction of the amount of green space. Furthermore, it shows that data collection by volunteers can be a useful approach to obtain large-scale and long-term data in a relatively easy way, in addition to raising public awareness to the natural environment.

1. Introduction

The expansion of metropolitan areas at unprecedented rates leads to the decline of native biodiversity (Marzluff, Bowman, & Donnelly, 2001). For long, the House Sparrow (*Passer domesticus*) has represented one of the rare exceptions to this pattern as House Sparrows were among the most common birds in Europe (Summers-Smith, 1988). While they initially thrived well in response to urbanization, in recent decades this species has

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suffered rapid and massive declines most pronounced in highly urbanized city centers (De Laet & Summers-Smith, 2007). Yet, while the majority of studies describe a substantial decline (reviewed in Shaw, Chamberlain & Evans, 2008; Summers-Smith, 2007), this pattern is far from consistent between areas. For instance, a large variation in House Sparrow trends have been noticed between city centers (Summers-Smith, 2003) with large declines reported from some towns and cities [e.g. London (De Laet & Summers-Smith, 2007), Edinburgh (Dott & Brown, 2000) and Hamburg (Mitschke, Rathje, & Baumung, 2000)] while populations are apparently stable (Berlin and Paris; Summers-Smith, 2003) or even increasing in others (urban areas in Wales; Crick, Robinson, Appleton, Clark, & Rickard, 2002). Furthermore, census counts suggest that the onset of the rural decline preceded the urban one, but that the rural decline has stabilized. In contrast, urban decline has been more dramatic and appears still to be in progress (De Laet & Summers-Smith, 2007; Robinson, Siriwardena, & Crick, 2005; Summers-Smith, 2003). Such a complex pattern complicates the identification of an overall driving force behind the House Sparrow decline, but rather suggests a combination of causal factors.

Several mechanisms have been put forward to explain the decrease in House Sparrows. House Sparrow declines may be caused by increased predation rates with the two most cited candidate predators being the Sparrowhawk (*Accipiter nisus*) and the Domestic Cat (*Felis catus*). Sparrows comprise up to 35% of the diet of Sparrowhawks (Frimer, 1989; Opdam, 1979; Tinbergen, 1946) and the timing of urban and rural population recovery of Sparrowhawks during the last decades (Anderson, 2006; Lensink, 1997) corresponds with that of the decline in urban and rural sparrow populations (Bell, Baker, Parkes, Brooke, & Chamberlain, 2010). An increase in feral and Domestic Cat populations has also been identified as a potential cause of the sparrow decline (Churcher & Lawton, 1987; Woods, McDonald, & Harris, 2003) as Domestic Cats have been estimated to kill up to 27 million birds in the UK in a span of 5 months only (Woods et al., 2003). In addition to such lethal effects, predation risk may have non-lethal effects that negatively affect fitness and population dynamics through behavioral and physiological changes (Beckerman, Boots, & Gaston, 2007; Cresswell, 2008). For instance, it has been shown that House Sparrows have a reduced body mass in the presence of predators to improve flight performance when escaping from predators, thereby increasing their risk of starvation mortality when food availability is unpredictable (MacLeod, Barnett, Clark, & Cresswell, 2006).

House Sparrow reduction has also been ascribed to changes in habitat structure leading to food shortage and a lack of nest sites. Gardens in areas with high socio-economic status became 'tidier' with more paving and non-native shrubs (Shaw et al., 2008), leading to lower food availability, in particularly the availability of invertebrates for young chicks (Peach, Vincent, Fowler, & Grice, 2008). Furthermore, low House Sparrow numbers in wealthy residential areas could be compounded by a lack of available nesting sites as modern or renovated buildings often lack holes and small crevices near roofs (Robinson et al., 2005; Shaw et al., 2008). On the contrary, the rural House Sparrow decline has been attributed to lack of overwinter food availability due to agricultural intensification (Chamberlain, Fuller, Bunce, Duckworth, & Shrubb, 2000). Another factor that has been suggested to explain the declining House Sparrow numbers is environmental pollution. In line with this, House Sparrow abundances have been observed to decrease with increased environmental radiation (Balmori & Hallberg, 2007; Everaert & Bauwens, 2007) and environmental pollutants related to traffic, such as vehicle exhaust emission (Robinson et al., 2005). Furthermore, similar to other bird species, House Sparrows may be negatively affected by insecticides (Hallmann, Foppen, van Turnhout, de Kroon, & Jongejans, 2014). Such pollutants not only affect House Sparrows in a direct way (Herrera-Dueñas, Pineda, Antonio, & Aguirre, 2014), but they may also have an indirect impact through detrimental effects on insect densities (Balmori, 2009; Hallmann et al., 2014; Robinson et al., 2005).

Given these mechanisms, we can expect that House Sparrows have also been declining in the highly urbanized Flemish region in Belgium. Although the available information is very limited, it indeed seems to confirm such pattern (de Bethune, 2004; De Laet, 2004; VLAVICO, 1989). However, large-scale, systematic data that allow us to study the underlying mechanisms were lacking. This is why the Flemish bird protection organization 'Vogelbescherming Vlaanderen' (VBV) launched a 'National House Sparrow Day' in 2002. Since then, Flemish citizens are annually encouraged to census House Sparrows in their living environment. This approach, known as citizen science, has already been demonstrated to provide scientists with lots of data at large spatial scales at a low cost (see Tulloch, Possingham, Joseph, Szabo, & Martin, 2013 for examples). For research projects that require many observations during a short time span and/or access to private properties that are often inaccessible for professional scientists (e.g. gardens), engaging volunteers might even be the only possible approach. Furthermore, volunteers may gain a sense of responsibility over the areas or populations they are monitoring and contribute considerably to local environmental activism (Carr, 2004). Finally, citizen science allows for a natural way to disseminate scientific results to non-scientific people as the obtained insights are usually widely publicized (e.g. Kaartinen, Hardwick, & Roslin, 2013). However, citizen science also has limitations. Often, participation is voluntarily and a survey design is lacking. As a consequence, it is more likely that participation is not equally spread across the study area but, for instance, rather reflects human population size because in more populated areas more potential participants are available. As a result, the data set may not be representative, which can reduce the reliability of the inference made if appropriate statistical measures are not taken.

Here, we analyze the results of 10 years of 'National House Sparrow Days', one of the first large-scale applications of citizen science in Belgium. We focus on House Sparrow abundances as well as census effort. We ask the following questions: (i) How did House Sparrow abundances and predator pressure evolve in Flanders over the last decade? (ii) Which human population parameters and landscape characteristics are associated with the putative House Sparrow decline? (iii) Is the census effort related to human population parameters? The following predictions were tested: (a) Sparrow numbers are negatively related with human population pressure, socio-economic status, degree of urbanization and predator pressure, and positively with the amount of green space and supplementary feeding. (b) Sparrow abundances have been decreasing and predator pressure has been increasing in Flanders over the past decade. (c) The decrease in sparrow numbers is more pronounced in municipalities with a larger increase in human population and predator pressure and in more urbanized areas. (d) Census effort is larger in municipalities with more inhabitants.

2. Methods

2.1. Bird census and demographic parameters

Annually, VBV launches a widespread call to count the number of chirping male House Sparrows during one day in the second weekend of April. This gives a good estimate of the number of breeding pairs (De Laet, Peach, & Summers-Smith, 2011). More specifically, participants were asked to assign the number of observed chirping male sparrows to one of seven categories. The average of the range of values in each category was used for statistical analyses (see Fig. 1). Participants were also requested to provide additional data on the location

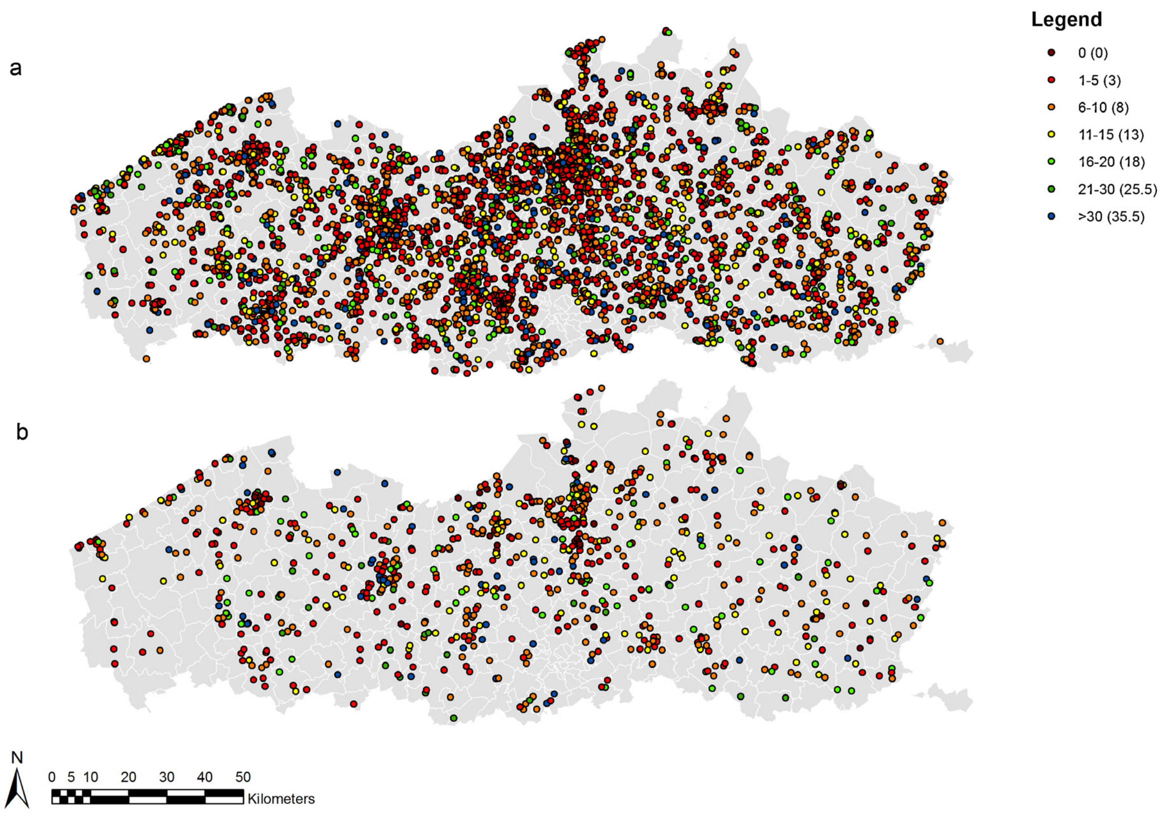

Fig. 1. Overview of locations in Flanders where chirping House Sparrow males (as an estimate of the number of breeding pairs) were counted during the period 2002–2011: (a) all locations (omitting zero counts) and (b) only locations where sparrows were counted in at least two years. If multiple data were available for a particular location, the highest number of observed sparrows is depicted in the figure. Between parentheses are the values into which House Sparrow categories were converted for statistical analyses. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(usually the garden) where the sparrows were counted: the occurrence of supplementary feeding (yes/no) and the presence of predators (yes/no). Potential predators include pets such as cats and dogs, but also other animals such as Sparrowhawks. In addition to the data provided by the participants, data on the surface area, human population size and density of all Flemish municipalities (reference date: 1 January of all years) and average salary per municipality (year 2011) were used as a source of information about the sampling location (Belgian Federal Government, n.d.).

2.2. Landscape characteristics

A land cover map with a 100 m resolution was created with land cover classes based on the Biological Valuation Map (Vriens et al., 2011) with 32-piece legend (BVM32). Nine categories were considered by combining the original 32 categories of the BVM32 based on the similarity between categories: cropland, forest, grassland, park, small landscape elements, thicket, urban, water and other (Table A.1). To relate the number of House Sparrows to the landscape characteristics, the proportion of each of the landscape characteristics within a 1 km buffer around each location was calculated, which is the spatial scale across which sparrows perform most of their movements (Vangestel, Braeckman, Matheve, & Lens, 2010; Vangestel, Mergeay, Dawson, Vandomme, & Lens, 2011). The total sampling area covered 45% of Flanders. Variation in the relative abundance of small landscape elements, such as gardens, trees, hedges and shrubs, between residential areas was not available and was not taken into account, despite the fact that their presence may enhance the survival of House Sparrows in urban zones (Chamberlain, Toms, Cleary-McHarg, & Banks, 2007; Vangestel et al., 2010). Lack of temporal values of landscape characteristics during the study period (10 years) prevented us from taking into account effects of landscape change. However, as it is unlikely that broad-scale landscape characteristics, as defined above, strongly varied during this time frame, we believe that this does not jeopardize the validity of our conclusions. Locations were not randomly sampled but instead reflected personal decisions to participate in the House Sparrow day. Although we have no reason to assume that this biased our conclusions, we cannot entirely exclude the possibility that it resulted in a loss of accuracy when averaging data across municipalities or buffers. All spatial analyses were conducted in ArcGis 9.2 software.

2.3. Data synthesis

Two data sets were extracted from the full data set for further analysis. The first data set ($n = 5759$; Fig. 1a) contains all data after the removal of zero counts (i.e. no sparrows were recorded). Zero counts were omitted because participants had the tendency not to report them (De Laet, personal observation). Because underreporting of zeros might affect our conclusions (e.g. if not randomly distributed across all locations without sparrows), we preferred to omit all zero counts from this dataset. The first data set was used to associate census effort with human population size and to relate sparrow abundances to landscape characteristics, human population pressure, socio-economic status, supplementary feeding and predator pressure. A second data set ($n = 2146$; Fig. 1b) contained all locations where sparrows were counted in at least two years. This data set was used to examine the trend in number of House Sparrows over time and to relate these trends to human population and predator pressure and to the degree of urbanization. Zero counts were retained in the second dataset as these counts were used to quantify temporal changes in sparrow abundance in sites with repeated observations.

2.4. Statistical analysis

The statistical analyses consisted of two main parts. First, we tested whether the census effort (i.e., the number of participants) was related to human population size via generalized estimating equations (GEEs) with log link and negative binomial distribution. Second, we studied if House Sparrow abundances were related to human population density (a measure of human population pressure), average salary (a measure of socio-economic status), landscape characteristics, supplementary feeding and the presence of predators (a measure of predator pressure), and whether abundances declined over time using linear mixed models (LMMs; see Table A.2). To investigate whether the trend over time differed between urban and rural areas, we included the proportion urban area and the two-way interaction in the previous model. To examine whether the evolution in number of House Sparrows over time was related to the evolution in human population density and predator pressure, we calculated the difference between endpoint and baseline values and submitted these values to a general linear model (GLM).

Sparrow abundances were averaged over municipalities/buffers in models containing human population parameters (measured at the municipality level) and/or landscape characteristics (measured at the buffer level), because counts pertaining to the same municipality/buffer do not contribute independent information. A higher weight ($\sqrt{n}$/sd with n the number of counts and sd the standard deviation of the counts per municipality/buffer) was assigned to municipalities/buffers with a higher census effort and lower variability in sparrow abundances to give more weight to more precise estimates to avoid that outlying observations distort our results. All GEE and LMMs included the variable year as random factor. We used the exchangeable working correlation structure for GEE and exponential serial correlation in LMMs as these resulted in the best model fit. The Kenward–Roger method was applied for estimating the degrees of freedom in all LMMs (Kenward & Roger, 1997). Backward selection was applied in models with multiple variables. Spatial correlation was not present in any of the models. The assumptions of normality and homoscedasticity were met where required. All statistical analyses were performed in SAS 9.2 (SAS Institute Inc. 2002–2003, Cary, NC, USA).

3. Results

3.1. Census effort

Since the first 'National House Sparrow Day' in 2002, 6270 complete census data were collected (88% of a total of 7160 counts; Fig. 1a). Data were considered incomplete when essential information was missing, i.e. when the number of observed sparrows and/or the complete address was not provided. The remaining census data covered 5014 unique locations, indicating that a restricted number of participants (18%) participated repeatedly at the 'National House Sparrow Day' (Fig. 1b). Of these, 13% participated twice, while 5% participated at least three times. The maximum number of entries per location was six (Fig. A.1). House Sparrows were counted in 304 of the 308 (99%) Flemish municipalities over the entire study period, but the number of participants per municipality ranged widely (between 1 and 460 participants). The larger the human population size, the more people counted House Sparrows ($\text{Chi}^2{}_1 = 54.76$, $P < 0.0001$, Fig. 2), and this positive relation was still detected when the two largest cities

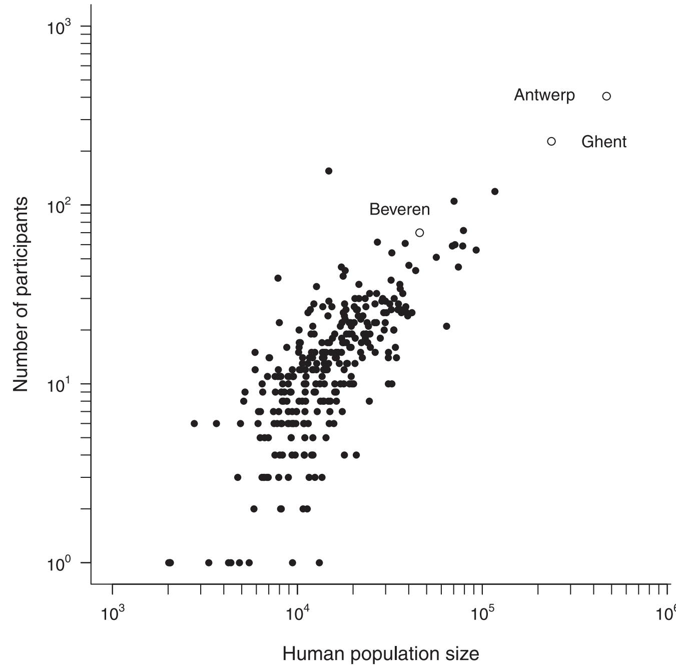

Fig. 2. Number of participants at the 'National House Sparrow Day' in relation to the human population size per municipality (averaged over all years of the study).

(Ghent and Antwerp, respectively, two and four times the third largest city, see Fig. 2), that possibly induced this relation, were removed ($\text{Chi}^2{}_1 = 156.81$, $P < 0.0001$). Therefore, more densely populated cities have more participants per area. For example, the cities of Ghent and Beveren (both approximately 150 km^2) have very different population densities (310 inhabitants/km^2 in Beveren versus 1585 inhabitants/km^2 in Ghent, January 2011), which is reflected in the total counts (227 versus 70 sparrow counts; Fig. 2).

3.2. Number of House Sparrows

Most records relate to group sizes of five males or less (see Figs. 1 and 3). A negative relation between human population density and the number of House Sparrows was observed (mean ± SE = −0.083 ± 0.034, $F_{1,1675} = 5.99$, $P = 0.015$). Furthermore, the proportion urban area in the surroundings was negatively related with the average number of House Sparrows ($F_{1,391} = 26.56$, $P < 0.0001$), mainly because in more urbanized areas fewer large (>20 sparrows) groups were observed, while the number of small (<11 sparrows) groups remained similar (Fig. 3a). The proportion cropland (mean ± SE = 7.07 ± 1.48, $F_{1,453} = 22.8$, $P < 0.0001$), grassland (mean ± SE = 8.92 ± 2.97, $F_{1,561} = 9.05$, $P = 0.003$) and parks (mean ± SE = 10.83 ± 4.14, $F_{1,479} = 6.84$, $P = 0.009$) showed positive associations with House Sparrow abundance. Sparrow numbers were not related to socio-economic status of the municipality, predator pressure and the presence of feeders (all $P > 0.14$). Based on repeated counts, numbers of House Sparrows significantly decreased during 2002–2011 ($F_{1,1318} = 62.40$, $P < 0.0001$; Fig. 3b). While an average of nine males were observed per location in 2002, the average dropped to six males in 2011. This was due to a decreased number of groups with more than 30 sparrows and more groups with five sparrows or less (Fig. 3b). The extent of the House Sparrow decline depended on whether predator pressure increased (23% of all locations), decreased (9%) or remained the same (68%, $F_{2,546} = 4.47$, $P = 0.012$) with House Sparrows significantly declining where predator pressure increased over time (estimate ± SE: −4.04 ± 0.87, $t_{546} = -4.64$, $P < 0.001$) or remained

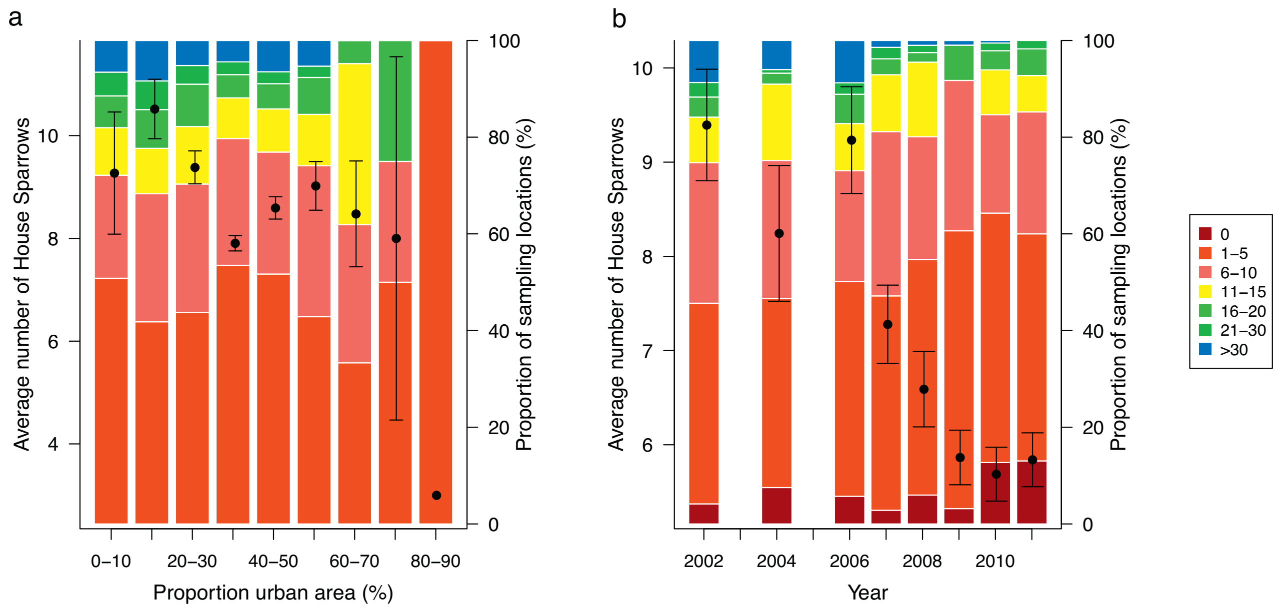

Fig. 3. Average (±SE) number of House Sparrows per sampling location (scatter plot) and proportion of sampling locations for each category of sparrow group sizes (stacked bars), in relation to (a) the proportion of urban area in the surroundings and (b) per year.

stable (estimate ± SE: −1.09 ± 0.51, t_{546} = −2.15, P = 0.032). The degree of urbanization (P = 0.47) and the human population density (P = 0.94) were both unrelated to the House Sparrow decline.

4. Discussion

4.1. The value of citizen science

This study showed that data collected by volunteers can provide valuable information. Without the help of volunteers, this study would simply have been impossible for several reasons. First, costs would have been considerable. It would have taken a single scientist more than 2.5 years to collect the data, with high transportation costs on top. Second, sampling was usually executed on private property (i.e. gardens), not accessible by scientists, both in terms of permissions and timing. Third and most importantly, hundreds of participants counted House Sparrows simultaneously and on the same day each year, excluding temporal variation, which could never be achieved by professional scientist(s). Furthermore, a beneficial side-effect of citizen science is that it provides a rare chance to raise public environmental awareness without additional efforts. Nevertheless, a few remarks on this application of citizen science should be made. An important consequence of the positive relationship between sparrow population size and number of participants is that less detailed data is available for municipalities with lower population density. An additional issue is that the majority of the participants only participated once making the data less useful for studying detailed trends over time. Furthermore, voluntary participation may lead to a distorted picture of the House Sparrow abundance in Flanders (e.g. because the absence of House Sparrows is often not reported) if no additional statistical adjustments are made.

4.2. House Sparrow counts

Similar to other European countries (De Laet & Summers-Smith, 2007; Shaw et al., 2008), the number of House Sparrow has been declining in Flanders. While in 2002, an average of nine males (as an estimate of the number of breeding pairs) were counted per sampling location, this number has been progressively decreasing to six males since then. Yet, while other studies showed that the strongest decrease in House Sparrow abundance is usually encountered in urban areas (De Laet & Summers-Smith, 2007; Robinson et al., 2005), this does not seem to be the case in Flanders, as we could not find any effect of the degree of urbanization on the House Sparrow decline over time. It is conceivable that in a densely populated region as Flanders even the most rural areas are still rather urbanized compared to other European regions and, hence, that trends in House Sparrow numbers do not differ between the most rural and most urbanized areas.

4.3. Putative causes of House Sparrow decline

Since this is a correlative study, the actual causal relationships cannot be determined, but the results suggest several reasons for the House Sparrow decline. In Flanders, House Sparrow abundances decreased over the last decade, which may be associated with the increase in the Flemish human population size during this period (Belgian Federal Government, n.d.). However, at the local scale, we could not demonstrate that House Sparrow declines were larger in municipalities with higher increases in human population densities, possibly because these increases were limited within the time frame of this study. Sparrow numbers were lower in more urban areas and higher where more cropland, grassland and parks surrounded the sampling location. These results are consistent with other studies that showed that life in the city is detrimental for many species, including House Sparrows (Aronson et al., 2014). Several mechanisms may underlie these outcomes. First, urban pollution may cause negative physiological effects, such as increased oxidative stress (Herrera-Dueñas et al., 2014; Isaksson, 2010), and negatively affect reproductive output through decreased chick body mass (Peach et al., 2008). Second, a lack of nesting sites is more likely in more urban areas because newly-built houses often lack suitable nesting cavities (Shaw et al., 2008). Yet, while we predicted such effects to be more pronounced in wealthier areas, we could not find an association between sparrow abundances and socio-economic status (Shaw et al., 2008), possibly because variation in socio-economic status is too low and its effect is too small.

Third, food availability is reduced in urban areas. Food shortage has already been indicated as one of the main causes of House Sparrow decline in urban areas affecting both nestlings and adults (Peach et al., 2008; Vangestel et al., 2010). Yet, a significant effect of supplementary feeding could not be demonstrated in this study. Possibly, the food that is mostly offered in feeders is not of sufficient nutritional value (e.g. breadcrumbs), cannot be reached with sufficient ease by House Sparrows (e.g. hanging peanut nets and fat balls) or is not provided at the moment of the year when it is most needed (e.g. insects during summer). Alternatively, the data does not adequately reflect all relevant feeders in the surrounding area.

Consistent with our predictions, House Sparrow abundances decreased significantly over time at locations where predator pressure increased, which was the case at 23% of the localities. Such an increase in predator pressure may be due to a possible recovery of urban Sparrowhawk populations, as has been shown in other European countries (Anderson, 2006; Lensink, 1997), but also by an increasing number of Domestic Cats associated with the increase in human population density (Belgian Federal Government, n.d.). Because of synergistic effects of predators and urban environment, House Sparrows may suffer more from urban predators than predicted from predator numbers alone. First, sparrow-hawks eat more sparrows in urban areas (Opdam, 1979; Tinbergen, 1946). Second, key cover habitats are more scattered in urban habitats, such that House Sparrows have to cover larger distances to find sufficient critical resources, thereby potentially increasing their predation risk (Vangestel et al., 2010). Third, a reduced nutritional condition in urban House Sparrows (Vangestel et al., 2010) may increase their risk-taking behavior. Fourth, reduced body mass may improve the ability to escape from predators, but may increase starvation risk when food availability is unpredictable, such as in urban areas (MacLeod et al., 2006).

4.4. Recommendations to increase House Sparrow numbers

Based on the results found, we can make some recommendations to facilitate higher House Sparrow abundances. The positive relation between House Sparrow numbers and the proportion of cropland, grassland and parks suggests that increasing the amount and changing the distribution of green elements in cities would have a positive effect. Because the House Sparrow is a highly sedentary species (Anderson, 2006), the aggregation of suitable habitat is necessary to make it readily available (Vangestel et al., 2010). In modern urban planning, many possibilities exist to increase natural resources without impairing urban development. Green walls and roofs may not only increase food, nesting and shelter availability in the city (Chiquet, Dover, & Mitchell, 2013; Fernandez-Canero & Gonzalez-Redondo, 2010), but may also help to connect existing green space (Strohbach, Lerman, & Warren, 2013). The 'lobe-city' ('ecopolis' city, Tjallingii, 1995) is another urban model to increase the connectivity between rural and urban areas (Rombaut, 2008). In a lobe-city, the edge between rural and urban areas is much more diffuse than in traditional compact cities, because of the built-up lobes that are interspersed with green areas that extend to almost the city center. However, despite higher House Sparrow numbers in rural areas (this study; Peach et al., 2008), House Sparrow abundances have also been declining there. Therefore, we suggest also that measures are needed in the agricultural landscape (e.g. leaving edges of cropland untouched, using hedgerows instead of fences to delineate fields and sowing in spring instead of autumn to increase food availability in winter).

5. Conclusions

Despite the fact that citizen science has several limitations, it is a useful approach to obtain large-scale and long-term data, especially in situations where the data cannot be collected by scientists alone. The results provide the first evidence of House Sparrow decline at the scale of Flanders, Belgium. The fact that fewer House Sparrows were observed in more densely populated, urban areas, while more sparrows were observed at locations surrounded by cropland, grassland and parks, suggest that advancing urbanization may be the major cause of the decline of this once very common bird species.

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Appendix A.

See Tables A.1 and A.2.

Table A.1
Overview of the landscape characteristics, together with the BVM32 codes they refer to.

Category	Definition	Code BVM32
Cropland	Cropland and species-poor grassland	BNAT, BVN, AGR
Forest	Forest	MBOS, BOSV, BOSZ
Grassland	Grassland (except species-poor)	XHB, MHV, XHV, HPGH, HPGD, HPGS, HPGV
Park	Plantings, parks and standard tree orchards	PLPRK, JKJ
Small landscape elements	Various types of small landscape elements	JKL, KB, KLE
Thicket	Felled areas, thickets and brushwood	OPSLG, RUIG, STRUW
Urban	Residential area	URB
Water	Marshes, ponds, wetlands and lakes	MOER, RIET, JKN, EWAT, ZILT, PLAS
Other	Remaining categories[1] or not mapped	DUIN, HEIDE, STRD, NG

[1] Include all categories whose area was too small in the sampling area to be considered separately.

Table A.2
Overview of all statistical models with sparrow abundance as response variable.

Prediction	Explanatory variables	Prediction supported (*P*-value)	Model	Zero counts included
Sparrow numbers are negatively related with human population pressure	Human population density	Yes (0.015)	LMM	No
Sparrow numbers are negatively related with socio-economic status	Average salary	No	LMM	No
Sparrow numbers are negatively related with degree of urbanization	Urban area	Yes (<0.0001)	LMM	No
Sparrow numbers are positively related with the amount of green space	Landscape characteristics (excl. Urban area)	Yes (<0.009 for cropland, grassland and park)	LMM	No
Sparrow numbers are negatively related with predator pressure	Presence of predators	No	LMM	No
Sparrow numbers are positively related with food availability	Supplementary feeding	No	LMM	No
Sparrow numbers have been decreasing over the past decade	Year	Yes (<0.0001)	LMM	Yes
The decrease in sparrow numbers is more pronounced in more urbanized areas	Year urban area year × urban area	No	LMM	Yes
The decrease in sparrow numbers is more pronounced in municipalities with a larger increase in human population pressure	Difference in human population density	No	GLM	Yes
The decrease in sparrow numbers is more pronounced in municipalities with a larger increase in predator pressure	Difference in presence of predators	Yes (0.012)	GLM	Yes

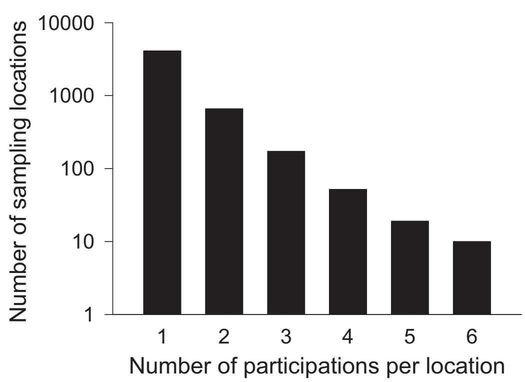

Fig. A.1. The number of sampling locations in relation to the number of participations per location.

Appendix B.

See Fig. A.1.

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