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Challenging the sustainability of urban beekeeping using evidence from Swiss cities

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Urban beekeeping is booming, heightening awareness of pollinator importance but also raising concerns that its fast growth might exceed existing resources and negatively impact urban biodiversity. To evaluate the magnitude of urban beekeeping growth and its sustainability, we analysed data on beehives and available resources in 14 Swiss cities in 2012–2018 and modelled the sustainability of urban beekeeping under different scenarios of available floral resources and existing carrying capacities. We found large increases in hives numbers across all cities from an average 6.48 hives per km^2 (3139 hives in total) in 2012 to an average 10.14 hives per km^2 (9370 in total) in 2018 and observed that available resources are insufficient to maintain present densities of beehives, which currently are unsustainable.

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INTRODUCTION

Cities are increasingly committed to sustainability goals (Sustainable Development Goal 11), leading to initiatives to enhance environmental justice and promote biodiversity and nature's contributions to people. This has led to an increase in greening activities in urban green spaces (UGS) and pro-environmental behaviours by local residents and city governments[1]. For example, in recent years beekeeping has increased in several cities in Europe, partly as a reaction to the current biodiversity crisis[2]. Honeybees (*Apis mellifera*) are perceived as key pollinators, and beekeeping is therefore seen by many as a conservation effort rather than an agricultural practice, which has generated debate and critisism[2,3]. Large honeybee densities can enhance competition between wild bees and honeybees[4–6], particularly when resource availability is low[7], although the interplay of other factors (e.g. spatial and temporal context[7,8]) complicates the picture. Nonetheless, although data is still scarce, the rapid, unregulated increase of urban beekeeping in a growing number of cities worldwide (e.g. London[9], Paris[10], Perth[7]) and the documented effects on other pollinator groups[10] has questioned the sustainability of urban beekeeping.

Beekeeping is a particular form of livestock raising. Livestock are in large part dependent on the resources provided by their owners, and beekeeping represents a special case for four reasons. First, beekeepers do not need to provide their own floral resources, as honeybees can move freely and exploit available resources. Second, it is impossible to control the movements and foraging locations of honeybees. Third, honeybees reproduce faster than other livestock. Fourth, beekeeping might not be perceived as an exploitative activity (regarding floral resources) because of the positive association between honeybees and pollination services. Still, floral resources might be limited, also in cities. For example, research in London has shown that in a large part of the city the existing resources are insufficient to maintain the current number of honeybees[9].

To improve our knowledge on the sustainability of urban beekeeping, in this study we aimed to answer the following questions: (1) To what extent is urban beekeeping increasing? and (2) Are the available floral resources sufficient to sustain the growing numbers of honeybees? To do so, we analysed urban beekeeping data from 14 cities in Switzerland, which represents a model country as it is compulsory to register beehives, over the period 2012–2018 (Fig. 1a, Supplementary Fig. 1, see "Methods") and landcover data at an unprecedented resolution. Eleven of the cities had data on precise spatial distributions and the number of beehives per location. For these eleven cities, we modelled the sustainability of urban beekeeping under different scenarios of available floral resources and existing carrying capacities.

RESULTS

Increase in urban beekeeping in Swiss cities

To assess how much beekeeping has changed in these cities over the considered period, we calculated the increase in the number of beekeeping locations and hives. We found that the total number of hives increased in 12 of the 14 cities (median increase = 69%, min. 1% in Thun, max. 2387% in Lugano). Further, in most cities the number of beekeeping locations (and possibly the number of beekeepers) increased (Supplementary Fig. 2), leading to a slightly lower ratio of the number of hives to the number of beekeeping locations (Fig. 1). Although the motivations for beekeeping are unknown, our results suggest that in most of the considered cities beekeeping is pursued by several people, each with a relatively small number of hives.

To investigate the temporal trend of beekeeping inside the cities, we first excluded cities without spatially explicit data (i.e. Basel, Chur and Geneva). We then divided each remaining city into 1 km^2 cells and counted the number of hives per cell per year. We found that the number of hives increased from 2012 to 2018 in the majority of cells and cities (Fig. 1), by 1 to 8 hives in 75% of the cells and by up to 198 hives in a few extreme cases.

Assessing the sustainability of urban beekeeping

We defined sustainable urban beekeeping (i.e. green cells in Fig. 2) as situations where the available UGS in a cell exceeds the UGS required to support existing beehives. UGS was used as a proxy for

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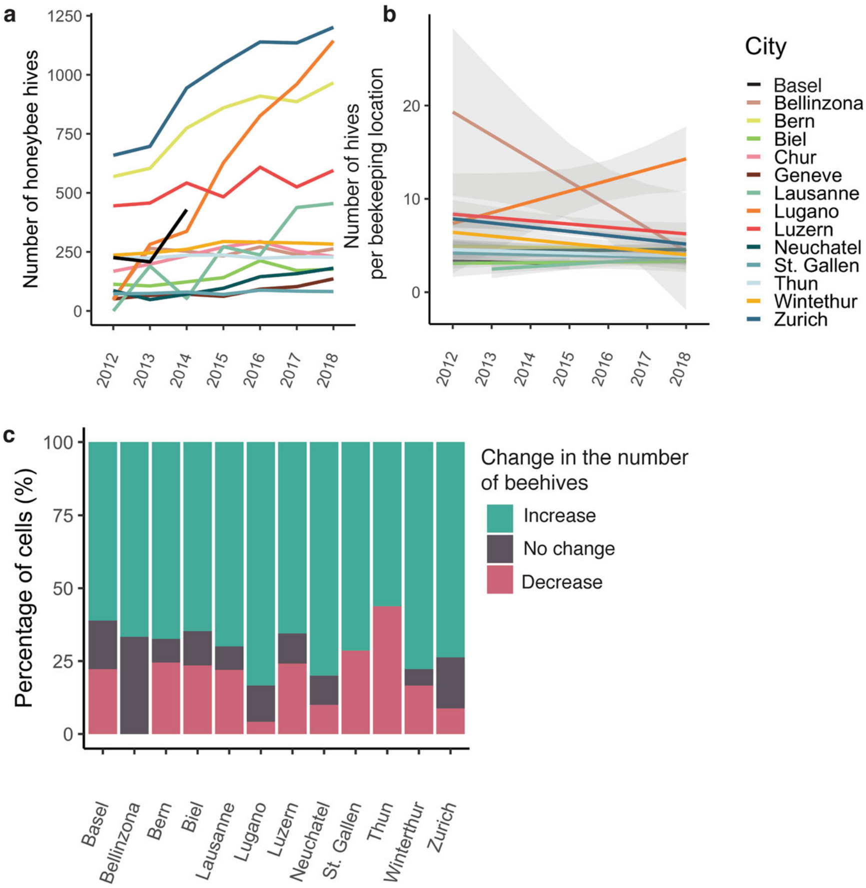

Fig. 1 Urban beekeeping trends in Swiss cities for the period 2012–2018. a Number of honeybee hives per year for all 14 Swiss cities. Each line and colour represents a single city. **b** Response curves showing the number of hives per beekeeping location per year for all of the Swiss cities except Geneva and Chur (where spatially explicit data were of low quality). Lines represent linear models and bands indicate 95% confidence intervals. Each line and colour represents a single city. **c** Percentage of cells in each city with an increase (green), decrease (red) or no change (dark grey) in the number of hives. See also Supplementary Tables 1 and 2 and Supplementary Fig. 2.

floral resources available for honeybees, obtained from[11] (see Methods) and assumed to be uniform in quality. We estimated the required UGS in a given cell using a carrying capacity value representing the maximum number of hives that can be sustained in a cell covered 100% by UGS. We modelled the sustainability under different scenarios of both carrying capacity (sustainable number of hives in a 1 km^2 cell) and available floral resources (amount of UGS in each 1 km^2 cell) for 2012 and 2018 (see Methods). Initially, following[9], we considered a carrying capacity of 7.5 beehives per km^2 of UGS. Because any carrying capacity value comes with assumptions, we additionally considered different carrying capacity scenarios, ranging from 0.5 to an unrealistic value of 75 hives per km^2 (10 times greater than in[9]). To further explore possible actions to enhance sustainable urban beekeeping, we simulated increases in available UGS from 0% (no increase) to 100%.

We found that in all cities, the estimated amount of available UGS was not enough to maintain the number of beehives in either 2012 or 2018 (Fig. 2). Cities such as Lugano, Zurich and Luzern had a particularly strong negative UGS balance (see Fig. 2 for Zurich and Supplementary Fig. 5 for the remaining cities; see Methods for calculation). Only carrying capacities >20 hives per km^2 resulted in 50% of cells with a positive UGS balance (Fig. 2). These carrying capacities are unlikely to be realistic, as they exceed the current honeybee densities in Switzerland of ca. 2 hives per km^2 (see ref. [6]). Increasing available UGS had a limited effect on the number of sustainable cells, in contrast to increasing the carrying capacity, and beekeeping remained unsustainable in most of the cells even with increases of >50% (Fig. 2 and Supplementary Figs. 3–5).

Comparison between 2012 and 2018 showed a clear densification and expansion of beekeeping (Fig. 2). While all cities had some cells without beehives in 2012, most occupied cells had a negative UGS balance (Fig. 2). In 2018, cities had a median increase of 52% (min. 5%, max. 983%) in the number of occupied cells compared with in 2012, and most of the occupied cells were unsustainable (Fig. 2, Supplementary Fig. 6).

DISCUSSION

Our results are in line with the increasing beekeeping trends observed in other cities[9,10]. In addition, our analysis suggests that the available UGS in cities might not be sufficient to cope with the current pace at which urban beekeeping is growing. The available UGS in both occupied and unoccupied cells might still be able to sustain current honeybee populations. However, continuous increases in the number of hives, with UGS likely not increasing at an equal pace, pose a challenging scenario in the near future for honeybees, not to mention other pollinating species which we did not consider here.

Urban beekeeping is a relatively new activity, yet there is a lack of regulation concerning sustainable densities, and increased beehive densities might have negative effects on biodiversity and on honeybees themselves. High densities of honeybee hives have been shown to deplete existing resources in natural[4] and agricultural[8] areas, ultimately negatively affecting other

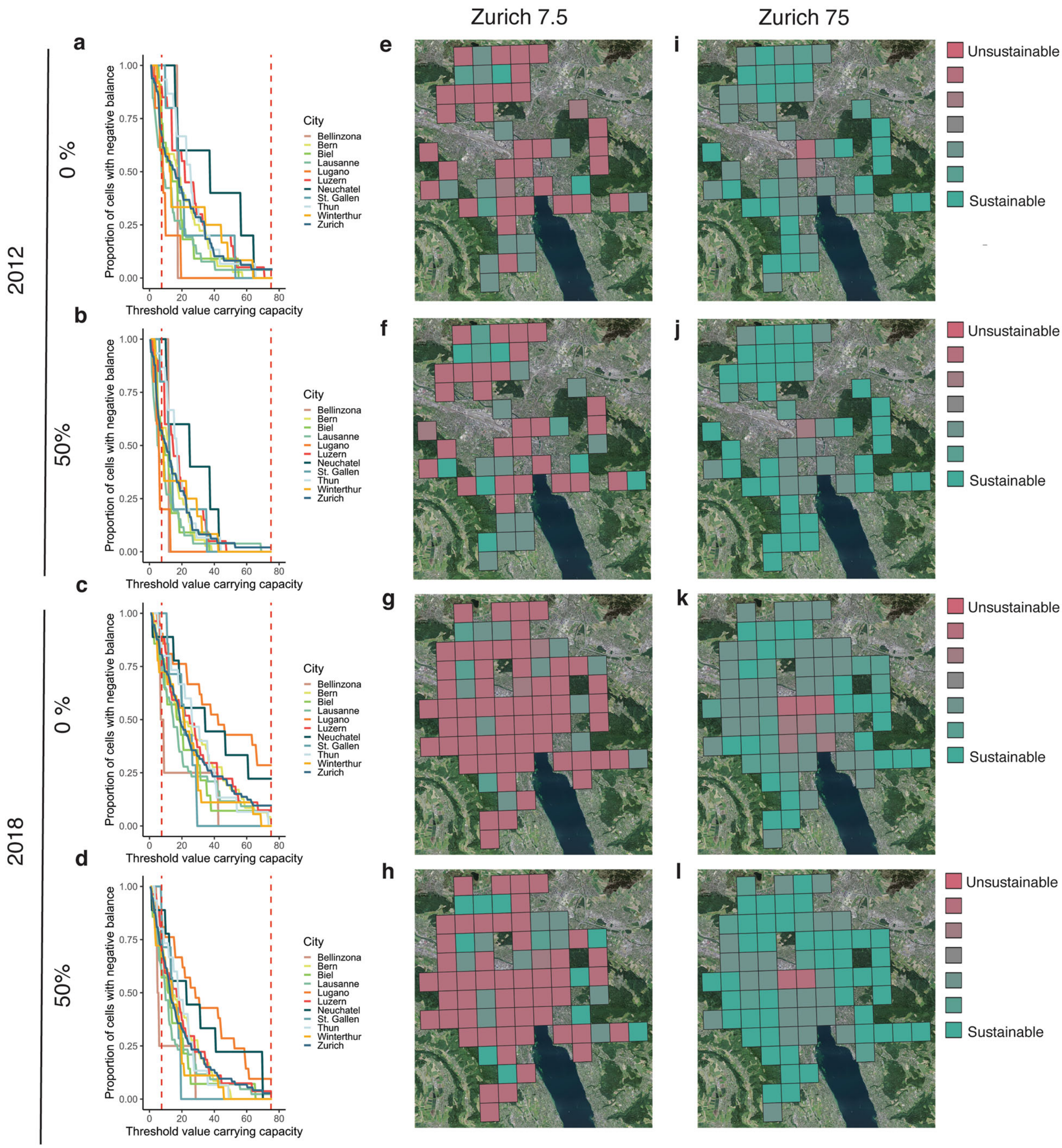

Fig. 2 Sustainability of urban beekeeping under different scenarios regarding the amount of available urban green space (UGS) and the carrying capacity for the years 2012 and 2018. a–d The proportion of cells with a negative UGS balance (Y-axis) (i.e. the available UGS is smaller than the required UGS based on the existing number of hives in the cell) for different carrying capacity values (*X*-axis) for all cities in 2012 (**a** and **b**) and 2018 (**c** and **d**), and considering a 0% (**a** and **c**) or 50% (**b** and **d**) increase in available UGS. Each coloured line represents the model for one city. Dashed red vertical lines indicate the carrying capacities used in the plots (**e**–**l**) and represent 7.5 and 75 hives per 1 km^2. **e**–**l** An example of the spatial distribution of the UGS balance in the cells in the city of Zurich for 2012 (**e**, **f**, **i**, **j**) and 2018 (**g**, **h**, **k**, **l**) considering an increase in both available UGS, from 0% (**e**, **g**, **i**, **k**) to 100% (**f**, **h**, **j**, **l**), and carrying capacity, from 7.5 (**e**–**h**) to 75 (**i**–**l**) hives per km^2. See Supplementary Figs. 3 and 4 for additional scenarios, Supplementary Fig. 5 for the maps for all cities and Supplementary Fig. 6 for additional information on the balances in the UGS. Data supporting this figure can be found in Supplementary Data 2. Orthophotos from Zurich were obtained from the SWISSIMAGE 25 from the Federal Office of Topography Swisstopo openly accessible[30].

pollinators[4]. Concerning urban ecosystems, in Paris the density of beehives was found to be negatively related to wild pollinator visitation rates[10], yet in Perth, where honeybees are not native, the effect of urban beekeeping on wild bees was mixed[7]. Cities are social-ecological systems, and individual decisions of stakeholders can have important impacts on the whole ecosystem. Adding hives in new and existing beekeeping locations might result in strong pressure on available resources. In agricultural contexts, uncontrolled increases of other livestock have led to what is known as a “tragedy of the commons”[12], when an uncoordinated and unregulated exploitation results in the depletion of the common resources. The same applies to urban beekeeping, but in an even more complex situation. Honeybees are not spatially limited and can exploit the available resources freely, regardless of ownership. This skews the perception of the relationship between the consumed and available resources, and thus of the sustainability of the system.

Our study represents a first attempt to quantify the sustainability of urban beekeeping yet with limitations. First, when we estimated the UGS we assumed all land covers equal and probably overestimated the available UGS. Future studies might improve the estimation of the UGS, and of resource availability, by better accounting by quantity, diversity and quality of floral resources provided by different UGS types (e.g. see ref. [13]) and estimate them across types of UGS in different cities as in[14], which could be combined with high resolution landcover maps such as[11]. Second, we could not incorporate the responses (e.g. densities, population dynamics) of both honeybees and other flower-visiting insects species with which honeybees might and can compete[10]. While population responses of wild pollinators might be difficult to obtain, they could be obtained more easily in honeybees through monitoring programmes.

There is a pressing need to create sustainable management strategies for urban beekeeping. Urban ecosystems can contain often important levels of biodiversity including pollinators[14,15], and thus need to be integrated in the current biodiversity conservation frameworks (e.g. IPBES[16], IUCN[17]). Concerning pollinators, anthropogenic activities such as urban beekeeping represent an critical challenge that has to be addressed to make use of the opportunities for conservation that urban ecosystem provide[3,18]. Managing beekeeping is a challenging task, especially in cities, due to the spatial scale at which it occurs, the prevailing positive view of honeybees and the services they provide, and the existing trade-offs between biodiversity conservation and anthropogenic activities. Nonetheless, the increasing number of evidences pointing out the unsustainability of (urban) beekeeping, including our study, calls for interventions to ensure a proper regulation. These interventions should result from a transdisciplinary engagement of both scientific research, urban policies and citizens as proposed by[3]. For instance, feasible, practical interventions could include: (1) regulating the number of beekeepers (or beekeeping locations) and the densities of hives[3,19], (2) ensuring a sufficient distance between hives as proposed by[19], (3) enhance floral resources and pollinator habitats in cities. This could be achieved by restoring existing impoverished habitats (e.g. transformation of lawns into grasslands[20], promote wild plants in small vegetation patches such as tree pits[21]) or by creating novel ones[22]. In that regard, citizen engagement promise to be a key tool[23].

METHODS

Study cities

We selected a total of 14 cities and urban agglomerations in Switzerland (Fig. 1). They were selected according to their population, area and availability of urban beekeeping data (Supplementary Table 2). Each studied city and urban agglomeration was divided into 1×1 km cells (Supplementary Fig. 1).

Urban beekeeping

Annual data on the spatial distribution of beekeeping locations and the number of hives at each location in the studied areas were obtained from the cantonal veterinary offices. Switzerland represents an exemplary country as beehive registration is compulsory since 2010[24]. The considered period was 2012–2018. As exceptions, data were only available from the period 2012–2014 for Basel and from 2013–2018 for Lausanne (Supplementary Table 3). The data from each veterinary office were checked separately and only records of beekeeping locations with reliable coordinates were included. For Chur and Geneva, where the beekeeping locations did not have precise coordinates, and in Basel, we only used the available data to study the increase in the number of hives over time.

Available urban greenspace

Data on available urban greenspace (UGS) were obtained from a continental-scale land-cover map of Europe (ELC10[11]). With a resolution of 10 m, the ELC10 map is currently the most detailed land-cover map of Europe, and it can distinguish between main features of the cityscape, such as gardens and hedgerows[6]. The ELC10 map was generated by classifying satellite imagery (Sentinel-1 and Sentinel-2) into eight classes of land cover using machine learning algorithms using data from the year 2018[11]. We considered the following land-cover classes as UGS: cropland, woodland, shrubland, grassland and wetland. For simplicity, we assumed (1) equal floral resources in all these land-cover classes, although they are expected to vary greatly, and (2) the same land cover composition in 2012 and 2018. We additionally simulated increases in the amount of available UGS by adding percentages to the original values in intervals of 10%, ranging from 0 to 100%. Spatial data process, including calculations on UGS and number of hives and beekeeping locations was done in QGIS v.3.10[25].

Modelling

We calculated the required UGS and the UGS balance for 2013 and 2018 in Lausanne, and for 2012 and 2018 in the remaining 10 cities. In a given city, for each cell and each year, we first calculated the total number of honeybee hives. We then calculated the required UGS in each cell according to the number of hives present and an estimated carrying capacity value, i.e. the maximum number of honeybee hives that can be sustain in 1 km^2 of UGS.

The UGS balance in a given year was calculated by subtracting the required UGS in a given cell from the available UGS in that cell. Equation (1) shows the calculation of the available UGS, Eq. (2) shows the calculation of the required UGS and Eq. (3) shows the calculation of the UGS balance:

$$\text{Available UGS}_{ij} = \text{AvailableECL10}_{ij} + \text{AvailableECL10}_{ij} * I \quad (1)$$

$$\text{Required UGS}_{ij} = \frac{\text{N}_{ij}}{\text{CCV}} \quad (2)$$

$$\text{Balance UGS}_{ij} = \text{Available UGS}_{ij} - \text{Required UGS}_{ij} \quad (3)$$

where i is the cell, j is the city, I is the simulated percentage of increase (in decimal form) in available UGS, N is the number of hives, CCV is the assumed carrying capacity and AvailableECL10 is the amount of available UGS based on the ECL10 map, without an increase.

The UGS balance was calculated for the different carrying capacity scenarios and increases in available UGS. Finally, for each city we calculated the proportion of cells with a positive balance (i.e. the required UGS for beekeeping was smaller than the available UGS) and with a negative balance (i.e. the required UGS for beekeeping was larger than the available UGS). All calculations were completed using R version 4.0.1[26] in RStudio version 1.4.1106[27].

DATA AVAILABILITY

Raw data on urban beekeeping can be obtained from cantonal veterinary offices under confidentiality agreement. Raw data on the land cover is available online in the Zenodo repository under the https://doi.org/10.5281/zenodo.4407051(see ref. [11]). Processed data used for the analyses can be found in the repository ENVIDAT under the https://doi.org/10.16904/envidat.239[28]. Data that support the findings of this study is presented within the main text, figures and the supplementary material. Orthophotos from Switzerland at 25 m resolution can be obtained from the Federal Office of Topography Swisstopo (https://www.swisstopo.admin.ch/en/geodata/images/ortho/swissimage25.html#links).

CODE AVAILABILITY

Code is available from Zenodo under the https://doi.org/10.5281/zenodo.5618254[29].

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AUTHOR CONTRIBUTIONS

J.C.A. and M.M. conceived the study and collected the data. J.C.A. analysed the data. J.C.A. and M.M. wrote and corrected the manuscript.

COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

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