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Research Note

Research Note: Garden-owner reported habitat heterogeneity predicts plant species richness in urban gardens

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ABSTRACT

Amidst ongoing urbanization and increased research on urban greenspaces, the biodiversity level of these spaces is an important variable. Attaining biodiversity estimates by asking non-expert greenspace users to assess aspects of a greenspace has a number of advantages over expert assessments (costs, sample size etc.). This article discusses an approach to such a citizen-science assessment of plant species richness using reported garden habitat heterogeneity and visually assisted reported plant species richness. We compare expert-assessed plant species richness with garden owner-generated estimates in a sample of 83 gardens. We show it is possible to predict approx. 50% of variation in plant species richness in gardens using just two visual survey questions regarding habitat heterogeneity and plant species richness.

1. Introduction

In interdisciplinary research on urban greenspaces and their interactions with humans the biodiversity of these spaces is often an important variable. While greenspace is defined in different ways, we use the term to refer to vegetated spaces in urban areas oriented to human needs, including domestic and allotment gardens which we focus on here (Taylor & Hochuli, 2017). Greenspace is a limited and even shrinking resource in many cities and hence the multifunctionality of such spaces, e.g., their role in underpinning biodiversity, ecosystem processes and associated services, is of increasing research interest (e.g. Aronson et al., 2017). Theoretical and empirical studies suggest that species-rich, structurally and/or functionally diverse vegetation (i.e. plant communities) is generally positively related to ecosystem functions and services as well as to the ability to maintain them in the face of environmental change (stability and resilience; e.g. Loreau, 2000; Díaz & Cabido, 2001; Oliver et al., 2015; Schwarz et al., 2017). Hence, diverse urban plant communities likely deliver a variety of cultural (e.g. psychological health benefits; Korpela, Pasanen, & Ratcliffe, 2018) and regulating services (e.g. pest control; Frey et al., 2018). For instance, a large number of studies provide evidence that urban greenspaces foster human physical and psychological health, though the role of biodiversity is not yet well understood (Hartig, Mitchell, Frumkin, & de Vries, 2014, Frumkin et al., 2017; Korpela et al., 2018).

One important urban greenspace type fostering human-biodiversity interactions are gardens (Langemeyer & Gómez-Baggethun, 2018). Despite their relatively small size, urban gardens can reach surprisingly high biodiversity levels, arguably most visible in the form of high plant species numbers (Frey & Moretti, submitted; Loram, Thompson, Warren, & Gaston, 2008; Smith, Thompson, Hodgson, Warren, & Gaston, 2006; Thompson et al., 2003). Since usually the majority of plants in a garden are cultivated, variance in plant species richness among gardens mainly depends on garden design and management concepts, rather than on processes such as colonization, extinction or species interactions (Hope et al., 2003; Thompson et al., 2003; Smith et al., 2006; Loram, Thompson et al., 2008; Swan, Pickett, Slavecz, Warren, & Willey, 2011; Cook, Hall, & Larson, 2012; Aronson et al., 2016). Garden design and management are, in turn, driven by a combination of the needs and attitudes of the garden owner, as well as the sociodemographic, cultural, economic and environmental contexts (e.g. Hunter & Brown, 2012; Cook et al., 2012; Goddard, Dougill, & Benton, 2013; Home et al., 2018).

As research on gardens typically involves large numbers of small vegetated patches that are difficult to access (e.g. Gaston, Ávila-Jiménez, & Edmondson, 2013), conducting expert surveys of their flora can be prohibitively costly and time-consuming. In addition, on-site

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garden surveys by biologists raise problems of safe-guarding anonymity which can be an important issue when researchers are looking to link biodiversity with sensitive personal data such as health status. In this study, as a solution to these problems, we propose a citizen-science approach in which researchers provide garden owners with a simple garden assessment instrument which has known associations with actual plant species richness.

The accuracy of citizen-science data is a relevant issue for such an approach, as this varies considerably among studies (Aceves-Bueno et al., 2017). More specifically, evidence that the biodiversity of urban greenspaces as perceived by non-experts corresponds to actual biodiversity (i.e. as estimated by experts) is mixed (Lee & Kendal, 2018). While Fuller, Devine-Wright, Gaston, Irvine, and Warren (2007) and Qiu, Lindberg, and Nielsen (2013) show that visitors to urban greenspaces estimate plant species richness quite reliably, Dallimer et al. (2012) report no significant association between non-expert and expert assessed species richness estimates. In more controlled settings such as experimental plant arrays or grassland patches there has been shown to be a significant positive association between perceived and actual plant species richness (Lindemann-Matthies, Junge, & Matthies, 2010, Southon, Jorgensen, Dunnett, Evans, & Hoyle, 2018). However, at high levels, plant species richness is underestimated (Lindemann-Matthies et al., 2010). Participants in these studies were asked to give a numerical estimate of the number of species present, either in numerical classes (Fuller et al., 2007, Dallimer et al., 2012, Southon et al., 2018) or by indicating an exact number (Lindemann-Matthies et al., 2010).

While accurately estimating species richness levels can be difficult for non-experts, assessing the presence or absence of land-use types and features in their own garden (e.g. a lawn, a pond or a compost heap) is arguably not. If each such element increases the spatial heterogeneity of a garden, for instance by adding new soil characteristics, light conditions or disturbance dynamics, then the number of plant species should also increase because each new site can serve as a new habitat. Such a habitat heterogeneity hypothesis has proved useful for predicting species richness across taxa and ecosystems, including anthropogenic environments (Duelli, 1997; Tews et al., 2004; Beninde, Veith, & Hochkirch, 2015; Stein, Gerstner, & Kreft, 2014).

Therefore, in our study we investigate options for a citizen-science assessment instrument of plant species richness in gardens that does *not* rely on the capacity of respondents to numerically identify the number of species present. Our main hypothesis in this study is that we can estimate garden plant species richness using a combination of two garden-owner provided variables, reported garden habitat heterogeneity and visually assessed plant species richness of certain garden areas.

2. Methods

2.1. Sample

We obtained a sample of 85 gardens (43 domestic and 42 allotment gardens) in the city of Zurich, Switzerland (47°22′0″N, 8°33′0″E). Gardens were chosen according to a stratified sampling design by visually assessing areal images and during field visits. The three independent strata employed were i) garden type (domestic vs. allotment), ii) a habitat heterogeneity/management intensity gradient and iii) an urbanization gradient (see Supplementary material for details). We consider domestic gardens to be gardens adjacent to single-occupancy houses with access restricted to the houses' occupants and allotment gardens to be publicly provided gardening lots access to which is restricted to the tenants. For simplicity, we use the term "garden owner" to refer to the participants in our study. However, participants with an allotment garden were legally tenants as allotments are leased and not bought in Zurich. Domestic garden owners were recruited by letter, phone and in person in the field, while allotment garden owners were enlisted through a call in the magazine of Zurich's allotment garden association and in person in the field (see Supplementary material for details). Variance in garden size was kept as small as possible to reduce potential confounding effects of area on species richness. Two gardens had to be subsequently excluded from the analysis since their owners did not fill in the questionnaire, resulting in a sample of 83 gardens.

2.2. Survey of actual plant species richness and classification of species

Biodiversity is a concept that comprises several aspects of biological organization, e.g. taxonomic, functional and phylogenetic diversity, and can be measured at different spatial scales (e.g. McGill, Dornelas, Gotelli, & Magurran, 2015). Here we focus on the taxonomic aspect of biodiversity at the scale of individual garden lots: the number of cultivated and spontaneously growing plant species that occur in a garden (i.e. plant species richness as a measure of taxonomic alpha (α) diversity; McGill et al., 2015). Since garden floras are composed of cultivated and spontaneously growing plant species which, potentially, react differently to habitat heterogeneity and are perceived differently by garden owners, we test whether our assessment instrument is able to estimate the number of only the spontaneous or only the cultivated plants. Likewise, from a conservation and ecosystem management perspective, native plant taxa are often preferred over alien taxa (e.g. van Kleunen et al., 2018). Therefore, we also consider how well the assessment instrument estimates the number of native taxa only.

A complete plant species inventory of each garden covering the entire vegetation period was made as described in Frey and Moretti (submitted). The origin of a plant individual or garden "population", i.e. whether a taxon was cultivated or whether it occurred spontaneously in a garden, was determined by consulting the Flora of the City of Zurich (Landolt & Hirzel, 2001) and/or by asking the garden owner in ambiguous cases (Frey & Moretti, submitted). Note that plant taxa can belong to more than one category (native, cultivated, spontaneous), since a taxon can occur spontaneously in one garden, while it is intentionally introduced and cultivated in another. Finally, both cultivated and spontaneous taxa can be native or alien.

2.3. Garden-owner reporting of garden habitat heterogeneity and plant species richness

To report habitat heterogeneity, garden owners were asked to mark the presence or absence of 7 land-use types and features that typically occur in Central European gardens and are also employed by garden owners to favor biodiversity (Loram, Warren, & Gaston, 2008; Goddard et al., 2013; Forman, 2014): berries, clipped hedges, unclipped hedges, dry walls, gravel surfaces, ponds/streams and wild/neglected areas (represented by icons; Fig. 1). We considered asking garden owners to report the presence/absence of 5 further garden features (compost heap, pile of branches, pile of rocks, shrubs and tall trees), but refrained from doing so due to the triviality of the question, i.e. the fact that these features are so readily recognized. This was done to reduce the length of the questionnaire handed to garden owners, as this research was part of an interdisciplinary project with many other topics covered in the questionnaire. Instead, we provided presence/absence data of these five features based on our (expert) garden survey. We argue that garden owners would give identical answers. An implementation of our approach could use an extended version of the assessment instrument shown in Fig. 1 (Supplementary Fig. S12).

In a second question, owners were asked to indicate presence or absence of four further land-use types that typically cover large proportions of garden area. For those among these four land-use types which were reported to be present, they were asked to indicate on a visual 3-level scale which level most resembled the respective land-use areas in their own garden. Each illustration on the 3-level scale depicted a possible plant species richness level (separate scales for flower beds, lawns, meadows patches and vegetable beds; Fig. 2).

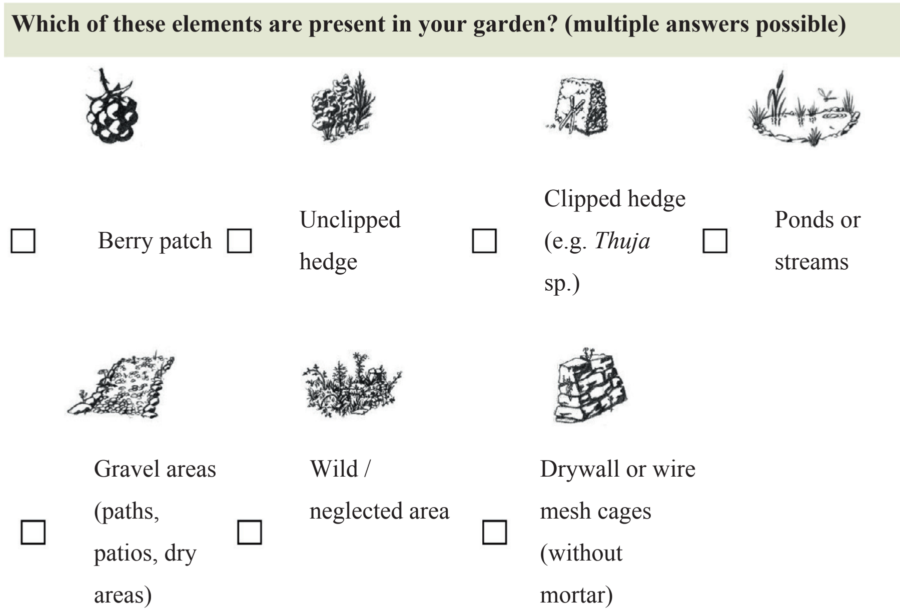

Fig. 1. Assessment instrument for reporting garden habitat heterogeneity. Icons visualize characteristic garden land-use types and features in gardens. Note that the instrument was translated from German into English and given a different layout for presentation in this article.

2.4. Calculation of predictors and statistical analysis

Two additive indices of structural and biotic diversity were calculated. The first index represents reported habitat heterogeneity and was calculated by summing the number of land-use types and features present in each garden, which results in a variable with a theoretical range of 0 to 16. This index is the sum of the land-use types reported with the instrument displayed in Fig. 1 (a number between 0 and 7), the simple garden features identified by the research team (a number between 0 and 5) and the land-use types reported by garden owners with the instrument displayed in Fig. 2 (a number between 0 and 4).

The second index, representing reported plant species richness, is the sum of the scales in Fig. 2, weighted by the number of the land-use types in Fig. 2 which the garden owner reported to be present. This variable ranges from 1 [poor] to 3 [rich].

Multiple linear regressions simultaneously using both additive indices as explanatory variables were then fitted to the richness of total, native, cultivated and spontaneous plant species. Model assumptions were investigated visually. We also tested for spatial effects and for a possible influence of garden area (see Supplementary material). All explanatory variables were centered and scaled to mean zero and one standard deviation prior to analysis and the response variables were transformed by the natural logarithm to improve the distribution of the residuals. All analyses were performed in R (R Core Team, 2017).

3. Results

We identified a total of 1081 taxa, of which 528 (49%) were native to Switzerland (Frey & Moretti, submitted). Average total plant species richness was 120 (sd ± 34) and ranged from 53 to 205. For native species it was 66 (sd ± 23, range 33–170), for cultivated species it was 79 (sd ± 31, 17–153) and for spontaneous species 41 (sd ± 11, 15–70). Mean garden size was 312 m^2 (sd ± 155 m^2).

The index for habitat heterogeneity took on values between 3 and 14 land-use types/features, with an average of 9 (sd ± 2.6). The average garden-owner reported (weighted) plant species richness level was 2.15 (sd ± 0.54, range 1–3).

Across all models, reported habitat heterogeneity was the stronger predictor of actual plant species richness than reported plant species richness (Table 1). Specifically, habitat heterogeneity was a strong predictor for native and cultivated plants. On the other hand, reported plant species richness was mainly associated with cultivated plants.

Model assumptions were well met in all models (Supplementary Figs. S1–S8). We did not detect signs of spatial autocorrelation in the residuals or in the response variables (Supplementary Fig. S9 and Table S1). Species richness of native and spontaneous plants was positively associated with garden area, but these associations were weak and did not substantially change the predictive performance of either model (Supplementary Fig. S10 and Table S2). Finally, there was no association between the urbanization degree and plant species richness (Supplementary Fig. S11).

The validity of our findings could be questioned based on the fact that we included some data collected by experts in our reported habitat heterogeneity index. To check what effect this might have, we ran our models with a reduced habitat heterogeneity index using only garden-owner reported habitats (i.e. without data on compost heaps, piles of rocks or branches, trees or shrubs). The resulting models differed only marginally from those in Table 1 (Supplementary Table S3).

4. Discussion

Our results show that the actual (total) plant species richness of gardens can be estimated – albeit in an approximate fashion – based on just two additive index variables calculated from visual survey questions. These questions have the advantage of being brief and visually attractive and thus can easily be used in citizen-science and similar contexts where brevity is important.

Moreover, the index variable of reported habitat heterogeneity was a stronger predictor for actual plant species richness compared to the index of reported plant species richness (Table 1). Thus, the concept of habitat spatial heterogeneity appears to be useful for predicting plant species richness based on reported land-use types and features of garden lots. In a general sense, our findings are consistent with other studies, confirming that the actual biodiversity of urban gardens can indeed be estimated to some degree of precision by non-experts, especially if suitable methods are used (e.g. Fuller et al., 2007; Lindemann-Matthies et al., 2010; Southon et al., 2018).

In addition to total plant species richness, our method produces

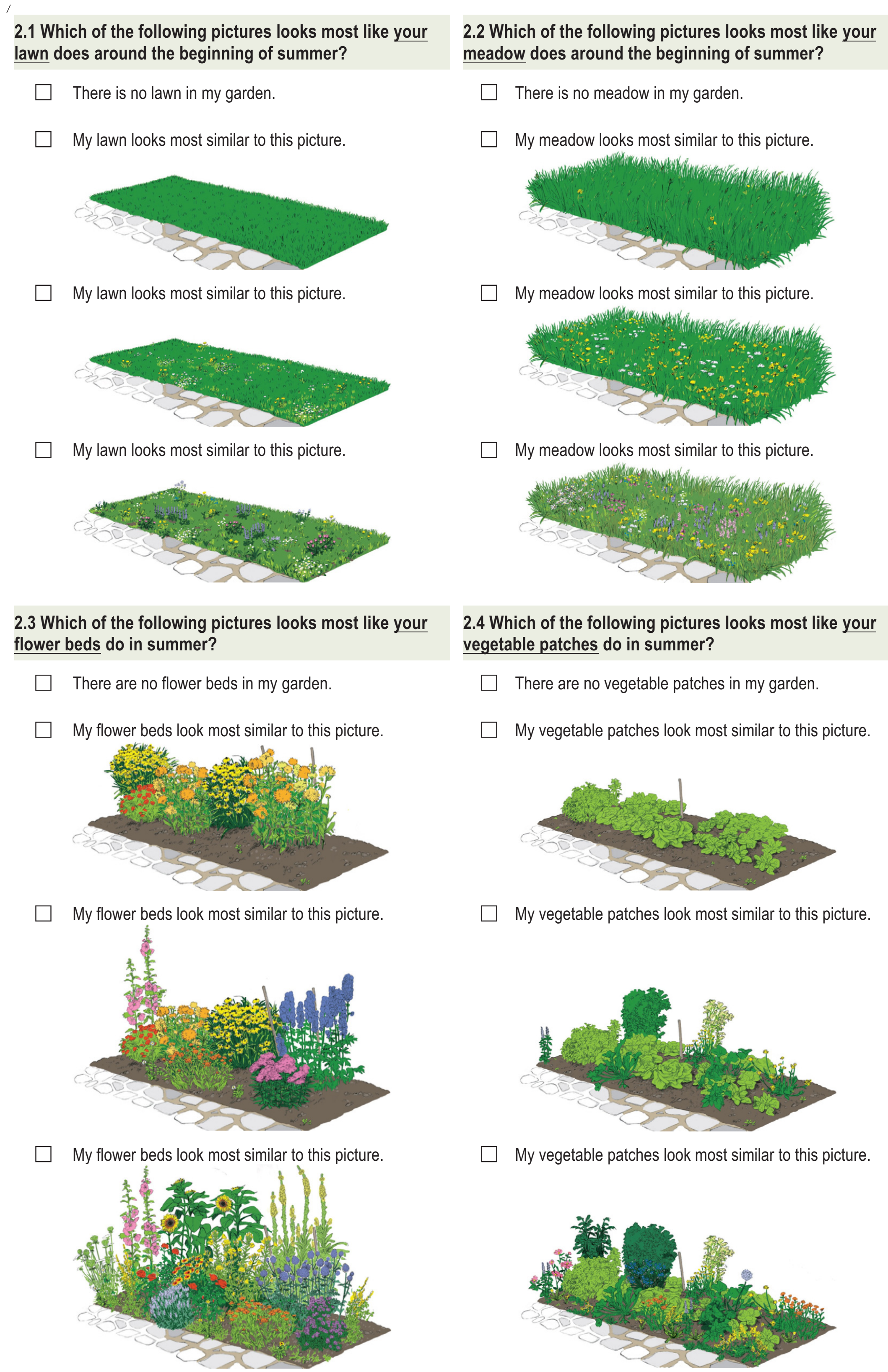

Fig. 2. Visual assessment instrument for reported plant species richness level. Illustrations of three levels of plant species richness in four common garden land-use types: (a) flower beds, (b) lawns, (c) meadows/wildflowers patches and (d) vegetable beds. From level one to level three, the species richness of depicted plants was increased. Note that the instrument was translated from German into English for presentation in this article.

Table 1
Multiple linear regressions models with the two (standardized) additive index variables from the visual survey questions as explanatory variables and actual plant species richness (of all, native, cultivated and spontaneous plants) as dependent variable. The explanatory variables are garden-owner reported plant species richness and (mainly) garden-owner reported habitat heterogeneity. N = 83 urban gardens. SE: Standard error.

Dependent variable of each model	Intercept		Reported plant species richness		Reported habitat heterogeneity		Explained variance (Adjusted R^2)
	β_1	SE	β_2	SE	β_3	SE	R^2
Model 1: All plants	4.74***	0.02	0.08***	0.02	0.17***	0.02	0.50
Model 2: Native plants	4.14***	0.03	0.08**	0.03	0.18***	0.03	0.46
Model 3: Cultivated plants	4.28***	0.04	0.12**	0.04	0.23***	0.04	0.42
Model 4: Spontaneous plants	3.67***	0.03	−0.00NS	0.03	0.12***	0.03	0.15

NS = not significant.
** $P < 0.01$.
*** $P < 0.001$.

estimates for species richness of native, cultivated and spontaneous plants, although the proportion of variance explained by the models is clearly lower for spontaneous plants (Table 1). The finding that the predictive power of the model is lower for spontaneous plants may be not be surprising since garden owners may perceive varying numbers of cultivated plants more strongly than of spontaneous plants, as the latter are often inconspicuous and co-occur in groups of closely related and morphologically similar species (e.g. *Veronica* spp.).

Incorporating this assessment instrument in a larger study – e.g. on psychological restoration and biodiversity – should be straightforward. Researchers could include the two visual questions (in Figs. 1 and 2) in whatever questionnaire they are using. An estimate of plant species richness per garden can be calculated using the two index variables and the parameters (β_1, β_2 and β_3) in Table 1. While the number of plant species calculated in this way is only an estimate, this variable will still reflect relative differences between plant species richness in gardens, which is often more relevant than absolute numbers. To stick with our example: for the purpose of investigating the association of garden plant species richness and psychological restoration, an instrument which reliably identifies relative differences between gardens' biodiversity would suffice. Additionally, our two-index approach has the advantage that it is less dependent than the numerical estimate approach on the capacity of non-expert respondents to identify species richness levels. Nevertheless, our indirect estimation method seems to have a similar validity and reliability as simple species number estimates by non-experts in some contexts (Fuller et al., 2007; Southon et al., 2018; but see Dallimer et al., 2012).

The value of our research lies primarily in it providing proof of two concepts. Firstly, (citizen-estimated) habitat heterogeneity is a valid way of estimating actual plant species richness and secondly visual questions can be used to estimate plant species richness in a citizen-science context. While we would expect these aspects to be generalizable, details of the questions may have to be adapted for use in research in contexts other than the one they were developed in. Specifically, in research on gardens in other eco-cultural settings and on greenspaces other than gardens, the choice of land-use types to be used as question items would have to be adapted and the validity of the new instrument would have to be tested with a small sample of gardens. It is worth noting that this need for adaptation is also due to the fact that gardens are a cultural artefact and thus differ across cultural spaces.

Two variables which could be imagined to improve performance of the assessment instrument are total garden area and the area of particularly species-rich land-use types such as flower borders (Loram, Warren et al., 2008). In our data, however, garden area had only weak effects, if any at all, which is probably due to a combination of low variance in area and to the dominance of species-poor lawns in larger gardens. A low and/or inconsistent effect of garden area on plant species richness has also been observed by other authors (Cook et al., 2012; Loram, Thompson et al., 2008; Thompson et al., 2003). This might particularly be the case in garden systems where garden areas are standardized, such as in allotments. It is, however, an important point to consider for future implementation. Where garden area varies more it may be necessary to include it in the assessment instrument to increase the predictive performance of the model, especially if spontaneous plants are the focus of research. However, this would require a reliable assessment of garden area by owners. While we did not attempt this in our study, we did ask owners to assess what proportion of their gardens were occupied by certain land-use types (lawn, vegetable patch etc.). Owner estimates were very unreliable and garden owners reported difficulties in answering these questions, so we abandoned this approach. Whether citizen-scientist estimates of total garden areas would be equally unreliable has to be left to future research.

In conclusion, our findings open new avenues on the potential of citizen-science approaches to sample reliable biodiversity data with sample sizes and at geographic scales that are currently not possible with expert surveys. Clearly, the potential for such approaches is great in anthropogenic ecosystems such as cities and, besides delivering valuable data, could foster public involvement and thus the mainstreaming of biodiversity conservation in cities (McKinley et al., 2017).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2019.01.013.

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