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The 'GartenApp': Assessing and Communicating the Ecological Potential of Private Gardens

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Received: 31 October 2019; Accepted: 20 December 2019; Published: 21 December 2019

Abstract: Private gardens make up large parts of urban green space. In contrast to public green spaces, planning and management is usually uncoordinated and independent of municipal planning and management strategies. Therefore, the potential for private gardens to provide ecosystem services and habitat and to function as corridors for wildlife is not fully utilized. In order to improve public knowledge on gardens, as well as provide individual gardeners with information on what they can contribute to enhance ecosystem services provision, we developed a GIS-based web application for the city of Braunschweig (Germany): the 'GartenApp' (garden app). Users of the app have to outline their garden on a web map and provide information on biodiversity related features and management practices. Finally, they are asked about observations of well recognizable species in their gardens. As an output, the gardeners are provided with an estimate of the ecosystem services their garden provides, with an evaluation of the biodiversity friendliness, customized advice on improving ecosystem services provision, and results from connectivity models that show gardeners the role of their garden in the green network of the city. In this paper, we describe the app architecture and show the first results from its application. We finish with a discussion on the potential of GIS-based web applications for urban sustainability, planning and conservation.

Keywords: green infrastructure; urban; ecosystem services; connectivity modelling; citizen science

1. Introduction

Urban green spaces (UGSs) can provide numerous ecosystem services that support the climate change resilience of cities, such as carbon storage in trees [1], cooling effects by evapotranspiration and shading [2,3] or flood protection by unsealed areas [4]. In addition, UGSs fulfill manifold recreational aspects for residents [5], support public health [6] and are key areas for people to experience wild plants and animals, engaging them in environmental conservation [7]. Large UGSs resemble islands in an urban matrix and can be biodiversity hotspots [8,9]. Other UGS elements, such as smaller parks, road verges, street trees, and gardens, may function as habitat and also as corridors for urban biodiversity [10–14]. To emphasize that not only the quantity but also the spatial configuration and connectivity of UGSs is important for functionality, the term 'green infrastructure' (GI) has been introduced [15].

Private gardens can make up a significant proportion of urban green space in cities [16,17], and therefore have an important role in the urban ecosystem [12,14,18,19]. Their ability to provide ecosystem services and habitat is scale dependent, however, and a certain size and quality is needed [3,11,20,21]. Single gardens are usually too small to have an effect and gardeners would need to coordinate design and management. Decisions on their management and design are being made on the individual level, however, often resulting in what Odum referred to as the 'Tyranny of Small Decisions,' i.e., a degradation due to small-scale and uncoordinated management [13,22–24]. In addition, the awareness for the public value of individual gardens for contributing to GI appears to be low [25]. Even if there is awareness, garden practices are strongly driven by perceived norms and do not necessarily reflect the values of the garden owners [24,25]. Hence, no easy solution for increasing the public value of gardens in providing ecosystem services and contributing to biodiversity conservation exists, but social processes play a key role [24,25]. In keeping with the UN Sustainable Development Goal 11.3 [26] and the Habitat III New Urban Agenda [27], these approaches should be inclusive and participatory.

Approaches to overcome the 'Tyranny of Small Decisions' commonly build on providing gardeners with relevant information on their role in the urban ecosystem, empowering and encouraging them to contribute, and engaging them through citizens science [13,22,24,28–30]. The latter is also important for improving the evidence-based planning of GI. While remote sensing is also contributing valuable data, e.g., traditional vegetation indices such as NDVI [31], impervious surface [32], or vegetation heights [21], remote sensing is unlikely to be capable of detecting small biodiversity related features, such as the flower diversity of a lawn or the availability of nesting boxes or fences that exclude wildlife from moving between potentially suitable patches [30]. Thus, consideration of both garden surveys as well as remote sensing information could lead to a comprehensive assessment of individual garden management [30,31]. With current technology, assessments of gardens can easily and effectively be performed with web-based applications that can host simple questionnaires along with mapping tools [31]. Ideally, such a system would allow for direct feedback between gardeners, scientists and municipalities.

In this paper, we present a web-based GIS platform, the 'GartenApp' (garden app), which provides and collects information on gardens. Gardeners in the city of Braunschweig (Germany) draw their garden on a map and enter whether they provide certain biodiversity enhancing features and manage their garden in a biodiversity friendly way. We use this information, along with vegetation heights derived from remote sensing material, to calculate ecosystem service provisioning by the garden, focusing on carbon storage, cooling, shading, and biodiversity potential. In order to show gardeners the role of their garden for GI, we present them with results from connectivity models. The connectivity of urban green space depends on the focal species, and taking 3D effects (i.e., vegetation heights) into account is important [14,21,33]. Therefore, we chose two model species that are common in gardens and well-liked [34] and represent two vegetation layers: the European hedgehog (*Erinaceus europaeus*) as a ground dwelling species and the red squirrel (*Sciurus vulgaris*) as a tree dwelling species. In addition to describing the app architecture, we show the first results from 75 gardens, surveyed with the GartenApp. Platforms such as the GartenApp could be valuable tools that can easily be adapted to be used for communication and knowledge transfer between scientists, citizens, and municipalities.

2. Materials and Methods

2.1. Study Area

Braunschweig is located in the federal state of Lower Saxony in northern Germany (52.264° N, 10.524° E). The municipality covers 192 km^2, the total population is 248,292 and the population density is 1288.5 km^2 (31 December 2018; [35]). Average precipitation is 637 mm, with monthly averages between 37 and 68 mm, and the average temperature is 9.5 °C, with January being the coldest (1.3 °C) and July being the warmest (18.3 °C) month (averages for period of 1981–2010, station ID 662 from [36]). The climate is classified as Cfb (warm temperate, fully humid, warm summer; [37]). The city is located on the transition from the fertile loess soils of the uplands in the southwest to the poor sandy soils of the lowlands in the northeast [38]. Elevation ranges between 60 and 112 m (digital elevation model of

Braunschweig from 2011). The city is located in the floodplain of the river Oker. The former old town is surrounded by a green ring of parks, gardens and alleys, clearly visible in the center of Figure 1. Also visible is the network of parks, meadows and lakes along the river Oker in the south and in the northwest of the green ring. Large forests and recreation areas can be found in the east, west and northeast of Braunschweig. The former old town was largely destroyed in World War II, but densely rebuilt since then and contains little green space. East and west of the green ring, dense tenement blocks from the Wilhelmine Period (second half of the 19th to 1918) are located, surrounded by less-dense multi-story housing from later periods. Otherwise, large parts of the city are single or semi-detached houses, including two garden cities from the National Socialist period (1933–1945) and several villages that are still partly surrounded by agricultural areas. In total, 8% (15.4 km^2) of the urban area is covered by urban green spaces (including sports fields and cemeteries), 11.2% (21.6 km^2) by forests and 36.5% (70.1 km^2) by agricultural areas [39].

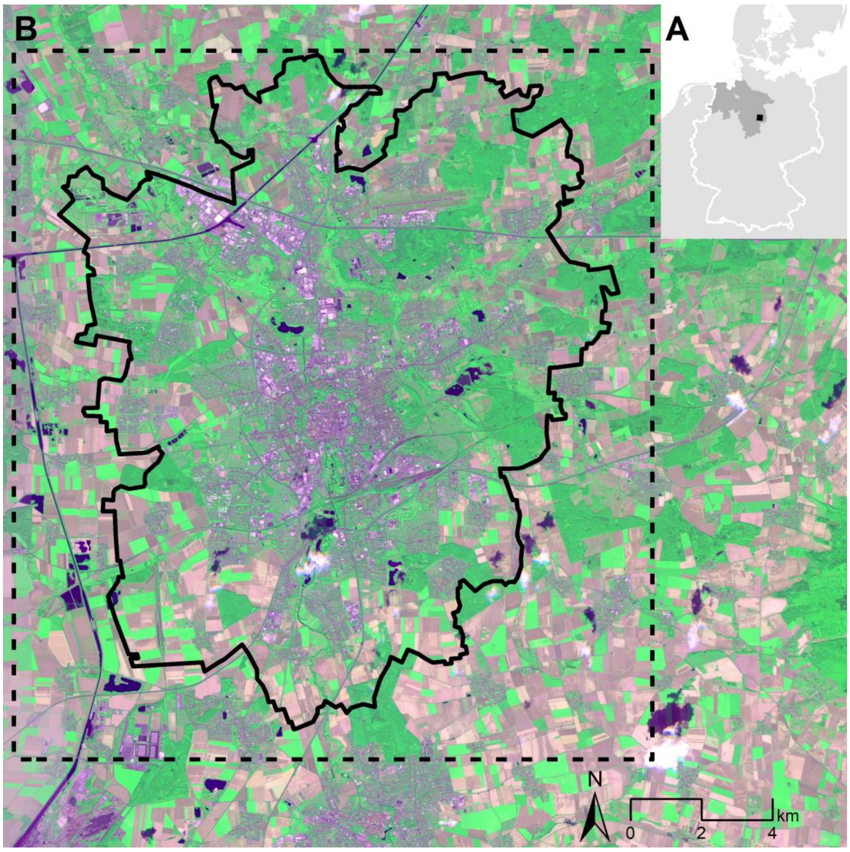

Figure 1. The location of Braunschweig (black square) in Germany (white line) and in the federal state of Lower Saxony (dark gray; (**A**)); and city of Braunschweig (black line) in a false-color satellite image highlighting vegetation (**B**). The GartenApp works within the dashed line. Data A: ESRI basemap Europe and [40]. Data B: RapidEye Science Archive Project-ID 00253; [40].

2.2. *Vegetation Heights*

In a first step, we classified an orthophoto mosaic with red, green, blue and infrared channels with a spatial resolution of 20 cm (Figure 2A), covering the bounding box of the municipal boundary (Figure 1; orthophoto mosaic from 18 May 2017; provided by the city of Braunschweig). We chose a classification into two classes—'vegetation' and 'other'—and used a 'Random Forest' machine learning approach with 1200 manually created training points (implemented with the package randomForest [41] in R (version 3.5.2; [42]). One-third of these points was used for validation and the classification error was less than 2%. The Random Forest model was then used to classify the entire dataset (Figure 2B).

In a second step, we created a 1 m resolution digital surface model (DSM) from LiDAR (laser scanning) data. Two LiDAR data sources were used. For the city of Braunschweig, a dataset with a resolution of 5 points per m^2 and a height precision of ± 0.15 m, obtained in the fall of 2011, was provided by the city of Braunschweig. For the areas within the bounding box, but outside of the municipal boundary, a dataset with a resolution of 3.5 points per m^2 and a height precision of ± 0.15 m, obtained in the spring of 2013, was provided by the regional planning authorities 'Regionalverband Braunschweig'. A digital terrain model (DTM; provided by the city of Braunschweig for areas within the municipal boundary, and interpolated from the LiDAR data for areas outside of the municipal boundary, using classified ground points and the Raster Interpolation toolbox in ArcGIS 10.6) was then subtracted from the DSM, in order to create net heights (Figure 2C). In a third step, the vegetation raster was resampled to a 1 m resolution and combined with the net heights. Finally, building footprints (from [43]) were subtracted in order to remove green roofs and tree canopy above buildings. In addition, vegetation below power lines (from [39]) was set to ground level, in order to remove artefacts from the power lines and poles (Figure 2D). All spatial analyses were carried out in ArcGIS 10.6.

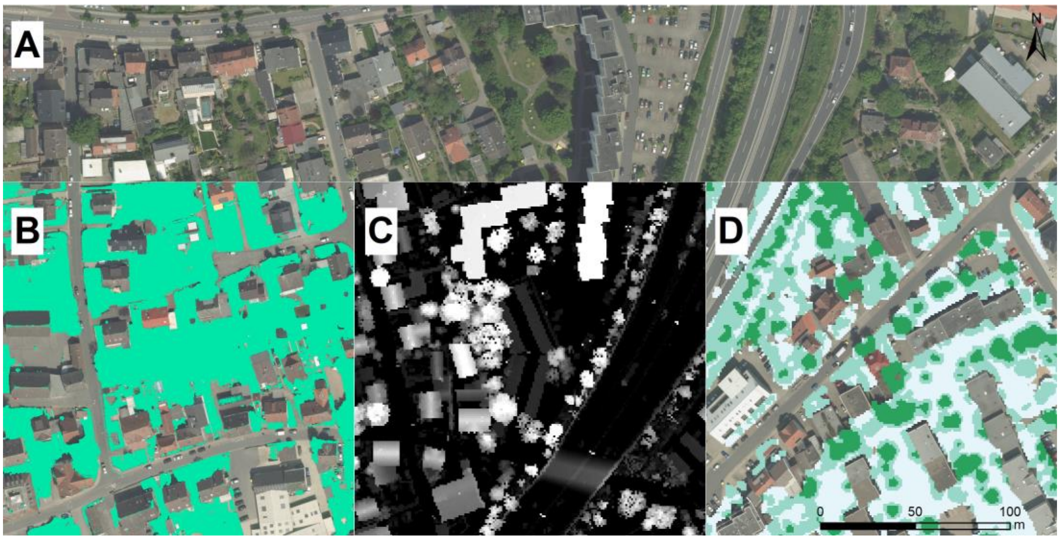

Figure 2. An overview on how vegetation heights were created: First, color infrared orthophotos (**A**) were classified into 'vegetation' and 'other' (**B**). The vegetation was then combined with net heights (**C**) to create a vegetation height layer (**D**).

2.3. Connectivity Modelling

We used the electric circuit theory based connectivity modelling software Circuitscape [44] to model connectivity maps for the European hedgehog as a ground dwelling species and the red squirrel as a tree dwelling species in Braunschweig. Circuitscape demands species-specific landscape resistance maps [44]. Relevant landscape elements were derived from vegetation height data (see Section 2.2) and cadaster data [39]. The maps had an extent of 18 × 28 km^2, with a resolution of 3 m for the squirrels (~40 × 10^6 raster cells) and 16 × 19 km^2 with a resolution of 2 m for the hedgehogs (~75 × 10^6 raster cells). Resistance values for squirrels were parameterized according to [45] and for hedgehogs, according to [46] (see Tables A1 and A2, respectively, for parameterization). In case of hedgehogs, we extended or slightly modified the parameterization of [46]: We set the landscape resistance of allotment gardens and cemeteries to high permeability (i.e., $R = 1\ \Omega$), while railways were assumed to act as a barrier (i.e., $R = 100\ \Omega$) and the canal in the northwest of the city as an absolute barrier (R = infinite). Publicly managed areas with grass and shrubs, as well as connected garden areas with a minimum of 1 ha, were set as core habitats. In the case of squirrels, we chose green spaces and forests of at least 10 ha as core habitats. These core areas were connected pairwise, choosing a maximum distance for hedgehogs of 1 km, and for squirrels of 2 km (distances based on typical roaming behavior [45,46]). The pairwise current flow was combined into city wide current flow density maps (Figure 3). Raster cells with high current flow density (Ampere per cell) have a high importance for connectivity, low flow densities a low importance for connectivity. The maps can be intuitively interpreted by lay people [44].

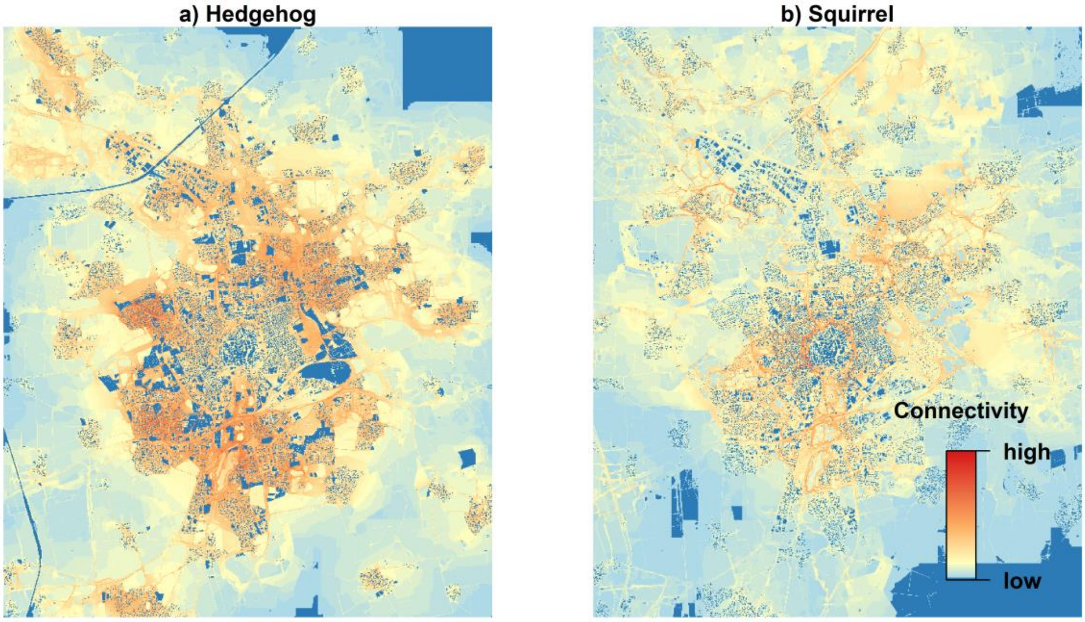

Figure 3. Current flow densities for (**a**) hedgehogs and (**b**) red squirrels. Current flow density is given as relative connectivity ranging between low and high, because absolute values are not comparable.

2.4. App Architecture

The GartenApp currently runs on two servers: (i.) a PostgreSQL 9.6 server with the PostGIS 2.3.3 extension is used for data storage, including the vegetation heights from Section 2.2 and current flow densities from 2.3; (ii.) a Shiny server v1.5.9.923 is used for hosting a RStudio Shiny app [47]. The app's frontend is divided into five main sections: (1) mapping the garden, (2) biodiversity questionnaire, (3) vegetation structure output, (4) ecosystem services assessment output, and (5) connectivity output. In the following, the individual sections are described in detail. Videos of the app in action are shown in Videos S1–S3.

2.4.1. Mapping the Garden

After some initial information on the app, gardeners are asked to draw a polygon around their garden. We used the Leaflet open-source JavaScript library for mobile-friendly interactive maps with the R package leaflet 2.0.1 [48]. The polygon is later used for a spatial query that loads vegetation height and current flow density data for the specific garden from the data base (using rpostgis 1.4.2 [49]), and for creating plots (see also Video S1).

2.4.2. Questionnaire on the Biodiversity Potential of Gardens

The biodiversity friendliness of garden management and design is assessed with 10 checkboxes that are based on peer-reviewed publications (Table 1). In addition, the biodiversity friendliness of lawn and planting beds is assessed, based on a recent study [50]. The user can select lawn, meadow, vegetable and flower plots that match sketches from [50] with radio buttons.

Table 1. Ecological functions of biodiversity friendly features in gardens derived from a literature survey.

Feature	Function	Reference
Nesting box for birds	increases species richness of birds; an indirect effect can be an increase in the number of bumblebee nests	[11,51]
Bird feeder	increased resource availability increases bird density and occurrence of certain bird species	[52–54]
Hedge	provide nesting opportunities for bumblebees; provision of shelter and litter for snails	[51,55]
Compost heap	increases number of bumblebee nests; habitat for beetles, springtails and mites; increases beetle and slug species richness	[51,55–57]
Fruit trees and berry shrubs	increases resource availability and habitat for birds and insects (sugar-rich fruits as resource for garden-inhabiting species, lipid-rich fruits for migrating species)	[58,59]
Deadwood storage	increases presences of fungi and other saproxylic species	[57]
Stone wall	habitat for lizards, insects and xerophilous plants and lichens; increases species richness of slugs, snails	[55,59]
Wild patches	increase diversity and abundance of bees	[60]
Nesting support for insects	increases survival probability of pollinators	[61]
Ponds	habitat for water plants, amphibians and insects; watering place for birds; increases presence of a broad range of wild species (e.g., foxes, moles, snakes)	[57,59,62,63]

At the end of the section, we ask the gardeners to check whether they observed certain species during the last 12 months within their own garden: squirrels, foxes, wild rabbits, hedgehogs, domestic cats, amphibians (e.g., treefrogs, toads), and reptiles (e.g., lizards). At the end of this panel, the gardener has to press the 'Calculate' button which triggers the download of data from the database and the calculation of ecosystem services (see also Video S2).

2.4.3. Vegetation Structure of the Garden

This section is the first results panel. The garden's vegetation structure is visualized as a bird's eye view on the garden. In order to simplify this, we present vegetation height in three classes: grass layer (<0.5 m), shrubs (0.5–4 m) and trees (>4 m; classification according to [21]). We use this section to explain (i) how the data was generated and (ii) reasons for possible errors. For example, if trees have been removed since 2011, they would still appear in the visualization. Depending on the respective amount of the vegetation-height classes, the gardeners are provided with a custom text. Structurally diverse gardens (grass layer, shrubs and trees each cover more than 15%) result in 'Well done, go on!'. If one class is lacking, we give simple recommendations such as 'Your garden is dominated by shrubs. A few trees and some grass/meadow patches can improve the vegetation structure of your garden!' (see also Video S3).

2.4.4. Ecosystem Services Assessment

Three ecosystem services that are closely related to vegetation are calculated and presented: carbon storage, cooling effects and shadowing. All three services are presented on a bar plot that spans 'low' (no vegetation in the garden) to 'high' (the whole garden is covered by trees). Carbon storage in tree stems was estimated according to empirical findings for single- and semidetached houses in the city of Leipzig (6.38 kg C m^{-2}; [1]). Vegetation heights below 2 m were neglected.

The cooling effect of the vegetation was estimated similarly to [3,64], applying a linear regression between air temperature and vegetation volume. We used air temperature from a sensor network of 15 weather stations in Braunschweig (see [65]), measured in 3 m height above ground level (to keep the sensors safe from destruction). We selected air temperatures measured at 15:00 (usually the maximum air temperature) at five windless and cloudless summer days in 2017 (2 June, 31 July, and 7, 28 and 29 August). Vegetation volume was derived from vegetation heights (Section 2.2) over an area with 10 m radius around each of the 15 weather stations. We applied a linear mixed effects model with air temperature as response variable, vegetation volume as fixed effects predictor and the date as random effects variable (random intercept). In the GartenApp, the cooling potential for each garden is presented as a barplot of the relative cooling potential derived from the fixed effects estimate. We set the maximum or optimum reachable cooling effect (100%) to a vegetation volume of 3000 m^3 which corresponds to a 300 m^2 garden completely covered by 10 m trees. For the assessment of the cooling potential, the intercept is neglected and only the slope of the regression line is used (this corresponds to the rate of temperature change, i.e., air temperature decreases by 0.6 °C when vegetation volume is increased by 1000 m^3; Table 2). Hence, we yield a relative cooling potential for the garden, independent from the actual air temperature and only on the basis of the vegetation volume. All analyses were performed in R (version 3.5.2; [42]) with package nlme (version 3.1–137; [66]) for mixed effects model fitting.

Table 2. Estimated regression parameters from linear mixed effects model fitting. Random effects variance of 'date' is 4.18. Approximate p-values for estimated parameters are $\ll 0.05$. χ^2 test for fixed effect yielded a significant effect of incorporating 'Vegetation volume' in the model ($\chi^2 = 88,\ d.f. = 1,\ p \ll 0.05$). Marginal explained variance ('fixed effects only') is $R^2_m = 0.14$ and conditional explained variance (fixed + random effects) is $R^2_c = 0.84$.

Parameter	Estimate	Standard Error	*t*-Value
Intercept [°C]	26.38	0.92	28.63
Vegetation volume [m^3]	-0.60×10^{-3}	6.38×10^{-5}	−9.38

Shading by vegetation is an effective way to reduce heat stress [67]. We calculated shading using the R package shadow 0.6.0 [68]. It calculates shading by simple 3D objects, depending on spatial location and time of day. In order to simplify the vegetation, the following steps are taken: (i) We remove pixels with a height below 2 m, because low vegetation casts hardly any shadow. (ii) We select all pixels with a height between 2 and 5 m, convert them into a spatial polygon and calculate the shadow for an object of that shape and a height of 2 m. (iii) We repeat step (ii) with all pixels with a height between 5 and 8 m, 8 and 11 m, and so forth, until the maximum height of the vegetation in the garden is reached. We choose intervals of 3 m, because the calculation takes quite a while and a higher resolution would have slowed down the app. In a final step, the individual shadows are dissolved, and the final area is calculated. Of course, this is a very simplified representation of trees. In order to reduce errors from simplification, we have chosen the shading for a day when the sun is at its highest (22 June, 12:00), i.e., when the sunrays hit the vegetation from above rather than from the side. For scaling the output barplot in the app, we compare the shadow area with the garden area. No shadow is considered the worst, though a shadow covering more than 110% is considered best (see also Video S3).

2.4.5. Biodiversity Assessment

Biodiversity potential is calculated according to 'Model 1' by [50]:

$$S_{\text{actual}} = 4.74 + 0.08 * S_{\text{reported}} + 0.17 * H_{\text{reported}}, \quad (1)$$

where actual plant species richness is S_{actual}, reported plant species richness according to the questionnaire is S_{reported}, and reported habitat variability is H_{reported}. Maximum biodiversity potential is reached when lawn, meadow, flower and vegetable patches are marked at highest diversity levels (maximum value of S_{reported} is 3) and all checkboxes referring to additive elements in the garden are checked and shrubs and trees are found in the garden (the maximum value of H_{reported} is 12). Since a particular value of actual plant species richness is difficult to interpret for the gardeners, we decided to present the biodiversity potential of the garden as proportional output: the minimum biodiversity potential (or 0%) equals the intercept of the above given formula and the maximum (or 100%) equals a value of 7.74, which is the maximum value that can be reached (see also Video S3).

2.4.6. Connectivity, Report and Option for Uploading Input

In this panel, the gardeners are presented with maps of the current densities for squirrels and hedgehogs from Section 2.3. so that they can explore whether their garden is potentially important for habitat connectivity of the two species. Below the panel, gardeners can download their personal garden report as a PDF and they can decide whether they want to store their input in the database (see also Video S3).

3. Results

Since 2016, we collected 75 gardens and backyards during five public events in: 'TU Night' (open day of the Technische Universität Braunschweig) in 2016, 2018 and 2019, 'Langer Tag der StadtNatur' (day of urban nature) in 2018, 'Aktionstag Natur zum Anfassen' (nature action day) in 2019. The garden areas range between 24 and 7060 m^2, with a median of 405 m^2 (N = 75; Figure 4). In 2019, we updated the questionnaire for the biodiversity assessment, and so the following results on gardens refer to the 26 gardens we collected since then. While more than half of the gardens provided nesting boxes and food for birds, deadwood and wild patches, open compost, nesting sites for wild bees, unclipped hedges and berry patches, 10 gardens provided drywalls and only four gardens provided ponds (Figure 5). In total, 17 gardeners checked the most diverse image for flower patches in the questionnaire. Only half of the gardens were used for growing vegetables (N = 14). Slightly more than one-third of the gardens provided meadow patches (N = 10). Four gardeners stated that they did not have a lawn or vegetable patches, but meadow and flower patches instead. Gardeners reached 36%–87% (median of 72%) of the potential maximum for biodiversity support in their gardens (Figure 6).

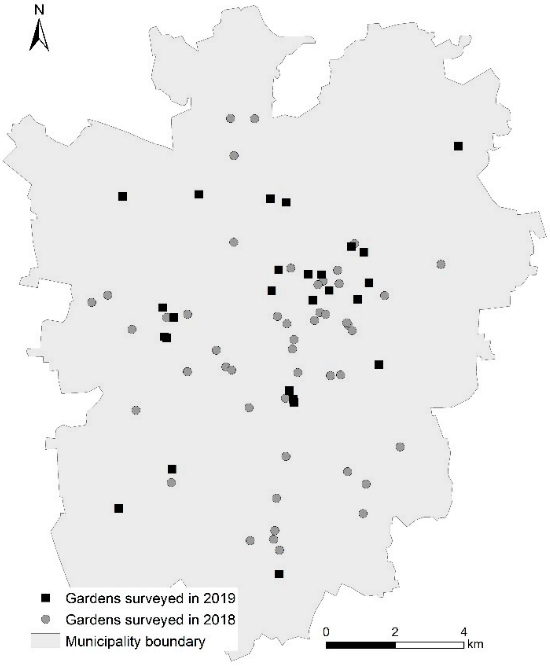

Figure 4. Locations of 75 gardens collected during several public events between 2016 and 2019. Black squares are gardens collected in 2019 after updating the questionnaire for the biodiversity assessment.

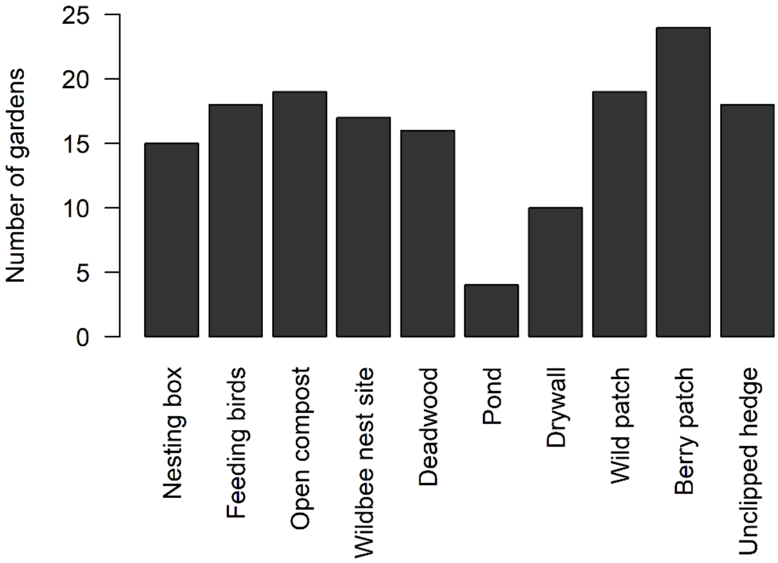

Figure 5. Presence of features that enhance the biodiversity potential of gardens for 26 gardens collected during three public events in 2019.

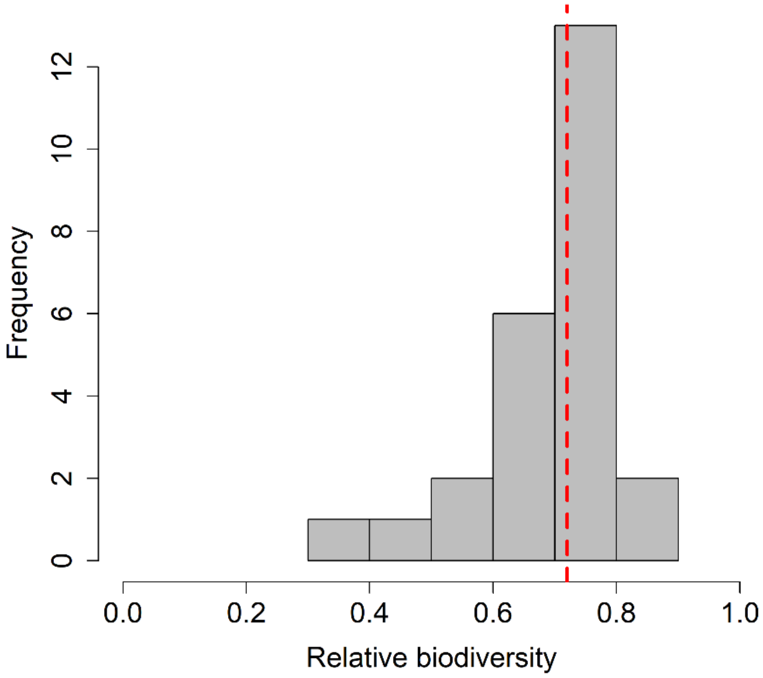

Figure 6. Relative biodiversity for 26 gardens collected during three public events in 2019. Maximum is reached when all checkboxes in the biodiversity questionnaire are checked and lawn, meadow, flower and vegetable patches are marked at highest diversity levels. The dashed line shows the median of relative biodiversity.

The comparison of gardener's observations of squirrels and hedgehogs (N = 75) with current densities showed no significant results. In the case of squirrels, the median of maximum current densities from the connectivity model was lower for absence statements than for presence statements (Figure 7a), but according to a Wilcoxon rank sum test, the effect is non-significant (W = 425, P = 0.19). For the hedgehogs, the median of maximum current densities from the connectivity model was also lower for absence statements than for presence statements, but again, the difference was not significant (W = 420.5, p-value = 0.36; Figure 7b).

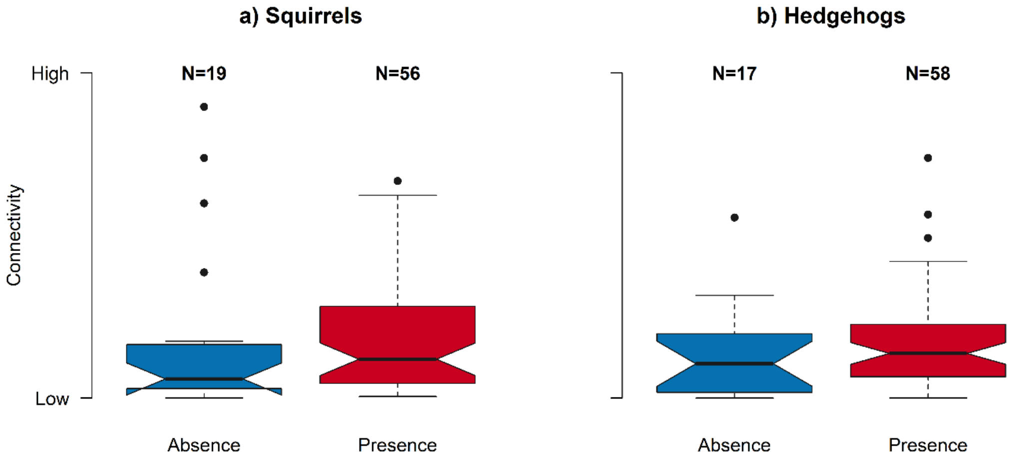

Figure 7. Maximum current density from the 75 gardens according to the connectivity models for (**a**) squirrels and (**b**) hedgehogs related to gardeners' observations of the presence/absence of these species in their gardens. Current flow density is given as relative connectivity ranging between low and high, since real values are not comparable.

4. Discussion

The GartenApp is a successful combination of what [31] is described as 'technology data' (i.e., remote sensing material) and 'in situ data' derived from citizen science surveys. Thus, the app could serve as a communication tool between scientists, citizens and municipalities. There are many potential additions to the app. The most evident one is to encourage friendly competition between gardeners for yielding the 'best garden or quarter' in terms of ecosystem services, biodiversity and connectivity. Other additions could focus on invasive plants or biocontrol, connectivity models for other species, or machine learning technologies for species recognitions. It is important, however, not to overburden the app, because of the potentially negative impacts on the user experience [69].

In order to be meaningful for gardeners, the quality of content is important. In our case, the LiDAR data is quite old, and we were frequently told during public events that changes have occurred since then. While remote sensing material is frequently updated in Germany, availability can be quite problematic. The quality of the connectivity models has not fully been assessed, because there are no systematic surveys of squirrels and hedgehogs in Braunschweig. A comparison with hedgehog observations from a citizen science project by the conservation non-profit organization 'Bund für Umwelt und Naturschutz Deutschland—BUND e.V.' has shown that current densities are significantly higher than at randomly chosen locations [70]. The comparison of current densities for gardens assessed with the GartenApp, showed no significant differences for observations of squirrels and hedgehogs, however. We can only speculate, but we would assume that people may not have observed the nocturnal hedgehogs in their gardens, even though they are present. With squirrels, the difference between gardens with and without observations is more pronounced, probably because they are clearly identifiable during the day and false negatives are unlikely. The availability of resources is not captured in the model, however, and, for example, a single hazelnut tree could lead to squirrel 'traffic' that the model would overlook. In any case, for improved connectivity models, systematic observations and tracking data would be needed [14]. Nevertheless, we consider the quality sufficient for illustrating the general role of the garden in the GI of Braunschweig. The computation of the models took several days. So, larger cities may have to reduce the spatial resolution. While the data on the server is quite large (in our case 34 GB), it does not affect the usability of the app, because only the data for the selected polygon and its vicinity are downloaded and processed.

There are also uncertainties linked to the ecosystem service and biodiversity assessment. The carbon storage calculation is rather simplistic and based on multiplying a factor to canopy cover, ignoring heights. While cooling is based on measurements from Braunschweig, it ignores the wider surrounding and features such as waterbodies or buildings. The shading by vegetation is important but may be dwarfed by the shading from buildings. For the current purpose of the app, these issues are of minor importance, however, because the main output are bar graphs with relative values on a scale from 'low' to 'high'.

We consider the selection of ecosystem services and modelled species to be quite representative for central and western Europe. If orthophotos, LiDAR data and detailed land-use maps are available, the app can easily be adapted. The role of gardens for stormwater management and retention is something that we would like to explore in the future. For other parts of the world, other ecosystem services and species may be more relevant. In Phoenix (Arizona, USA), for instance, issues related to water conservation are extremely important [29,71]. Since the GartenApp is a flexible platform rather than a static software, it can be adapted to such needs.

The results gathered with the GartenApp thus far should be interpreted with care. While they cover many parts of the city (Figure 4), the sample size is small and the kind of people who visit a 'day of urban nature' or an info booth on urban nature at the open day of the University are probably not very representative of average gardeners. This would also explain why so many biodiversity enhancing features are present (Figures 5 and 6). Thus, in a next step, the effectiveness of the GartenApp in serving as a communication tool between scientists, citizens and municipalities that can reach a wider audience and induce real-world changes should be tested. We do not expect the app to be a stand-alone tool, because, after all, direct human interaction in local communities and real-world examples are essential for change and stewardship [24,72–74], and raising awareness and appealing to values may not be enough to encourage changes in gardeners [25,71]. Of the five stimulating levers of a toolbox for garden governance described by [24], two could be supported by the GartenApp. The first lever, 'enable,' includes providing and sharing information in a simple, correct, orderly and accessible fashion. In that line, the GartenApp could enable and nudge citizens into changing garden design and management, e.g., by demonstrating how this contributes to biodiversity conservation, ecosystem service provision, or both. In fact, a common request by users was to see how their garden compares to others. Another lever, 'explore,' includes collecting data on domestic gardens for analyzing success or failures. In the GartenApp, we have started exploring the quality of the connectivity models with information provided by the gardeners.

5. Conclusions

Gardens make up large quantities of UGSs and cities cannot afford to ignore this resource. Here, we have introduced an innovative web application that makes state-of-the-art research directly available to citizens and, at the same time, allows them to contribute their local knowledge. It is based on open-source software and can be adapted to local needs. From our own experience, but also considering the literature, the GartenApp will, however, not have a big impact as a standalone tool. Instead, we view the GartenApp as a building block for the governance of gardens to overcome the 'Tyranny of Small Decisions.'

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/12/1/95/s1. Video S1: The app in action part 1; Video S2: The app in action part 2; Video S3: The app in action part 3.

Author Contributions: Conceptualization, A.-K.S. and M.W.S.; Writing—Original Draft, A.-K.S. and M.W.S.; Formal analysis A.-K.S., M.W.S. and M.A.; Software A.-K.S. and M.W.S.; Writing—Review and Editing, A.-K.S., M.W.S., M.A. and B.S.; Funding acquisition, B.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the program 'Science for Sustainable Development' of the Volkswagen Foundation and the Ministry for Science and Culture of Lower Saxony (METAPOLIS, grant No. ZN3121).

Acknowledgments: We thank the city of Braunschweig and the Regionalverband Braunschweig for providing geodata. Thanks to Andreas Dahlkamp who contributed to an early version of the GartenApp and to Julian Jentsch for setting up the servers and for technical support.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. The landscape resistance values used for the Circuitscape modelling of squirrels, based on resistance set 'R26' from [45].

Description	Resistance
Buildings	No Data
Water	1000
Agricultural land	800
Railway, roads, impervious surfaces	800
Trees	1
Shrubs	10
Grass layer	100

Table A2. The landscape resistance values used for the Circuitscape modelling of hedgehogs, based on resistances from [46].

Description	Resistance
Gardens	1
Pasture	1
Public green areas	1
Allotment gardens	1
Cemeteries	1
Deciduous forest	3
Grove	3
Sports area	5
Airfield	5
Ruderal	6
Small streets	8
Impervious	14
Paths	16
Squares	16
Opencast mining	39
Mixed Forest	50
Tram	100
Swamp	100
Highways	100
Railway	100
Coniferous forest	100
Big streets	100
Waterbodies	100
Arable land	100
Buildings	No Data
Canal	No Data

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