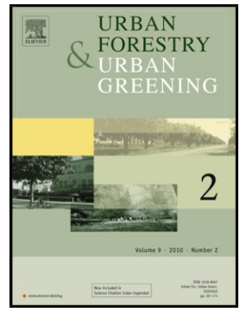
Cabral, I., **Keim, J.**, **Engelmann, R.**, **Kraemer, R.**, Siebert, J., **Bonn, A.** (2017):
Ecosystem services of allotment and community gardens: A Leipzig, Germany case study
Urban For. Urban Green. **23** , 44 – 53

http://dx.doi.org/10.1016/j.ufug.2017.02.008



Title: Ecosystem services of allotment and community gardens: a Leipzig, Germany case study

Authors: Ines Cabral, Jessica Keim, Rolf Engelmann, Roland Kraemer, Julia Siebert, Aletta Bonn

PII: S1618-8667(16)30254-0
DOI: http://dx.doi.org/doi:10.1016/j.ufug.2017.02.008
Reference: UFUG 25855

To appear in:

Received date: 16-6-2016
Revised date: 10-2-2017
Accepted date: 11-2-2017

Ecosystem services of allotment and community gardens: a Leipzig, Germany case study

Ines Cabral[1,2,3;*], Jessica Keim[1,3], Rolf Engelmann[2,3,4], Roland Kraemer[1,3], Julia Siebert[1,4], Aletta Bonn[1,3,5]

[1] *German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Deutscher Platz 5e, 04103 Leipzig*

[2] *Martin Luther University of Halle-Wittenberg*

[3] *Department of Ecosystem Services, UFZ - Helmholtz-Center for Environmental Research – UFZ, Permoserstraße 15, 04318 Leipzig*

[4] *Department of Systematic Botany and Functional Biodiversity Research, Institute of Biology, University of Leipzig, Johannisallee 21-23, 04103, Leipzig*

[5] *Institute of Ecology, Friedrich Schiller University Jena, Donburger Str, 07743 Jena*

*Corresponding author. E-Mail address: ines.cabral@idiv.de (I. Cabral)

Abstract

Allotment gardens and community gardens provide important ecosystem services to urban communities, such as local climate and water regulation, as well as habitat provision for biodiversity. Using the city of Leipzig as a case study, we assess the effect of urban gardening type and intensity of management on ecosystem services and biodiversity by comparing allotment and community gardens. Employing a stratified sampling design, we assessed 30 allotment plots of different management intensity, including vacant plots, and six adjacent community gardens along a gradient of urbanity, using in-depth field surveys, remote sensing analyses and interviews. Our results show a bimodal relationship of overall vascular plant species richness with management intensity with highest species richness in medium intensively-managed plots, as they provide space for both cultivated edible and ornamental species as well as native, spontaneous species. In comparison to allotment gardens, community gardens provide a higher ratio of permeable soil surface and a slightly higher microbial soil activity, implying important differences in water regulation and nutrient cycling properties. With regards to climate regulation, old mature trees make a considerable contribution to above ground carbon storage, but are largely restricted to communal areas of the allotment estates due to code regulation. Based on our results, we discuss the impact of allotment gardening association codes and garden type and ways forward for gardeners and urban planners to promote biodiversity and ecosystem services provision.

Keywords: Ecosystem services, biodiversity, community gardens, allotment gardens

Introduction

Urban gardens, such as allotments and community gardens, can be viewed as one of the earliest deliberate nature-based solution implementation to achieve multiple environmental and societal goals by promoting urban green spaces to provide benefits to human well-being (Bell *et al*, 2016; Kabisch *et al* 2016; Cabral *et al*, 2017). Historically, allotment gardens were set up with the primary goal to mitigate poverty by providing fresh food among factory workers during the industrial revolution or later during wars and depression times (Barthel *et al.*, 2013). In fact, the original specific goal, at least by *Schreber* (Deutsches Kleingärtnermuseum, 2001), who founded the German allotment movement in Leipzig, was actually to provide opportunities for recreation, especially for children. Recently, allotment gardens have been recognized as important assets for ecological and societal goals such as local climate mitigation, water regulation and provision of biodiversity as well as recreation, health and social cohesion in cities (Bell *et al,* 2016; Breuste and Artmann, 2015; Genter *et al,* 2015; Haase *et al,* 2014a). They form important green infrastructure islands in dense urban areas with their large extensive permeable surface areas that provide for run-off regulation and cooling through evapotranspiration (Langemeyer *et al,* 2016), and they have important roles in providing habitats for diverse species and conservation benefits to cities (Davies *et al,* 2009, Galluzzi *et al*, 2012; Goddard *et al*, 2010).

Knowledge on quantifying ecosystem services in green urban areas is still scarce but critical for planning, management and decision making (De Groot *et al*, 2010; Haase *et al*, 2014a, b). While to date much more research attention has been placed on public green spaces than private green spaces (Breuste *et al*, 2015), some key projects have also focused on assessing biodiversity in domestic gardens (Smith *et al*, 2006). Although frequently studied as being part of the domestic gardens, allotments are in need of a more thorough assessment (Borysiak *et al*, 2016). In fact, two recent studies on allotments in Manchester and Poznan (Speak *et al*, 2015; Borysiak *et al*, 2016) have provided important insights on how allotments can contribute to regulating, provisioning and cultural services. They suggest that the diversity of spontaneous flora of allotments can serve as a good bio-indicator of ecological functions (Borysiak *et al*, 2016). Other quantitative studies of community gardens have shown their importance for e.g. pollinators such as bees (Guitart *et al*, 2012), while studies on soil functions in urban gardens remain rare, apart from considerations of soil contamination regulation. Allotments differ in structure from domestic gardens, since allotments are often subject to prescriptive gardening association codes or by laws. These local and national codes also address management and usually enforce weeding on pathways and to some extent within the plot. For Germany, for example, they stipulate that at least a third of the area should be allocated to the cultivation of edible species (SLK, 2013; Federal Allotment Garden Law - *Bundeskleingartengesetz*). Regulations also forbid tall trees with large canopies within the plots. In contrast, community gardens provide a new form of gardening with less strict regulations. They are often an expression of social and political identity, with diverse users from non-profit organizations, including cultural and neighborhood groups, to schools or faith based organizations (Guitart *et al*, 2012).

While traditionally many central European cities have had large areas allocated to allotment gardens, these are threatened in some fast-growing cities due to competing land-use schemes (Keshavarz and Bell, 2016). In Leipzig, this threat is more recent and started after a period of urban shrinkage after the German reunification. In fact, allotment estates (large fenced garden estates with over 100 plots of around 400m² or less) and also community gardens (former urban voids and brownfields with an interim use for gardening) are now under threat by densification plans and activities since 2010 (Rall and Haase, 2011).

The city of Leipzig is of particular interest due to its history with the *Schreber* movement and the large number of both allotments and community gardens (Cabral and Weiland, 2016). While there have been studies in Leipzig on the contribution of allotment gardens to e.g. climate regulation (Strohbach *et al*,2012) and the contribution of community gardens to cultural services (e.g. Cabral and Weiland, 2016), this study is the first to compare the different service provisions and biodiversity of community gardens and allotment gardens.

Along a gradient of urbanity, we compare the impact of garden management type and intensity on biodiversity patterns, in particular plant species richness and composition, and ecosystems services. For ecosystem services we specifically assess supporting ecosystem services by employing soil microbial activity as a proxy for nutrient cycling and assessing habitat provision through manmade structures, provisioning services by comparing edible plant species composition and cultivation patterns between gardens, as well as regulating services by addressing climate and water regulation through assessment of above ground carbon storage properties and permeable surface area ratios in both allotment and community gardens.

Methodology

Case study area

Our study area is the City of Leipzig (Figure 1) located in eastern Germany with around 570,000 inhabitants. From 1930 to 2010, the city lost almost one third of its population due to several economic crises and political changes (Strohbach *et al.*, 2009). After 2010, economic recovery has resulted in demographic regrowth, while Leipzig still has to cope with large urban voids. Faced with the process of shrinkage, the municipality decided to use its voids for more public green spaces, including leasing vacant lots for community gardens (Rall *et al.*, 2011). The city hosts 276 allotment estates covering 1229 ha (Statistisches Jahrbuch, 2015). Overall, the city has over 23 m^2 of gardening area per inhabitant, which is one of the highest ratios among European cities (Stadt Leipzig Grünflächenamt, 2005). The general characteristics of urban gardening in Leipzig are given in Table 1.

These allotment estates host up to 22% of all shrubs and small trees of the built-up area of Leipzig, and 11% of the city´s grassland area is located in allotments (Banzhaf and Kollai, 2015). Additionally, the entire municipality features longstanding and extensive forest areas and parks, resulting in almost 121 m^2 of green space *per capita* (Banzhaf and Kollai, 2015). According to Haase *et al* (2014b) the shrinkage of the city has affected the green infrastructure and changed the ecosystems services provisioning. Since population growth has resumed in 2010, so has the pressure on urban green area structures, hence affecting biodiversity and ecosystem services.

Sampling design and plot selection

The sampling design consisted of both a broad and an in-depth survey of plots in six allotment estates and their adjacent community gardens (Table 2). We sampled plots using a stratified, spatially diverse and representative sampling design, similar to previous studies by Speak *et al* (2015) and Borysiak *et al* (2016). Estates were selected along a gradient of urbanity to study the variation of ecosystem service provision from central estates to the periphery. We selected two suburban (SU) allotment estates, two semi-urban (SM) allotment estates and two urban (U) allotment estates, defined as located less than 100 m, or more than 500m, and 1000m from the edge of the built-up area, respectively (Table 2).

For the broad survey, we mapped the management intensity of all 708 plots for each allotment estate, based on a visual assessment of the vegetation structure. We identified 3 levels of management intensity matching gardening association code enforcement classification: high intensity (compliant) plot, medium intensity (non-compliant) plot and vacant plot. A high intensity plot is defined as a plot with a high apparent level of maintenance (weeding, mowing and pruning on all available land), a medium intensity plot is usually characterized by a small (or non-existent) lawn and no evidence of mowing, i.e. significant amount of weeds, occurrence of spontaneous vegetation on pathways or even non-managed patches of land, and a vacant plot is defined as an abandoned, over-grown plot. For each allotment estate, we selected five plots for in-depth analysis consisting of two high intensity plots, two medium intensity plots and one vacant plot. While our sample of 5 plots per allotment estate is smaller than the 10 randomly selected plots by Borysiak *et al* (2016) in Poznan, our systematic and stratified selection of plots across a gradient of management intensity allows for a highly representative and in-depth sampling design.

Overall, we assessed a total of 36 plots, i.e. 6 vacant plots, 12 medium- intensity plots and 12 high-intensity plots with a total area of 0.75 ha in allotment estates, and 6 adjacent community gardens, that are structurally not subdivided into plots and that comprised a total area of 2.3 ha.

Methods for assessing biodiversity and ecosystem services

For assessing land cover and (micro) habitat provision in the gardens, we conducted field surveys in each plot to map allocation of land to the cultivation of edible plants (including berry bushes), ornamental plants (including hedges), lawns and fruit trees, as well as the proportion of sealed ground via paths or buildings as well as water bodies (such as ponds). This is in accordance with the land cover classification for Leipzig by Banzhaf and Kollai (2015). Ecological amenities or manmade structures that attract fauna (Davies *et al*, 2009) were also surveyed using field surveys. We identified stumps, beehives, insect hotels and bird houses, within the selected plots. Visual image interpretation of high resolution, multi-spectral images (aerial photos with visible light and near infrared, 3 cm resolution) collected by drone flights (senseFly Ltd`eBee drone) at an altitude of 400 m during July 2015, further allowed to assess total number of trees as well as mapping communal ponds, private ponds and pools within the gardens.

We assessed biodiversity and three main ecosystem services classes: supporting, provisioning services and regulating services, using the methods and indicators described in Table 3.

(Agro)Biodiversity - Composition and species richness of vascular flora

Survey methods for biodiversity assessments in allotments have varied in previous studies. Speak *et al* (2015), for example, assessed vascular flora across allotment plots during summer and in most cases from behind the fence. Borysiak *et al* (2016) surveyed vascular flora of allotments in all common areas and in 10 selected plots from July to September, with random selection of plots dependent on obtaining permission to enter from accidental encounters with the owners. Our survey in Leipzig was carried out strategically employing a stratified design accounting for management intensity in five plots within each of the six allotment estates, from late May to early July 2015. We accessed the plots on an appointment based schedule to allow for accompanying interviews with the owners during the visit. We conducted an in-depth field survey of vascular flora in all plots, excluding plant species that were only detectable and identifiable in spring and autumn. Individual plot sizes ranged from 120 m^2 to 400 m^2. The botanical survey was conducted separately for the three patch types (edible plant, ornamental plant and lawn area) and included all edible and non-edible vascular plant species. Within the ornamental patches, the ornamental species were only counted and not identified to the species level to reduce the workload of plant identification caused by the high number of alien species. The non-edible species were assigned to the woody life forms (trees, shrubs, subshrubs and climbers) and the herb life forms (perennial, biennial and annual). All species were also classified as alien or native according to Jäger (2011). We defined spontaneous species as species that were non-edible herbs and native in Germany. This group of species is most likely similar to the group of species known as «weeds» according to the allotment gardening association code. A list of most common plant species delineating both edible species (likely cultivated) and non-edible species is shown in Appendix A1 (Table A1.1). Other habitat structures included areas dominated by trees in the community gardens or ruderal areas in the vacant plots. In order to assess agrobiodiversity, we evaluated the surveyed species composition and in addition conducted 23 structured interviews with the gardeners of selected allotment plots.

Supporting services - Microbial activity as proxy for nutrient cycling

For investigating supporting services we assessed soil microbial activity as a proxy for nutrient cycling. We collected soil samples for each plot from three different patches: areas for edible plants, ornamental plants and lawn. The samples were collected within two weeks in June 2015, using a soil core sampler with 2 cm diameter and 10 cm drill depth. In total, 87 samples from allotment gardens and 18 samples from community gardens were analyzed for microbial activity. The samples were sieved through 2 mm before microbial assessments in the laboratory. To quantify soil microbial activity, pH measurements were conducted and soil microbial parameters were measured using an O_2 microcompensation apparatus (Scheu, 1992). Basal respiration (ml O_2 h^{-1} per g soil dry mass) was determined without the addition of substrate, and measured as the mean of the O_2 consumption rates 17–23 h after the start of the measurements. Soil microbial biomass (µg C g^{-1} per g soil dry mass) was determined by using a substrate-induced respiration (SIR) method, adding glucose as a substrate.

Climate regulation – Above-ground carbon storage in trees

In order to understand the role played by urban allotments in climate regulation, we surveyed all six allotment estates by mapping all mature trees (over 5m tall) and classified them into deciduous/fruit and evergreen trees. Following similar studies by Strohbach *et al* (2012) for domestic gardens based on Jenkins *et al* (2003), we assessed above-ground carbon storage in trees for two allotment estates at the opposing ends of the urbanity gradient and differing average plot sizes: an urban allotment estate *Mariannengärten* with small plots (average size of 150 m^2 per plot), and a suburban allotment estate *Naturfreunde* with large plots (average size of 400 m^2 per plot). Mature trees for the selected five plots and the allotments' playgrounds or communal areas were identified as mixed hardwood or softwood trees and tree stem perimeter was measured at breast height. Applying the parameters shown in Table 4, we calculated biomass by applying the following allometric equation by Jenkins *et al* (2003).

$$bm = Exp\,(\beta 0 + \beta 1\, ln\,.\,dbh) \qquad [\mathrm{Kg}]$$

For both allotment estates we then calculated the above-ground carbon stock of the five plots of each estate and its common playground and estimated the above-ground carbon storage in trees for the remaining plots. For this we assumed different parameters for deciduous/fruit trees and conifer trees (Jenkins *et al*, 2003; Table 4) and multiplied those values by the total number of similar trees in each allotment estate (cf. Appendix A3).

Statistical analysis for biodiversity, land cover and soil microbial activity (nutrient cycling)

In order to quantify and compare the species richness in the vacant, medium and high intensive plots, we used the concept of Hill numbers, also known as the effective number of species (see Chao *et al*, 2014 for a recent review). We used a sample-size-based rarefaction (represented by solid lines, c.f. Figure 4a and 4b) and extrapolation curves (represented by dashed lines, up to double the reference sample size, c.f. Figures 4a and 4b) for Hill number q=0 (corresponds to species richness). The 95 % confidence intervals were obtained by a bootstrap method based on 200 replications. To compute and plot seamless rarefaction and extrapolation sampling curves we used R with the package iNEXT (Hsieh, Ma and Chao, 2016) with the assumption that the compared plots are almost equal in size.

To analyze differences in proportional land cover of different vegetation patches in the garden plots, we used linear models with arcsin transformation of the dependent variable (Sokal and Rohlf, 1994). First, we analyzed the differences between the three allotment garden management intensity types (high, medium, abundant) and community gardens, using F Tests (Anova) for the independent variable. In case of a significant difference, we analyzed pairwise comparisons using t-tests with Tukey correction.

To analyze the soil data, we used linear mixed effect models (R version 3.2.2 with the packages lme4 and nlme). The different gardens were incorporated as a random effect. First, we analyzed the differences between allotment gardens and community gardens. Then, within allotment gardens we tested the effects of distance from the edge of the built-up area, vegetation patch (edible plants, ornamental plants, lawn) and management intensity level.

Results

Across the total of 708 plots of the 6 sampled allotments estates, a visual assessment of intensity identified the majority of plots as high-intensity plots (73 %), with a lower number of medium-intensity plots (25 %) and only few vacant plots 2%. The number of medium-intensity plots tended to increase along the urban-suburban gradient (Figure 3).

Habitat provisioning through manmade structures

The number of manmade habitat provisioning structures and microhabitats (ponds, stumps, insect hotels, bird houses) was higher in the suburban allotment plots than in the urban plots. Other supporting structures like livestock shelters, beehives and stone walls, were only provided in community gardens. Hedges were common in both garden types and provide bird nesting spots and winter refuge.

Biodiversity - species richness and distribution patterns

For allotment gardens, we surveyed a total area of 0.75 ha in 30 plots (6 vacant, 12 medium and 12 high intensity) and recorded 290 edible and non-edible plant species (excluding number of species within the ornamental patches) including 140 spontaneous species. For community gardens, we surveyed a total area of 2.3 ha and recorded 255 edible and non-edible plant species, including 157 spontaneous species. Total species richness for the surveyed allotment plots was highest in medium intensity plots with a total of 221 species recorded (Figure 4a), including 110 spontaneous species.

Species richness of spontaneous species was up to twofold higher in vacant and medium intensity plots compared to high intensity plots (Figure 4b) The community garden data on species richness was not conclusive, since plot sizes differed greatly (ranging from 0.1 ha to 1.4ha) and thus brought challenges for comparative analyses due to species-area relationships.

The most common spontaneous species in the surveyed plots were grass species like *Lolium perenne* followed by *Taraxacum sect. ruderalia* and *Oxalis corniculata* (see Appendix A1). The most common fruit trees were apple *Malus domestica* and cherry trees *Prunus avium* and *P.cerasus* (considered as mixed hardwood for biomass calculation) and the most common coniferous trees were spruce *Picea abies* and cedar *Chamaecyparis lawsoniana* and *Thuja occidentalis* (considered as softwood for biomass calculation) (see Table 4 and Appendix A1). In order to gauge the attitude of gardeners towards spontaneous species, we asked them whether they kept wild or unmanaged areas in their garden. More than 60 % of allotment gardeners denied this, while keeping unmanaged areas was an important feature for all community gardeners.

The proportional area per plot allocated to cultivation patches for edible and ornamental species or lawn as well as structures, such as paths and buildings, differed significantly with regards to garden management type and intensity (Figure 5). There was a significant difference between all plots for the proportional area allocated to edible species cultivation ($F_{3/32}$ = 4.03, p = 0.015) with significant pairwise differences only between high intensity plots and vacant plots ($t_{32\ AGhigh\text{-}AGvacant}$=2.860, p= 0.035) as well as for vacant plots and community garden plots (t_{32} =2.747, p= 0.046). There was also a significant difference between all plots for the proportional allocation of area of ornamental species ($F_{3/32}$ = 12.390, p < 0.001) and lawn ($F_{3/32}$ = 16.535, p < 0.001). Pairwise comparisons showed significant differences between community gardens and all allotment plot types for proportional allocation of patch sizes for both ornamental species ($t_{32\ CG\text{-}AGhigh}$ = 5.699, p < 0.001; $t_{32\ CG\text{-}AGmedium}$ = 5.136 , p < 0.001; $t_{32\ CG\text{-}AGvacant}$ = 2.811, p = 0.040) and for lawn ($t_{32\ CG\text{-}AGhigh}$ = 6.893, p < 0.001; $t_{32\ CG\text{-}AGmedium}$ = 4.433, p < 0.001; $t_{32\ CG\text{-}AGvacant}$ = 2.817, p = 0.040). In addition, there were significant differences between the different allotment management intensities for lawn area, i.e. between high and medium intensity plots ($t_{32\ AGhigh\text{-}AGmedium}$= 3.013 p < 0.025) as well as high intensity and vacant plots ($t_{32\ AGhigh\text{-}AGvacant}$ = 3.641 p < 0.005). There was no significant spatial area representation difference for fruit trees. Naturally, these distribution parameters are linked, while the comparisons clearly demonstrate the focus on food species cultivation and less attention to ornamental species cultivation for community gardens, while high intensity allotment plots devote almost equal area to the cultivation of edible, ornamental and lawn vegetation patches, thereby complying with allotment code regulations. Time and resource intensive cultivation of edible and ornamental species take less spatial precedence in medium intensity and vacant plots.

Supporting services - Soil microbial activity as proxy for nutrient cycling

Allotment gardens and community gardens differed significantly in their microbial basal respiration rate ($p= 0.048$) with community gardens showing higher basal respiration than allotment gardens. We could not detect significant differences in soil parameters across the different management intensity types among allotment plots (vacant, medium and high). The type of vegetation patch (edible, ornamental, lawn) from where the soil samples were taken within one allotment garden plot had a significant effect on microbial biomass ($p = 0.004$, Appendix A2). Highest microbial biomass was found on lawn areas, lowest microbial biomass on edible areas. Also the water content was significantly influenced by the vegetation patch type ($p = 0.0038$). Edible areas showed the highest values for soil water content, while lawn showed the lowest values. The location of gardens in the city had a significant effect on soil pH ($p = 0.019$) and a marginally significant effect on soil water content ($p = 0.055$) in allotment gardens. In both cases the highest values were found in semi-urban gardens, the lowest values in suburban gardens. For details see Appendix A2.

Food provision – Spatial allocation of patch sizes and species composition of edible species

As reported above and shown in Figure 4, spatial allocation of patches for food species cultivation was similar for community gardens and high and medium intensity allotment plots. Here, we employed land cover as a proxy for food provision, as we could not ascertain a reliable estimate of food yield from field surveys or interviews. The detailed botanical survey showed that the number of edible species grown in allotments and community gardens was 93 and 98, respectively (Appendix A1, Figure A.1.1), however with different species composition. While vegetable species contributed to less than half of all edible species in community as well as in allotment garden plots, allotments tended to have a higher diversity in fruit tree cultivation, while the variety of culinary and medicinal herbs tended to be higher in community gardens.

Climate regulation – Above-ground carbon storage through trees

Mapping mature trees (above 5 m high) across all 6 allotment estates showed an overall predominance of deciduous trees in garden plots, mostly fruit trees (Figure 6), and a higher abundance of trees in suburban than urban allotment estates. Trees within plots were often small (max height of 5m) because of regular pruning according to the allotment regulation codes. Therefore, each tree contributes little for carbon storage and climate regulation. In the allotments communal areas and playgrounds, however, both evergreen and deciduous trees (mostly non-edible) were on average larger and had bigger canopies, allowing for shading and local cooling.

In our study, we calculated the carbon storage per hectare exemplified for two allotment estates by surveying all trees across all plots. The above-ground carbon storage was estimated at 4.3 ton C per ha for the urban *Mariannengärten* estate, and 7 ton C per ha for the suburban *Naturfreunde* estate (c.f. Appendix A3).

Water regulation – Distribution of permeable surfaces

We used permeable surface area as proxy for water retention and infiltration potential of stormwater run-off. Our assessment showed that allotments have a lower ratio of permeable surface (around 65-75%) in comparison to community gardens with a much larger ratio (around 95%). There was a significant difference between all plots for the proportional area of impermeable area, consisting of paths ($F_{3/32} = 13.60$, $p < 0.001$) and buildings ($F_{3/32} = 6.041$, $p = 0.002$) with significant pairwise differences between community garden plots and all allotment plots regardless of management intensity for path area ($t_{32\ CG\text{-}AGhigh} = 6.340$; $t_{32\ CG\text{-}AGmedium} = 4.405$; $t_{32\ CG\text{-}AGvacant} = 4.312$, all $p < 0.001$). For proportional ground cover of buildings there were significant differences between community gardens and high and medium intensity allotment plots ($t_{32\ CG\text{-}AGhigh} = 4.136$, $p = 0.001$; $t_{32\ CG\text{-}AGmedium} = 3.496$, $p = 0.007$) but no significant difference to vacant plots. As community gardens are not subdivided into individual plots, they have fewer buildings per area. Our results are within the range of land-cover classification derived through remote sensing by Banzhaf and Kollai (2015) for all allotments in Leipzig, who could show that overall allotments were composed of 5% mature trees (above 5 m), 48% shrubs and small trees, 20% grass area, 26% non-vegetated ground, such as paths and buildings, thus allowing for 74% of permeable surface area. Waterbodies can also play an important role for water retention. We recorded several private ponds and communal ponds in both allotments and community gardens that can also contribute to local cooling in urban areas through evaporation.

Discussion

Our study shows significant differences in biodiversity patterns and ecosystem services provision between allotment and community gardens (Table 5) and with respect to management intensity in allotment gardens.

Urban gardens can function as a rich harbor for biodiversity. Allotment gardens in Germany have been recorded to host over 2000 crop and ornamental species (BDG, 2008), both native and exotic. Although numerous studies show a prevalence of exotic species (Smith *et al*, 2006; Bigirimana *et al*, 2012; Jaganmohan *et al*, 2012), we can show that species richness of native or spontaneous species can also be high in allotments, contributing to two thirds of all species. In our study we recorded 290 edible and non-edible species that included 140 spontaneous species (48%) with field surveys in 0.75 ha across 6 allotment estates. This ratio of spontaneous species is slightly less than results in recent studies in Manchester and Poznan (Speak *et al,* 2015; Borysiak *et al*, 2016). Speak *et al* (2015) recorded a total of 87 vascular and cultivated species, 70% of which were native within 9 allotment estates (1.5 ha) and Borysiak *et al* (2016) recorded a total of 357 species, of which 256 (72%) were spontaneous across 11 allotment estates (3.5 ha). Allotment gardens can therefore be considered as biodiversity hotspots for native species within urban green infrastructure (Borysiak et *al*, 2016).

Overall, the high number of plant species shows the importance of both allotments and community gardens for urban biodiversity due to the high diversity of microhabitats offered by gardens (Goddard *et al,* 2010; Speak *et al,* 2015; Smith *et al,* 2006). This is in line with remote sensing studies in Leipzig that mapped a high structural and morphological diversity for allotment gardens (Banzhaf & Kollai, 2015) hosting a large amount of shrubs and therefore providing ideal conditions for breeding birds or insects. In addition, manmade structures for fostering native fauna are abundant. Here, community gardens tended to provide more diverse microhabitats than allotments, such as habitats for amphibians (ponds and stone walls), beehives and livestock shelters.

Management intensity, however, can significantly affect plant species richness and composition. For allotment plots in our study, species richness exhibited a bimodal function with management intensity with highest species richness in medium intensity plots compared to low intensity (vacant) and high intensity plots. Plots managed at medium intensity levels offer high structural complexity and a variety of microhabitats, thereby providing the best synergies between a near-natural environment with habitat provision for native species and an anthropogenic space for cultivating a high variety of edible and ornamental species, which maximizes species richness. Too restrictive gardening management according to allotment codes or bylaws, however, can affect the distribution of spontaneous plant species and large trees and may ultimately reduce native species richness and associated services. This result has implications for code enforcement by garden associations and urban planning. Indeed, our interviews showed that most allotment gardeners did not necessarily value 'wild' areas and the occurrence of spontaneous plant species in their gardens, while for community gardeners this was a welcome aspect of their garden design and management.

Allotment and community gardens can also foster genetic agrobiodiversity, similar to domestic gardens (Galluzzi *et al*, 2010). Our study shows that allotments produce as many crop varieties as community gardens. They differ with respect to herb varieties that are more pronounced in community gardens and fruit varieties that are cultivated to a larger extent in allotments. This variation may be due to the different history of use, i.e. fruit trees take time to grow and many community gardens have been established only quite recently, the oldest being 20 years old. Thereby, allotment and community gardens contribute as an important green space feature in the urban landscape fostering the cultivation of agrobiodiversity, a feature of biodiversity not often considered in urban conservation management. Agrobiodiversity conservation, with an emphasis on the maintenance of landraces in urban gardens can provide important opportunities for gene bank conservation (Barthel *et al*, 2013).

While allotment gardens have recently become more recreation (Breuste and Artmann, 2014) and health driven (Genter *et al*, 2015), also with respect to food production through horticulture valued as a means for both enjoyment and stress reduction (Hawkins *et al*, 2011) as evident from our interviews with gardeners, they have in the past provided important services by ensuring food security during crises (Barthel *et al*, 2013; Buhtz *et al*, 2008; Camps-Calvet *et al*, 2015) and continue to do so globally in many cities. In fact, Leipzig allotment gardens supplemented food to grocery stores due to foot shortages before 1989 as reported in the interviews with gardeners. More recently, from 2007 to 2011, around 10 % of gardens have also provided fresh horticultural produce for food banks, an initiative funded by the City of Leipzig through the social project “*Tafelgärten in Kleingartenvereinen*” (Cabral and Weiland, 2016).

Investigation on the below-ground effect of management intensity, shows that a) community gardens have a higher soil basal respiration rate than allotment gardens; and that b) less-managed patches (lawn) within allotment gardens have generally a higher microbial biomass than patches for edible and ornamental species. Surprisingly, however, the management intensity levels itself within allotments seemed to have no influence on the measured soil parameters. Possibly, the visually assigned management intensity categories were too broad for measuring actual levels of disturbance relevant for below-ground processes. Soil water content, although leading to strong significant effects within allotment gardens, may be a weak variable, since watering in gardens is likely to be done rather selectively, i.e. plants that are known to require a lot of water are watered more often, leading to biased results. Furthermore, only weak correlations were found between overall plant species richness and soil microbial activity (c.f. Appendix A2, Figure A2.5). Spontaneous plant species richness showed a weak positive relationship with soil microbial biomass, indicating that some of the positive feedback mechanisms between above-ground plant diversity and below-ground microbial activity that have been reported for other study systems (e.g. Lange *et al,* 2015) hold also true for urban gardens.

Gardening in allotments has always depended on rainwater harvesting and ground water. Since the City of Leipzig detected water contamination in ground water in some allotment estates (Stadt Leipzig, 2005), public water supply has been provided to most allotment estates. Nevertheless, our assessment shows that rainwater harvesting is still common in all allotment gardens and quite popular among community gardens. This allows for sustainable irrigation to take place.

By using remote sensing image analysis we were also able to verify that within the 6 surveyed allotment estates, swimming pools are more common than (artificial) ponds, and that most are found within suburban allotment estates. As for larger communal ponds, only two were recorded, one in a suburban allotment estate (*Naturfreunde*) and another in a semi-urban community garden (*Stadtgarten Connewitz*).While the former are important for recreation and individual well-being and cooling, water bodies in general also contribute to local cooling through evapotranspiration and to run-off retention. A greater representation of ponds, e.g. in common areas of allotments, could therefore allow for enhanced recreational opportunities and microclimate regulation, as well as for providing microhabitats for a range of species such as fish and aquatic wildlife that indirectly also impacts on terrestrial species composition (Knight *et al*, 2005).

The contribution of allotments to climate regulation through carbon storage and sequestration is limited due to a strict code imposed by the allotments association that forbids large canopies and tall trees in plots. Nevertheless, allotment estates can host a significant number of trees and in some cases even very large trees in their playgrounds or communal areas. Since allotments codes determine for trees to be pruned to prevent shading in adjacent plots (Stadtverband Leipzig der Kleingärtner, 2003), larger plots are more likely to host taller trees. Accordingly, we found a higher ratio of mature trees per area within suburban allotment estates which have comprehensively larger plots. In fact the total number of mature trees ranged from 19.8 trees/ha in urban estates, to 30.2 trees/ha in suburban estates, including trees within the communal playground area, thereby increasing the estates' contribution to above-ground carbon storage and climate regulation. Ultimately, larger plot sizes or a relaxation in bylaw regulations in urban allotments could potentially increase the abundance and size of trees and thus maximize climate regulation capacities of urban gardens.

According to Strohbach *et al* (2012) and based on their canopy coverage assessment, above-ground carbon storage in urban gardens (including both domestic gardens and allotments) can amount to over 14 t C/ ha. In our estimation, based on stem measurements taken in 5 plots per allotment estate, carbon storage in mature trees in the urban allotment estate was estimated at only 4.3 t C/ ha for the urban estate and at around 7 t C/ ha for the suburban estate. Both values are lower than in the previous study in Leipzig. These differences may be due to the fact that we did not consider shrubs, a considerable vegetation type in allotments, as all plots are supposed to be enclosed by hedges or fences according to code regulation.

Allotment and community gardens can play an important role in water regulation similar to other urban green spaces by enhancing water infiltration through unsealed soils to absorb rainwater and reducing surface run-off from storm water in dense urban areas. In all our surveyed gardens, the amount of permeable surface area was large and thereby provides an important asset to water regulation in the city. Sealed ground through tracks, paths and buildings contributed to around 25%-35% of allotments area, whereas community gardens comprised less than 5% sealed ground. We observed that on communal allotments' paths, obligatory weeding enforced by the code regulation, led at times to impervious surfaces, limiting potential water infiltration. Therefore, an ease on code regulation could promote more water infiltration and spontaneous species distribution, simultaneously. In addition, due to their spatial arrangement in the city, allotments in Leipzig may also contribute to water retention in case of flooding events (Strohbach *et al*, 2012). Since the City of

Leipzig is located on a floodplain, and allotments are commonly located close to canals, these are usually affected by floods and can serve as retention areas.

Conclusions and Outlook

Our study shows that allotment gardens and community gardens in Leipzig provide important biodiversity and ecosystem services, with significant differences between services provisioning across garden types. The contribution of each garden type critically depends on the degree of management intensity and to some extent on its location within the city. As for management intensity, we showed that plots that are less compliant to garden association codes exhibit a higher overall and spontaneous species richness and a higher soil microbial activity that supports nutrient cycling. Thus, a loosening of gardening codes could foster and enhance biodiversity conservation by e.g. allowing for less weeding as well as promoting native species within the plots (or even tolerating vacant plots) and ultimately fostering wild areas within common spaces. In comparison to allotment gardens, community gardens are more prone to foster native, spontaneous plant species and, coupled with this, exhibit higher soil microbial activity due to less intensive cultivation measures, indicating higher soil nutrient cycling. Our study provides novel data with regards to climate and water regulation potential mediated through large trees and permeable surfaces on allotment estates and community gardens, identifying their contribution to above-ground carbon storage and run-off or flood mitigation. We hope this information can inform city planners with important pointers for fostering the contribution of allotments and community gardens towards enhanced provision of native biodiversity and ecosystem services in urban areas.

Acknowledgements

We would like to thank all gardeners for allowing us to survey their gardens and for providing valuable information through their interview statements. We are also grateful to Ulrich Pruschitzki for reviewing the carbon storage assessment and to Volker Grescho, Christian Langer and Dirk Mikolajewski for assistance in data recording and analysis. Finally, we would like to thank all reviewers for their attentive comments and to Henrique Pereira for supporting this project.

References

1. Banzhaf, E., Kollai, H., 2015. *Monitoring the Urban Tree Cover for Urban Ecosystem Services -The Case of Leipzig, Germany*. ISPRS -International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-7/W3, 301–305.

2. Barthel, S., Parker, J., Ernstson, H., 2013. *Food and green space in cities: a resilience lens on gardens and urban environmental movements*. Urban Studies: 0042098012472744

3. Bell, S., Fox-Kämper, R., Keshavarz, N., Benson, M., Caputo, S., Noori, S., Voigt, A. (eds.), 2016. *Urban Allotment Gardens in Europe*. Routledge, London.

4. Bigirimana, J., Bogaert, J., De Cannière, C., Bigendako, M.-J., Parmentier, I., 2012. *Domestic garden plant diversity in Bujumbura, Burundi: role of the socio- economic status of the neighborhood and alien species invasion risk*. Landscape and Urban Planning, 107:118–126.

5. Borysiak, J., Mizgajski, A., Speak, A., 2016. *Floral biodiversity of allotment gardens and its contribution to urban green infrastructure*. Urban Ecosystems: doi:10.1007/s11252-016-0595-4

6. BDG, 2008. *Artenvielfalt -Biodiversität der Kulturpflanzen in Kleingärten.* Bundesverband Deutscher Gartenfreunde, Berlin.

7. Breuste, J., Artmann, M., 2015. *Allotment Gardens Contribute to Urban Ecosystem Service: Case Study Salzburg, Austria*. Journal of Urban Planning and Development, 141(3): A5014005

8. Buhtz, M., Lindner, M., Gerth, H., 2008. *Städtebauliche, ökologische und soziale Bedeutung des Kleingartenwesen,* Forschungen, 133. Bundesamt für Bauwesen und Raumordnung: Bonn.

9. Cabral, I., Weiland, U., 2016. *Urban gardening in Leipzig and Lisbon: a comparative study on governance and resilience*. Proceedings of the Conference «Growing in cities: Interdisciplinary perspectives on urban gardening», COST action TU1201: Basel.

10. Cabral, I., Costa, S., Weiland, U., Bonn, A., 2017. Urban gardens as multi-functional nature-based solutions for societal goals in a changing climate. In: Kabisch, N., Stadler, J., Korn, H., Bonn, A. (eds.). *Nature-based solutions to climate change adaptation in urban areas - Linkages between science, policy, and practice*. Springer, Berlin.

11. Camps-Calvet, M., Langemeyer, J., Calvet-Mir, L., Gomez-Baggethun, E., March, H., 2015. *Sowing resilience and resistance in times of crisis: the case of urban gardening movements in Barcelona*. Partecipazione e Conflitto, 8: 417-442.

12. Chao, A., Gotelli, N. J., Hsieh, T. C., Sander, E. L., Ma, K. H., Colwell, R. K., Ellison, A. M., 2014. *Rarefaction and extrapolation with Hill numbers: A framework for sampling and estimation in species diversity studies*. Ecological Monographs, 84: 45–67.

13. Davies, Z. G., Fuller, R. A., Loram, A., Irvine, K. N., Sims, V., Gaston, K., 2009. *A national scale inventory of resource provision for biodiversity within domestic gardens*. Biological Conservation, 142: 761-771.

14. De Groot, R.S., Alkemade, R., Braat, L., Hein, L., Willemen, L., 2010. *Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making*. Ecological Complexity, 7: 260–272.

15. Deutsches Kleingärtnermuseum, 2001. *Deutschlands Kleingärtner vom 19. zum 20. Jahrhundert*. Deutsches Kleingärtnermuseum, Leipzig.

16. Galluzzi, G.s, Eyzaguirre, P., Negri, V., 2010. *Home gardens: neglected hotspots of agro-biodiversity and cultural diversity*. Biodiversity and Conservation, 19: 3635-3654.

17. Genter, C., Roberts, A., Richardson, J., Sheaff, M., 2015. The contribution of allotment gardening to health and wellbeing: A systematic review of the literature. British Journal of Occupational Therapy, 78 (10), 593–605.

18. Goddard, M., Dougill, A., Benton, T., 2010. *Scaling up from gardens: biodiversity conservation in urban environments*. Trends in Ecology and Evolution, 25: 90-98.

19. Guitart, D., Pickering, C., Byrne, J., 2012. *Past results and future directions in urban community gardens research*. Urban Forestry & Urban Greening, 11: 364–373.

20. Haase, D., Larondelle, N., Andersson, E., Artmann, M., Borgström, S., Breuste, J., Gomez-Baggethun, E., Gren, Å., Hamstead, Z., Hansen, R., Kabisch, N., Kremer, P., Langemeyer, J., Rall, E.L., McPhearson, T., Pauleit, S., Qureshi, S., Schwarz, N., Voigt, A., Wurster, D., Elmqvist, T., 2014a. *A Quantitative Review of Urban Ecosystem Service Assessments: Concepts, Models, and Implementation.* Ambio, 43: 413-433.

21. Haase, D., Haase, A., Rink, D., 2014b. *Conceptualizing the nexus between urban shrinkage and ecosystem services.* Landscape and Urban Planning, 132: 159-169.

22. Hsieh, T., Ma, K., Chao, A., 2016. iNEXT: an R package for rarefaction and extrapolation of species diversity (Hill numbers). Methods in Ecology and Evolution: doi:10.1111/2041-210X.12613

23. Hawkins, J.L., Thirlaway, K.J., Backx, K., Clayton, D.A., 2011. *Allotment gardening and other leisure activities for stress reduction and healthy aging*. HortTechnology 21, 577-585.

24. Jäger, E.J., 2011. *Rothmaler - Exkursionsflora von Deutschland*. Springer Spektrum Berlin.

25. Jaganmohan, M., Vailshery, L.S., Gopal, D., Nagendra, H., 2012. *Plant diversity and distribution in urban domestic gardens and apartments in Bangalore, India*. Urban Ecosystems, 15: 911–925.

26. Jenkins, J. C., Chojnacky, D. C., Heath, L. S., Birdsey, R. A., 2003. *National-scale biomass estimators for United States tree species*. Forest Science, 49: 12–35.

27. Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., Haase, D., Knapp, S., Korn, H., Stadler, J., Zaunberger, K., Bonn, A., 2016. *Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action*. Ecology and Society, 21.

28. Keshavarz, N., Bell, S., 2016. A history of urban gardens in Europe. In: Bell, S., Fox-Kämper, R., Keshavarz, N., Benson, M., Caputo, S., Noori, S., Voigt, A. (eds.). *Urban Allotment Gardens in Europe*. London, Routledge, pp. 8−32.

29. Knight, T., McCoy, M., Chase, J., M., McCoy, K., and Holt, R., 2005. *Trophic cascades across ecosystems*. Nature, 437: 880-883.

30. Lange, M., Eisenhauer, N., Sierra, C. A., Bessler, H., Engels, C., Griffiths, R. I., Mellado-Vazquez, P. G., Malik, A. A., Roy, J., Scheu, S., Steinbeiss, S., Thomson, B. C., Trumbore, S. E., Gleixner, G., 2015. *Plant diversity increases soil microbial activity and soil carbon storage*. Nature Communications, 6: 6707.

31. Langemeyer J., Latkowska M.J., Gómez-Baggethun E.N., 2016. Ecosystem services from urban gardens. In: Bell, S., Fox-Kämper, R., Keshavarz, N., Benson, M., Caputo, S., Noori, S., Voigt, A. (eds.). *Urban Allotment Gardens in Europe*. Routledge, London, pp. 115-141.

32. Rall, E., Haase, D., 2011. *Creative intervention in a dynamic city: a sustainability assessment of an interim use for brownfields in Leipzig, Germany*. Landscape and Urban Planning, 100: 189-201.

33. Scheu, S., 1992. *Automated measurement of the respiratory response of soil microcompartments: active microbial biomass in earthworm feces*. Soil Biology and Biochemistry, 24: 1113-1118.

34. Smith, R. M., Thompson. K., Hodgson, J. G., Warren, P.H., Gaston, K, J., 2006. *Urban domestic gardens (IX): Composition and richness of the vascular plant flora, and implications for native biodiversity*. Biological Conservation, 129: 312-322.

35. Sokal, R.R., Rohlf, F.J., 1994. *Biometry: The Principles and Practice of Statistics in Biological Research*. Stony Brook University, Freeman and Company, New York.

36. Speak, A., Mizgajski, A., Borysiak, J., 2015. *Allotment gardens and parks: Provision of ecosystems services with an emphasis on biodiversity*. Journal of Urban Forestry & Urban Planning, 14: 772-781.

37. SLK, 2013. *Kleingärtenordnung*. Stadtverband Leipzig der Kleingärtner e.V.- http://stadtverband-leipzig.de/de/gesetze-und-verordnungen.html?download=14:kleingartenordnung-des-stadtverbandes-leipzig-der-kleingaertner-2013 (accessed 10 Oct 16)

38. Stadt Leipzig Grünflächenamt, 2005. *Kleingärtenkonzeption*. Stadt Leipzig Grünflächenamt, Leipzig.
39. Statistisches Jahrbuch, 2015 Available in http://www.leipzig.de/news/news/druckversion-des-statistischen-jahrbuches-2015-liegt-vor/
40. Strohbach, M., Haase, D., 2012. *Above-ground carbon storage by urban trees in Leipzig, Germany: analysis of patterns in an European city.* Landscape and Urban Planning, 104: 95–104.
41. Strohbach, M., Haase, D., Kabisch, N., 2009. *Birds and the city: urban biodiversity, land use, and socioeconomics*. Ecology and Society, 14 (2): 31

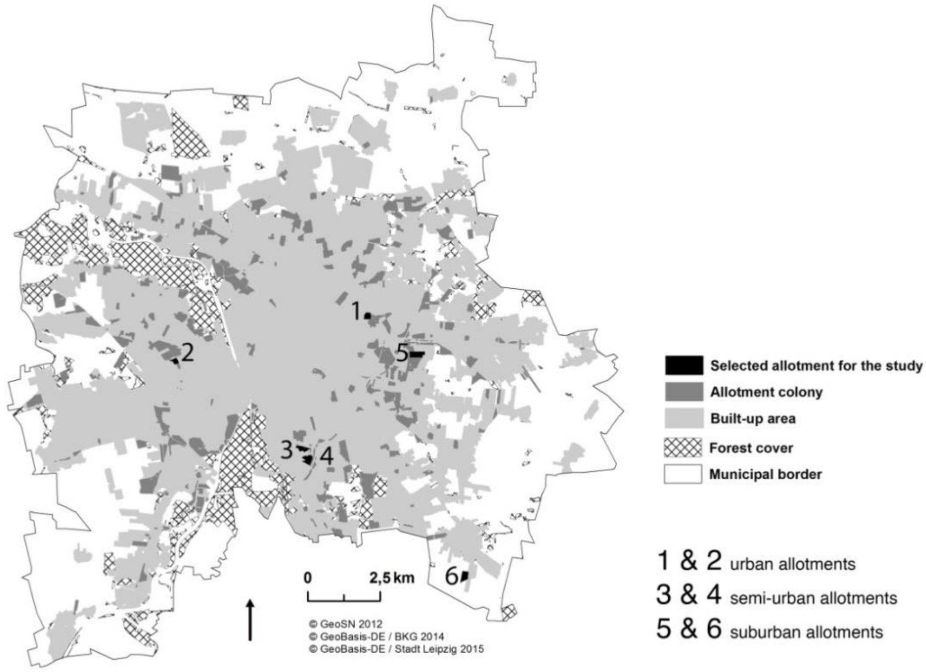


Figure 1.Location of all allotment estates and the surveyed estates within Leipzig, Saxony (Germany). For an interactive map please check: www.gartenwerkstatt-leipzig.de

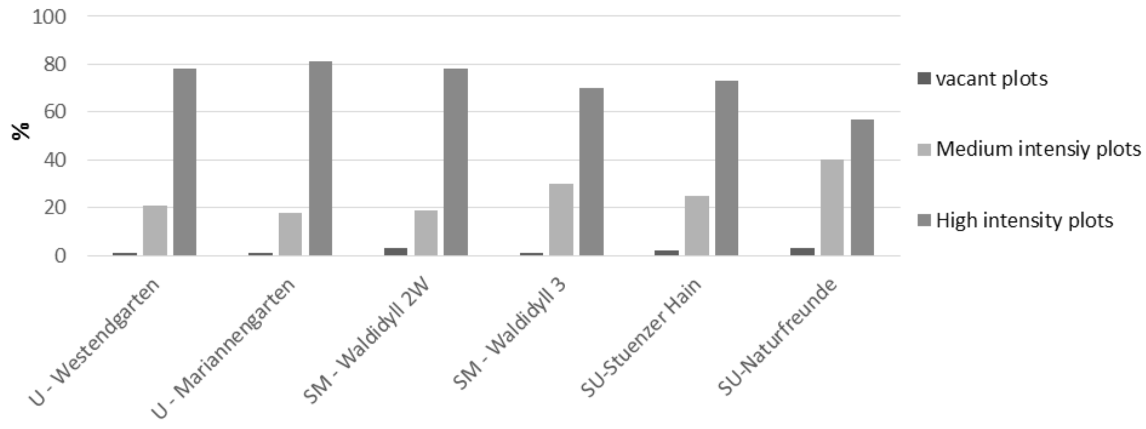


Figure 3. Ratio of management intensity plots per allotment estates (total 708 plots, 6 estates). The allotment estates are arranged along an urban-suburban gradient from left to right (U-urban, SM-semi urban, SU-suburban).

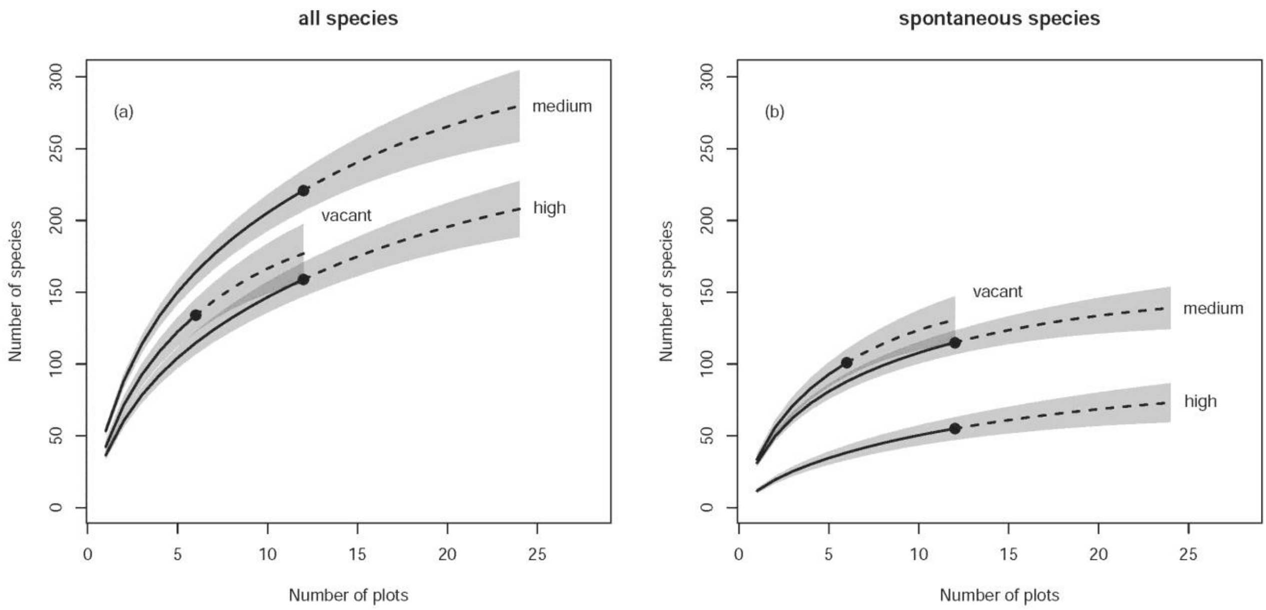


Figure 4. Comparison of a) overall species richness and b) spontaneous plant species richness, across different management intensity type plots in allotments. (Note: all plant species richness includes edible and non-edible species, but excludes species from the ornamental patches; spontaneous species includes all non-edible herbal species. The dashed line represents an extrapolation. Grey areas represent 95 % confidence intervals.)

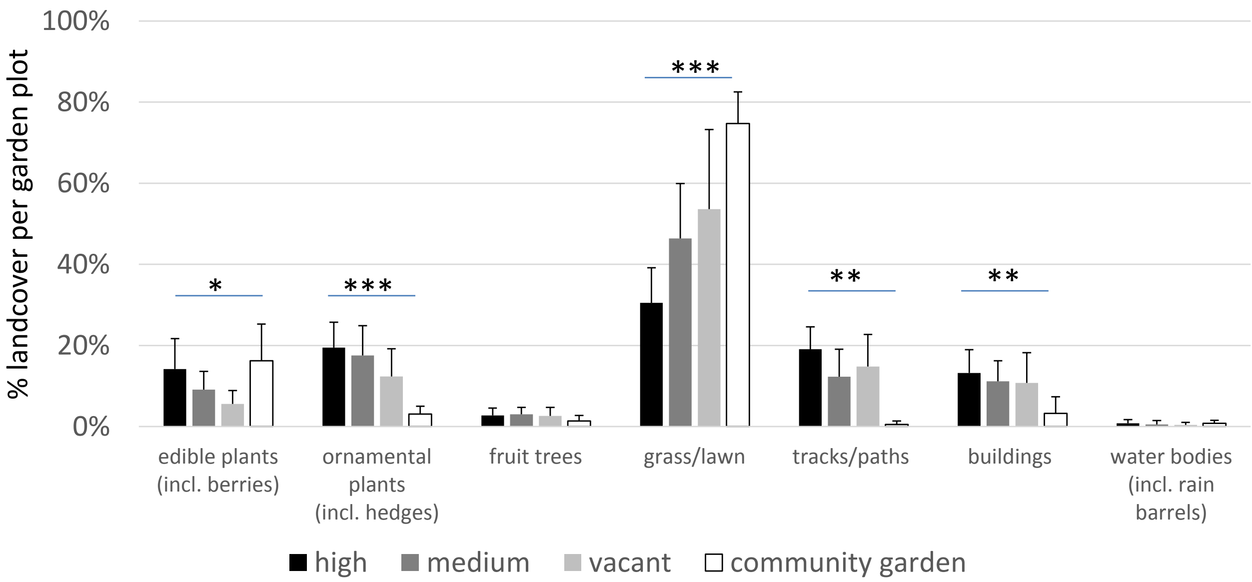


Figure 5: Distribution of land cover across different garden management types (allotment gardens with high, medium and vacant plots and community gardens). Note: Asterisks above the bars refer to the significance (of difference) between all plots, so pairwise significance is not indicated in the figure (* equals $P \leq 0.05$; ** equals $P \leq 0.01$; * equals $P \leq 0.001$).**

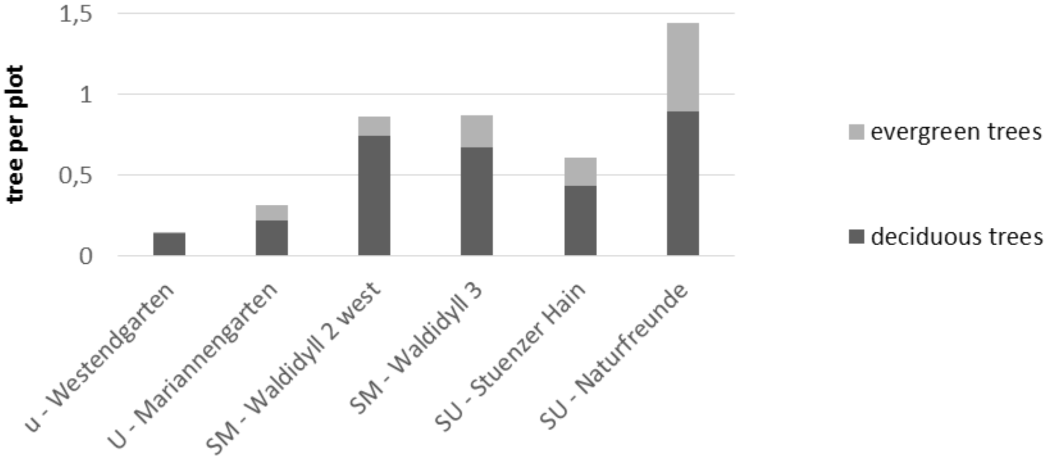


Figure 6. Abundance of mature trees per plot across a urban-suburban gradient (U -urban, SM – semi-urban, SU – suburban)

Table 1. Characteristics of the two urban gardening types in Leipzig (2015)

	Total Area (ha)	**Proportion of city area (%)**	**Gardening area *per capita* (m^2)**	**No. of gardens**	**Garden age range (years)**	**Average Size (ha)**	**Range of plot[1] size (m^2)**
Allotment gardens (estates)	1229	4	23	276	50-150	4	120-400
Community gardens	6.1	-	-	8	1-20	0.7	870-7,000

[1] the term plot is used as a property unit, i.e. a single garden plot within an allotment estate

Table 2. Characteristics of allotment gardens (AG) and community gardens (CG) selected along a gradient of distance to the edge of built-up area

Allotment garden estates (AG)	**Area of AG (ha)**	**No. of plots**	**Adjacent Community Garden (CG)**	**Area of CG (ha)**	**AG´s distance to edge of built-up area (m)**
SU-Naturfreunde	6	120	Ernte mich	1.4	0 (suburban)
SU-Stuenzer Hain	5	120	Solidarische Feldwirtschaft	0.7	0 (suburban)
SM-Waldidyll 3	3.2	135	Stadtgarten Connewitz	0.43	600 (semi-urban)
SM-Waldidyll 2 (west side)	2.5	110	VAGaBUND	0.14	600 (semi-urban)
U-Westendgärten	2.7	155	Annalinde	0.12	1400 (urban)
U-Mariannengärten	2.7	168	Querbeet	0.87	1200 (urban)

Table 3. Methods employed to assess ecosystem services

Ecosystem service	**Method**	**Indicator**
Supporting services		
Habitat provision	Onsite field surveys and aerial imagery collected by drone flights for mapping land cover	Land cover and manmade structures, such as ponds, rainwater deposits, stumps, beehives, insect hotels and bird houses
Biodiversity	In-depth botanical surveys (one per plot)	Species richness and distribution patterns
	Questionnaires/interviews with gardeners on gardening techniques	Willingness to provide space for spontaneous species / weeds
Nutrient cycling	Soil microbial activity: basal respiration and microbial biomass; soil water content	Microbial activity as proxy for nutrient cycling
Provisioning services		
Food provision	In-depth botanical surveys and land cover mapping	Species composition and proportional land cover of edible plant species patches
Regulating services		
Climate regulation	Tree distribution of mature trees (> 5m height) across all allotments; stem diameter measurements for trees for 2 allotment estates.	Above-ground carbon storage in trees
Water regulation	Field surveys of land cover	Permeable surface cover as proxy for water infiltration potential

Table 4. Parameters for estimating tree biomass (Jenkins *et al*, 2003)

		Parameters		max *dbh*
		β_0	β_1	(cm)
Hardwood	Soft maple	-1.9123	2.3651	66
Mixed hardwood	Oak	-2.4800	2.4835	56
Softwood	Cedar	-2.0336	2.2592	250

bm = total aboveground biomass (kg) for trees 2.5 cm and larger
dbh = diameter at breast height (cm)
Exp = exponential function
Ln = natural log base "e" (2.718282)

Table 5. Comparison of ecosystem service provision and biodiversity in allotment and community gardens

Ecosystem service	Allotment gardens	Community gardens
Supporting		
Habitat provision	Less variety of manmade habitat structures	Higher variety of manmade habitat structures
	Highest species richness in plots with medium management intensity	
Nutrient cycling	Soil microbial activity dependent on land cover (highest in lawns)	Enhanced soil microbial activity compared to allotments
Provisioning Services		
Food provision	Cultivation of edible species highest in plots of high management intensity	Cultivation of edible species comparable to high and medium intensity allotment gardens
	Equal number of crop varieties as community gardens	
	Higher fruit species richness	Higher herb species richness
Regulating Services		
Climate regulation	Tree carbon storage highest in communal areas and limited in garden plots due to species selection and/or pruning	N/A
	Higher tree above-ground carbon storage in suburban plots with larger plot sizes	N/A
Water regulation	65-75% permeable surface area	95 % permeable surface area

N/A - not available