Urban biodiversity and carbon sinks - Do they overlap? Case study of Helsinki Metropolitan Area, Finland.

Kinnunen, A.

2022

Kinnunen , A & Lampinen , J 2022 , ' Urban biodiversity and carbon sinks - Do they overlap? Case study of Helsinki Metropolitan Area, Finland. ' , IOP Conference Series: Earth and Environmental Science , vol. 1101 , no. 2 , 022005 . https://doi.org/10.1088/1755-1315/1101/2/022005

http://hdl.handle.net/10138/355550
https://doi.org/10.1088/1755-1315/1101/2/022005

PAPER • OPEN ACCESS

Urban biodiversity and carbon sinks – do they overlap? Case study of Helsinki Metropolitan Area, Finland.

To cite this article: A Kinnunen and J Lampinen 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1101** 022005

Urban biodiversity and carbon sinks – do they overlap? Case study of Helsinki Metropolitan Area, Finland.

A Kinnunen[1], **J Lampinen**[2]

1 Aalto University Department of Built Environment, Otakaari 4, 02150 Espoo, Finland
2 University of Helsinki, Department of Economics and Management, Faculty of Agriculture and Forestry, Latokartanonkaari 7, 00790 Helsinki, Finland

antti.e.kinnunen@aalto.fi

Abstract. Amongst the greatest global environmental challenges of our time are climate change and biodiversity loss. Feedback mechanisms associated with warming climate could also lead to large-scale biodiversity losses worldwide and it would therefore be logical to seek mitigation methods beneficial for both impact categories. However, research on the topic remains relatively scarce. Our study focuses on two key aspects of environmental sustainability, carbon storage capacity and species biodiversity, to determine whether these correlate at different levels of urban density. GIS-datasets are utilized to estimate the carbon storage potential and species diversity across the urban landscape as well as their association at different levels of urban land use intensity. The results highlight the importance of small green spaces at dense urban cores, indicating that in environments where green infrastructure is limited high species diversity and carbon storage are more likely to overlap, whereas at urban fringe the observed relationship is weaker and divergence of the two impact categories becomes more probable. The study draws attention to the role fragmented, limited green spaces play at establishing functioning ecosystems at local scale and provides new information to support the development of sustainable planning and management practices across the urban land use gradient.

1. Introduction

Traditional views on urban planning have emphasized density as prime metric for sustainability. However, some notable research has challenged this perspective, highlighting the importance of green spaces amidst grey city infrastructure in maximizing urban environment's ecosystem function and service potential [1, 2]. Urban planning in Finland has employed the concepts of 'garden cities' and 'forest suburbs' introduced by Sir Ebenezer Howard (1850-1928) and Dr. Otto-Iivari Meurman (1890-1994) respectively, combining elements from international urban green space planning with local natural environment [3]. Hence, they encompass compact planning practices accounting for both built and natural perspectives of the associated living environment and thus make Finland a prime candidate to study the potential of environmental benefits in urban setting.

Individually, the topics of urban carbon sequestration and storage and biodiversity have gained increasing interest in the scientific subject literature during the early 21st century. Overlap between urban carbon sinks and biodiversity has also been touched upon previously in a handful of studies e.g., [4-6] yet existing research has largely focused on either of the two impact categories at a relatively small spatial scale. As such, regional scale studies focusing on the statistical association of urban carbon sinks and biodiversity remain scarce.

The aim of this research was to address a current gap in literature by examining the overlap between carbon sinks and biodiversity in the urban landscape. To achieve this the study focused on two metrics, estimated total carbon storage of public green areas and number of species for selected taxonomic groups to analyse their association across the urban density gradient, operationalized via floor area ratio (FAR). The research hypothesis was that the statistical association between carbon sinks and species diversity would be stronger at urban core areas, where the available green space is scarcer and gradually diminish towards the urban fringe, where abundant green space allows for the divergence of these two impact categories. To the author's knowledge, this work is the first of its kind carried out on a metropolitan, intercity level encompassing the whole surrounding urban landscape.

2. Materials and methods

2.1. Study area and sites

The study area was the Helsinki Metropolitan Area in southern Finland, including the capital city of Helsinki, and the surrounding cities of Espoo, Kauniainen, and Vantaa as well. The study area is located in hemiboreal climate and vegetational zone in its entirety and encompasses a wide range of natural habitats from marine littoral zones to evergreen inland forests.

A spatial grid consisting of standard 1 km^2 cells was laid over the study area to establish individual study sites for which the biodiversity and carbon storage metrics were analysed based on pre-existing data. The number of study sites was delimited based on urban density and species diversity metrics laid out in the following related subchapters. The final study sites ($n = 385$) along with the overall study area are presented in figure 1.

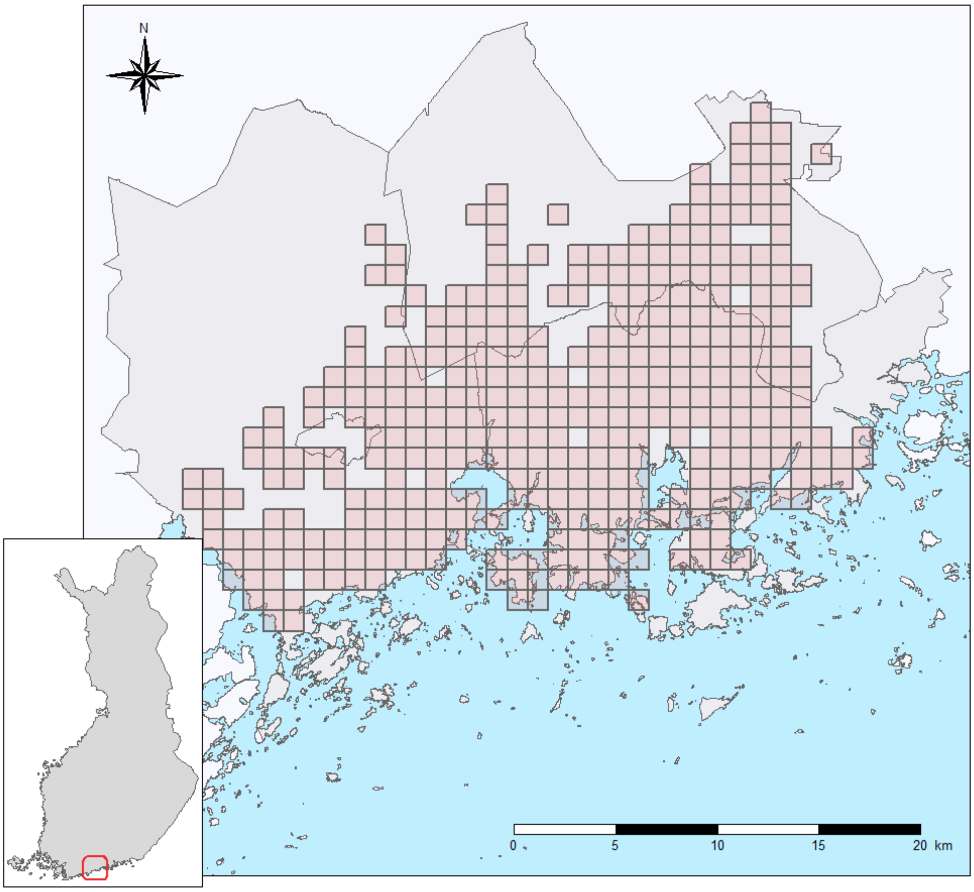

Figure 1. Location of Helsinki Metropolitan Area in Finland (red square, index map) and study sites represented by 1 km^2 coloured in grid cells [7].

2.2. *Species diversity*

The species diversity dataset utilized in the study was downloaded from the Finnish Biodiversity Information Facility utilizing the R-package finbif version 0.6.1 [8]. For this study, observations on vascular plants, bryophytes, and fungi and lichen informal taxonomic groups were utilized. The data was downloaded on 1st of September 2021. The minimum spatial accuracy of an individual observation was set to 1 km and record reliability to reliable or unassessed. The subsequent dataset was further delimited temporally by filtering out observations made prior to the year 2010 to reflect current trends in regional land use.

The resulting dataset was spatially subset by the study site grid and sites with less than 20 overall observations were dropped to limit extremely observation poor sites out of the analysis. Finally, individual species amount per study site, or the so-called α-diversity was summarized based on scientific taxon names.

2.3. *Urban density*

For this study, floor area ratio (FAR) was utilized as an indicator of urban density [9]. FAR was calculated by dividing the total floor area of an individual study site with the grid cell surface area. As a preliminary measure, sites with FAR less than 0.05 were dropped from the analysis, as they were perceived to no longer reflect urban land use form but rather the zone of transition between urban periphery and rural hinterland of dispersed settlements, typical for the Finnish urban-rural landscape gradient. The sites were then subsequently divided into FAR based density classes of equal sample size representing high, mid-high, mid-low, and low levels of urban density. The class cut-off points occurred at approximately 0.3, 0.17, and 0.11 FAR, respectively.

2.4. *Carbon storage*

The carbon storage dataset utilized in the study was based on GIS-data on publicly maintained green spaces estimated carbon sequestration and storage potential published by Helsinki Region Environmental Services [10]. This dataset included a wide array of different green spaces from old urban remnant forests to open fields and park lawns. The calculation of the CSS potential was based on GIS-data on forest inventories and green space maintenance classifications, which were then complimented with forestry and land cover data from the Finnish Forest Centre, Natural Resources Institute of Finland and Helsinki Region Environmental Services. The description of the materials and methodology utilized for the estimation can be found in more detail from the related final report (in Finnish) [11].

The total carbon storage per green space was transformed to carbon density by calculating green space surface area and dividing the carbon storage with it. The green spaces were then spatially subset with study site grid and surface areas for the resulting polygons calculated again. The previously calculated carbon densities were used to estimate the total amount of carbon stored in tonnes by public green spaces per study site utilizing equation 1:

$$\frac{(\sum_{i=0}^{n} i = t * A)}{1000} \quad (1)$$

where t = average carbon density of individual green space in kg/m2, A = surface area of individual green space polygon in m2 and n = total number of green spaces per study site. The descriptive statistics and ranges of the utilized variables are presented in Table 1.

Table 1. Descriptive statistics of the variables utilized for calculating the total carbon storage of study sites.

Variable	Min	1st Q	Median	Mean	3rd Q	Max
t	0.01	0.027	0.032	0.033	0.038	0.113
A	1.0	17.8	33.0	182.1	70.7	586719.2
n	250	3218	4132	4039	4851	6892
Tot. C storage (t)	0.75	14.58	20.33	21.58	27.44	98.33

2.5. *Statistical analysis* The data was tested for normality by utilizing Shapiro-Wilk standardized test as well as visual examination of histograms and quantile-quantile plots, and for homogeneity of variance utilizing Levene's test with sample median. NMDS analysis with ordination plots was applied to visualize the similarity of species communities' composition between the FAR based urban density classes.

Both Shapiro-Wilk's test results and visual inspection of the data indicated non-normal distributions for species α-diversity as well as total carbon storage across study sites and urban density classes. Thus, Spearman's rank correlation coefficient was utilized to estimate the statistical association between the two impact categories. Results of Levene's test indicated that the variance of species α-diversity across study sites did not significantly differ between FAR based density classes but did for total carbon storage. As numerous assumptions of standardized analysis of variance were violated for both dependent variables, non-parametric Kruskal-Wallis test was utilized instead to test for statistically significant differences between them across the urban gradient. Post-hoc Dunn's tests with Benjamini-Hochberg adjustment were utilized when applicable to determine the pairwise differences across density classes.

3. Results

The results of the study showed that green space surface area per study site and size of individual green spaces increased drastically from the urban core towards the low development sites. This was reflected in total carbon storage amounts, which exhibited a similar pattern. Interestingly, however, species α-diversity did not correlate with the observed trend in green space metrics, remaining virtually identical across the urban gradient. Statistical association between carbon storage and species diversity was comparatively high at sites of high-mid urban development before completely vanishing at the peri-urban fringe area.

3.1. *Green space association with FAR*

Both study site total green space surface area and average surface area by maintenance class, a rough indicator of habitat type, decreased sharply with increasing FAR from urban fringe towards the core ($r_s = -0.562$, $p < 0.001$*** and $r_s = -0.442$, $p < 0.001$***, respectively). The number of individual public green spaces per study site was not heavily affected by FAR, but nevertheless slightly increased with it ($r_s = 0.091$, $p = 0.7$) and the average size of individual green space clearly decreased with increasing FAR ($r_s = -0.485$, $p < 0.001$***).

3.2. *Carbon storage and species α-diversity*

Estimated total carbon storage in the study area varied from 0.75 to 98.33 t C per site. Carbon storage was negatively associated with urban density, with highest storage amounts occurring at urban periphery and Spearman's rho indicating a clear negative correlation ($r_s = -0.46$, $p < 0.001$***). The increase in carbon storage with decreasing density was evident in the boxplots and Kruskal-Wallis test results as well, which indicated that the total amount of carbon stored per study site tended to increase towards the urban fringe (figure 2). The subsequent Dunn's test results indicated that the difference in total carbon storage median value was significant between all of the established urban density classes.

Observed species α-diversity ranged from 15 to 522 across study sites. Unlike total carbon storage, species diversity was not associated with FAR ($r_s = 0.03$, $p > 0.5$), reflected by the Kruskal-Wallis test results (figure 2). As Kruskal-Wallis test indicated no significant differences between the FAR based density classes, post-hoc Dunn's test was not performed. NMDS ordination implied that the species community composition was relatively similar across the urban density gradient, with slight divergence from the norm for the high density class and greatest difference in average community composition between high density and low density sites. The intraclass β-diversity (dissimilarity of species communities across individual sites) was alike for all density classes with average similarity values ranging from 0.45 to 0.53 (figure 3).

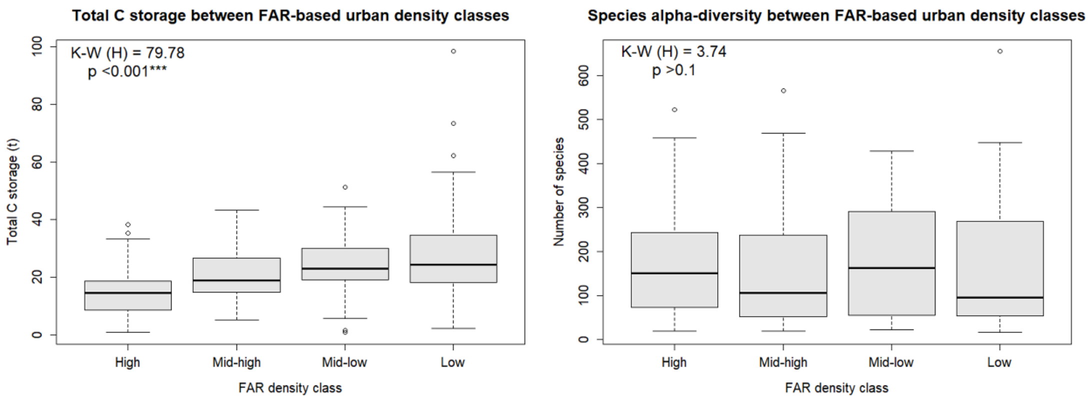

Figure 2. Boxplots of total carbon storage and species α-diversity across FAR-derived urban density classes and results of the Kruskal-Wallis test (upper left corner). Black horizontal lines reflect the medium value of observations, grey boxes to the 25-75 quartile range.

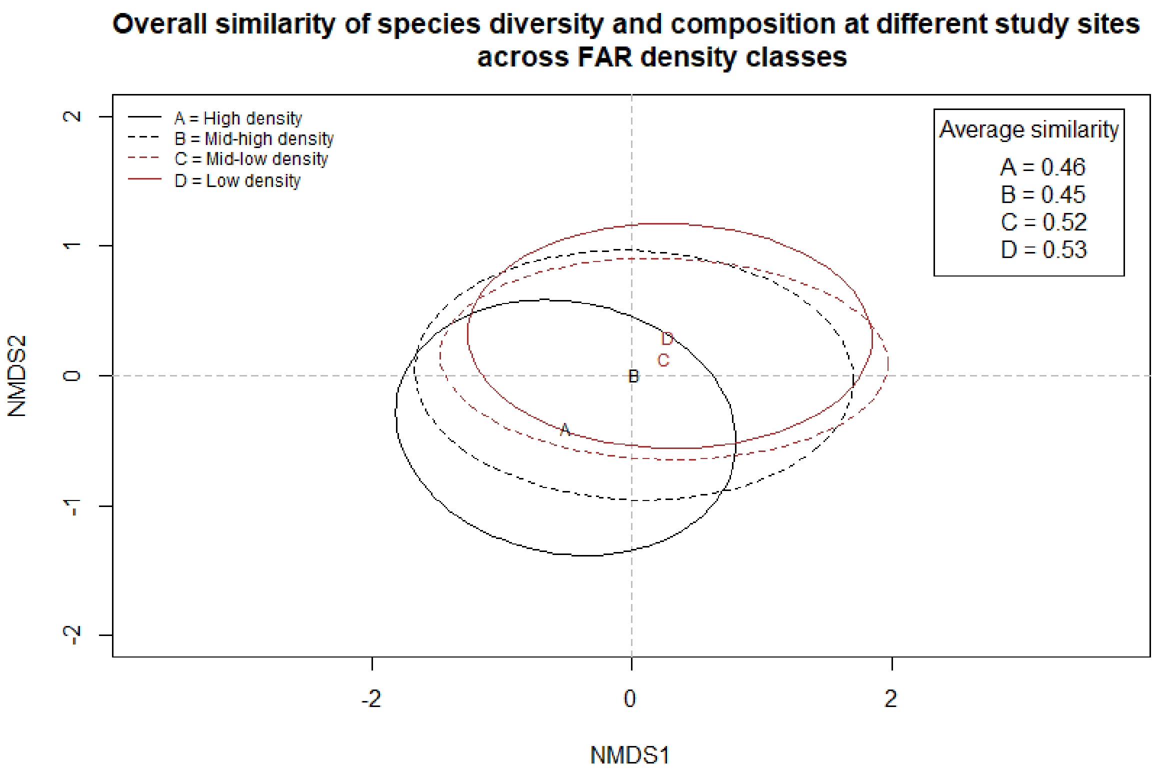

Figure 3. NMDS ordination plot. The diagonal of the ellipse reflects the variability in species composition across study sites and overlap between two separate ellipses the similarity in their overall γ-diversity. Intraclass average similarity values reflecting the species β-diversity are presented in the upper right corner.

3.3. Overlap between carbon storage and species diversity

The statistical association between species α-diversity and total carbon storage was delicate but distinguishable across the whole study area ($r_s = 0.182$, $p < 0.001$***). When examined individually across FAR based urban density zones, the relationship grew stronger at high-, mid-high- and mid-low density sites, and vanished completely at the low density class (figure 4). Correlation coefficients were comparable across the three most urban categories, with statistical significance indicating a slightly weaker relationship for the mid-low density class. The observed correlations were of weak to medium strength and contained high estimate uncertainty, but accounting for the uncontrolled study setting and high sample size the related interpretations could be made with fair confidence.

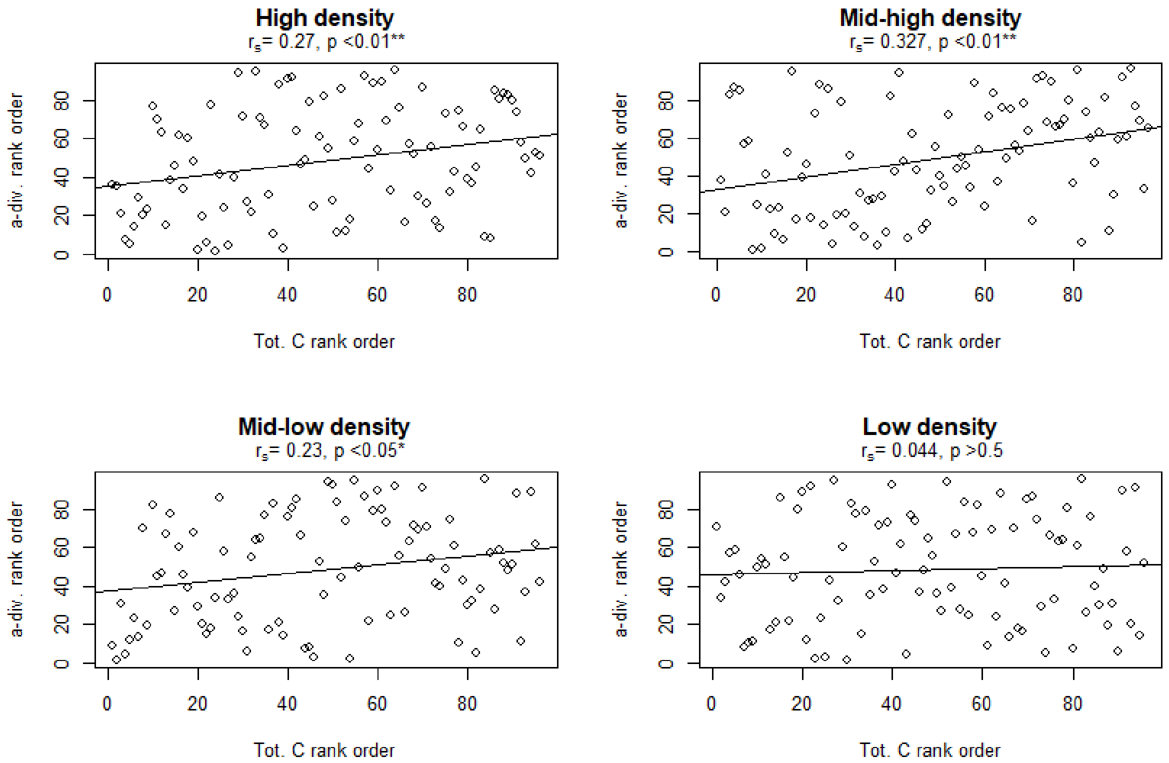

Figure 4. Statistical association between rank orders of total carbon storage and species diversity at different levels of FAR based urban density.

4. Discussion and conclusions

The aim of this research was to examine the relationship and potential overlap between total carbon storage and biodiversity of selected informal taxonomic groups. The research hypothesis was that the overlap of the two impact categories would be positively correlated with urban density, being strongest at high density core areas, and steadily decrease when moving towards the peri-urban sites.

The observed correlations indicated a significant overlap of the two impact categories across most of the urban landscape. Correlation between carbon sinks and high biodiversity was stronger at sites of intensive urban development but remained relatively constant across the study area before collapsing at urban fringe. Thus, the strength of statistical association did not gradually diminish with urban density as initially presumed but rather exhibited a strong stepwise drop. However, for the most part a clear overlap of urban carbon sinks and biodiversity can be interpreted from the results. The research hypothesis was as such partially realized. Although the correlation coefficients were generally weak, they can be deemed sufficient to draw the proposed conclusions, accounting for the limitations and uncertainties present in the data.

The non-existent association between carbon storage and species biodiversity at urban fringe is likely explained by the greater individual ecosystem size and connectivity at sites of low housing density, where vast areas of herbaceous vegetation such as meadows could be more common. These might host great species biodiversity, especially in the case of herbaceous vascular plants but lose in carbon storage capacity to sites with greater aboveground storage potential. Furthermore, as both the proportion of green land cover surface area and surface area by public maintenance class tended to increase with decreasing urbanization, the results could indicate that the observed correlation between high carbon storage and species diversity is driven by individual habitat size and fragmentation. This was further supported by the decrease of individual green space size and slight increase in total number of green spaces with increasing density. As total available green space becomes scarcer and quantity of individual green spaces increases, spaces with relatively high carbon storage and biodiversity could be more likely to co-occur at the same 1 km^2 study sites. Hence, in this study setting the driving force behind the association of carbon storage and species biodiversity at urban environment could be interpreted as resource scarcity.

Species γ-diversity and community composition were relatively similar across all density zones, which could indicate that the same habitats are present in zones of different urban land use intensity. Interestingly, the observed increase in total green space area per study site with decreasing urban density did not translate to increases in α-diversity, although generally increasing ecosystem size has been argued to lead to increase in local species diversity [12]. The result can be interpreted to present a special case of the habitat amount hypothesis suggested by [13], where the total species richness of a sample site is more dependent on the cumulative area of individual habitat patches than on any individual patch surface area. As urban environment is generally characterized by mosaic-like heterogeneity of land cover [14] the individual habitats likely occur in smaller patches in dense areas and could thus be more probable to co-occur at the same 1 km^2 study sites. Even as larger habitats hold a greater number of ecological niches and hence species per ecosystem, the overall species diversity is likely evened out across the urban gradient via increasing ecosystem heterogeneity per study site with higher degree of urbanization. In other words, smaller green space size could make it more probable for multiple diverse macrohabitats to occur at same study sites, whereas in urban fringe they are more likely to occur at large as individual ecosystems. At urban fringe the individual habitats could very well host more species per ecosystem, but at the studied spatial scale this did not translate to increases in the observed α-diversity. Increasing site-wise habitat heterogeneity makes it also more probable for relatively high value green spaces in one or both impact categories, species diversity and carbon storage, to co-occur at the same study sites. The results can thus be interpreted to highlight the importance of small green spaces in urban landscape, as they can support a diverse array of ecosystem services at the local scale [15].

It needs to be emphasized that the results should not be interpreted to favour small green patches at heavily urbanized environments at the expense of large green spaces at urban fringe and beyond. These vast and better-connected green areas host larger carbon stocks and likely also contribute disproportionally to sustaining the regional species pool. However, the smaller green spaces at zones of intensive urban development likely provide to green corridors that allow the dispersal of peri-urban species deeper towards the urban cores, enabling population transfer along the urban gradient and thus improving the fitness of related metapopulations in the fragmented landscape [16, 17]. As such their importance to the overall urban ecosystem health and function should not be underestimated and their value needs to be recognized in urban planning.

The study setting included some data related uncertainties. As carbon storage amounts were derived from estimations rather than actual field measurements the associated measurement error could have been pronounced. However, the error was likely similar across the urban gradient. In addition, species observations were compiled from multiple independent sampling campaigns across a range of years and as such could have been subject to numerous reliability and validity issues regarding sampling intensity, methodology and reporting of the results. This was addressed in the study by utilizing crude species observations instead of indices of diversity as a metric for estimating site-wise α-diversity, as the internal validity of indices could not have been ensured. However, as the site-wise γ-, β- and α-diversities were relatively similar between the FAR-derived density classes there was no reason to suspect that these uncertainties varied across the urban gradient. Hence the utilization of the data to estimate the association of total carbon storage and species diversity across the urban land use gradient was justified.

In this study, the biodiversity aspect mainly encompassed aboveground terrestrial ecosystems, with belowground organism communities represented only partly by the inclusion of the fungal taxonomic group. However, as recent evidence points to the importance of belowground biodiversity in providing to the overall ecosystem health and services [18, 19], future studies on the subject could extend the scope to include belowground macro- and micro-organism communities in more detail as well. The data available for this study was limited, as belowground organism communities remain far less studied than aboveground ones and are thus underrepresented in the Finnish Biodiversity Information Database.

Only one metric of urban density, FAR, was utilized in this study to reflect the intensity of urban land use. However, urban infrastructure comprises of more elements than just buildings and in the future the association between carbon storage and species diversity could be studied more thoroughly utilizing multiple measures better encompassing the whole nature of built environment. For example, areas utilized mainly for transportation and industrial purposes may contain high proportions of impervious surfaces that further increase the fragmentation of urban green, despite containing relatively low indices of FAR. Furthermore, as the results could be interpreted to reflect the impact urban landscape small-scale heterogeneity has on the association between carbon storage and biodiversity future research could inspect this relationship further by including perhaps the most prominent providers of small-scale heterogeneity in urban green, residents of the city. The green space data utilized in this study was limited to public areas, whereas private residential yards and gardens have been estimated to contribute approximately 35-50 %, even up to 85 % to the overall urban green infrastructure with substantial impact for both city-wide carbon storage and biodiversity [4, 20, 21, 22]. Therefore, a clear gap was present in the study setting in this regard and future studies on the subject could also include the role private green plays in contributing to this relationship.

In conclusion, the results of this study highlight the importance of small-scale heterogeneity and green patches in dense urban zones for species biodiversity and urban carbon sink conservation, whereas at urban fringe landscape scale variation likely caused the divergence of the two impact categories. The relationship was not linear however, as carbon sinks and biodiversity overlap followed a relatively similar pattern across the urban gradient only to completely vanish at the urban fringe. The implication of the results is that carbon sinks and biodiversity hotspots tend to overlap in the urban environment and increasing density makes this association more probable, but not in a linear fashion. However, more research on the subject is needed to better understand the observed trend.

References

[1] Whitford V, Ennos A R and Handley J F 2001 "City form and natural process" - indicators for the ecological performance of urban areas and their application to Merseyside, UK *Landscape and Urban Planning* **57** 91-103
[2] Fuller R A and Gaston K J 2009 The scaling of green space coverage in European cities *Biology Letters* **5** 352-55
[3] Hautamäki R and Donner J 2021 Modern living in a forest – landscape architecture of Finnish forest suburbs in the 1940s-1960s *Geografiska Annaler: Series B, Human geography* DOI: 10.1080/04353684.2021.1989320
[4] Cameron R W F, Blanusa T, Taylor J E, Salisbury A, Halstead, A J, Henricot B and Thompson K 2012 The domestic garden – its contribution to urban green infrastructure *Urban Forestry & Urban Greening* **11** 129-37
[5] Schmitt-Harsh M, Mincey S K, Patterson M, Fischer B C and Evans T P 2013 Private residential urban forest structure and carbon storage in a moderate-sized urban area in the Midwest, United States *Urban Forestry & Urban Greening* **12** 454-63
[6] Tresch S, Moretti M, Le Bayon R-C, Mäder P, Zanetta A, Frey D and Fliessbach A 2018 A gardener's influence on urban soil quality *Frontiers in Evironmental Science* **6** 1-17
[7] National Land Survey of Finland. Helsinki Metropolitan Area municipalities and Finland GIS data [GPKG]. National Land Survey of Finland; 2021 [cited 10 Nov 2021] Available from: https://tiedostopalvelu.maanmittauslaitos.fi/tp/kartta
[8] Finnish Biodiversity Information Facility. Species data [CSV]. Finnish Biodiversity Information Facility; 2021 [cited 1 Sep 2021] Downloaded via R package finbif version 0.6.1, also availabe on request from: https://laji.fi/en
[9] Cities' building surveying departments. Building data [WFS]. Helsinki Region Environmental Services; 2020 [cited 21 Oct 2021] Available from: www.avoindata.fi/en
[10] Simosol Ltd., Tapio Ltd. and Ramboll Ltd. Carbon sink mapping of Helsinki metropolitan area [WFS]. Helsinki Region Environmental Services; 2021 [cited 10 Nov 2021] Available from: https://www.hsy.fi/en/environmental-information/open-data/
[11] Simosol Ltd., Tapio Ltd. and Ramboll Ltd. 2021 *Estimation of the Carbon Sinks and Storages of*

Helsinki Metropolitan Area – Final Report (Helsinki: Helsinki Region Environmental Services)
[12] Lawton J H 1999 Are there general laws in ecology? *Oikos* **84** 177-92
[13] Fahrig L. 2013 Rethinking patch size and isolation effects: the habitat amount hypothesis *Journal of Biogeography* **40** 1649-63
[14] Cadenasso M L, Pickett S T A and Schwarz K 2007 Spatial heterogeneity in urban ecosystems: reconceptualizing land cover and a framework for classification *Frontiers in Ecology and the Environment* **5** 80-8
[15] Wintle B A et al. 2018 Global synthesis of conservation studies reveals the importance of small habitat patches for biodiversity *PNAS* **116** 909-14
[16] Hanski I 2011 Habitat loss, the dynamics of biodiversity, and a perspective on conservation *Ambio* **40** 248-55
[17] Rybicki J and Hanski I 2013 Species-area relationships and extinctions caused by habitat loss and fragmentation *Ecology Letters* **16** 27-8
[18] Bardgett R D and van der Putten W H 2014 Belowground biodiversity and ecosystem functioning *Nature* **515** 505-11
[19] Wagg C, Bender S F, Widmer F and van der Heijden M G A 2014 Soil biodiversity and soil community composition determine ecosystem multifunctionality *Proceedings of the National Academy of Sciences of the United States of America* **111** 5266-70
[20] Allinson D et al. 2016 Measurement and analysis of household carbon: the case of a UK city *Applied Energy* **164** 871-81
[21] Goddard M A, Dougill A J and Benton T G 2010 Scaling up from gardens: biodiversity conservation in urban environments *Trends in Ecology & Evolution* **25** 90-8
[22] Rudd H, Vala J and Schaefer V 2002 Importance of backyard habitat in a comprehensive biodiversity conservation strategy: a connectivity analysis of urban green spaces *Restoration Ecology* **10** 368-75

Acknowledgement
The study was funded by the Strategic Research Council at the Academy of Finland (Co-Carbon 335201; 336238).