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Research Paper

Mapping public support for urban green infrastructure policies across the biodiversity-climate-society -nexus

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HIGHLIGHTS

- Strong public support for UGI policies that advance climate benefits.
- Public willing to trade-off well-being benefits, but not biodiversity, for climate.
- Values, access to UGI explain support for different outcomes across the BCS -nexus.
- Frequent use of urban forests correlates with support for climate outcomes.
- New method for targeting climate, biodiversity, and well-being outcomes in UGI.

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ABSTRACT

Urban green infrastructure can help cities tackle biodiversity loss and support well-being, but also contribute to climate change mitigation. This can be enhanced with green infrastructure policies that favor biodiversity, residential well-being, or climate benefits such as carbon sequestration. However, assessing public support for policies favoring specific green infrastructure outcomes, or potential trade-offs between them, is vital to understanding the social implications that such policies may have upon implementation. This paper presents the results of a public participation GIS (PPGIS) survey ($n = 3\,237$) in Helsinki, Finland, concerning public support for policies favoring diverse climate, biodiversity, and well-being outcomes in green infrastructure. The results of the survey, derived with spatial and aspatial analyses, indicate that urban residents strongly support green infrastructure policies that favor climate benefits such as carbon sequestration, and are more willing to compromise the well-being benefits, rather than the biodiversity, of green infrastructure in favor of climate benefits. The results also reveal how support for policies favoring different green infrastructure outcomes varies spatially across the city, manifesting into priority areas of support for climate, biodiversity, and well-being outcomes. Finally, different ways of valuing and utilizing green infrastructure, and the socio-economic background of the respondents, predict support for policies favoring different green infrastructure outcomes. Our methods and results help take global political targets of mitigating climate change and reversing biodiversity loss into practice in cities in a manner that acknowledges the plurality of understandings on how green infrastructure should be managed, for whom, and most importantly, where.

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1. Introduction

Climate change and biodiversity loss are tightly interlinked, existential challenges that nations are grappling to address with ambitious political targets to reduce carbon emissions and restore biodiversity by 2030 (Convention on Biological Diversity CBD, 2021). As the two crises progress, integrative solutions that identify interactions and balance trade-offs between different policy targets are becoming increasingly urgent (Liu et al., 2018), as currently discussed in the context of the 'biodiversity-climate-society (BCS) -nexus' (Pascual et al., 2022).

In cities, attempts to address climate change and halt biodiversity loss increasingly draw on urban green infrastructure (UGI) (City of Helsinki 2021a). This is fueled by substantial global evidence pointing to the potential of UGI in helping cities mitigate and adapt to rapidly changing climatic conditions (Choi, Berry, & Smith, 2021) and protect and restore biodiversity (Connop et al., 2016), while providing crucial well-being benefits to urban residents (Reyes-Riveros et al., 2021, Iungman et al., 2023).

However, framing UGI as a solution to climate change mitigation or biodiversity loss in cities must acknowledge the interdependency between different UGI climate, biodiversity, and well-being outcomes: Both the close association between the well-being benefits and biophysical characteristics of UGI (Carrus et al., 2015), and the contextual and spatio-temporally variable relationship between carbon storage and biodiversity (Di Marco, Watson, Currie, Possingham, & Venter, 2018), give rise to complex interactions and feedbacks between different UGI climate, biodiversity, and well-being outcomes across the BCS-nexus.

Consequently, the effects of UGI policies addressing only one dimension of the nexus (e.g. climate) are likely to extend to other dimensions, as either co-benefits or trade-offs (Pascual et al., 2022). For example, simplistic efforts to maximize carbon uptake, such as afforestation, may translate to costs to biodiversity (Seddon, Turner, Berry, Chausson, & Girardin, 2019, Gómez-González, Ochoa-Hueso, & Pausas, 2020), while efforts to foster biodiversity in urban grasslands, such as interventions to transform lawns into meadows, may conflict with specific well-being benefits such grasslands would otherwise deliver (Lampinen et al., 2021).

Harnessing UGI as a solution to climate change mitigation or biodiversity loss in cities without acknowledging the potential trade-offs inherent to such framing may also have severe implications on the social acceptability of UGI policies that aim to achieve this. This is because public support for the implementation of environmental policies is a crucial determinant for their long-term success (Kyselá, Ščasný, & Zvěřinová, 2019). Understanding how UGI policies addressing specific dimensions of the BCS-nexus are supported or opposed, and by whom, calls for a participatory approach (Pineda-Pinto, Nygaard, Chandrabose, & Frantzeskaki, 2021) that recognizes diverse stakeholder values for and attitudes towards specific UGI policies.

Unfortunately, the literature concerning the relationships between different UGI outcomes, and public support for policies addressing such outcomes remains skewed, with studies primarily focusing on the potential co-benefits or trade-offs between UGI well-being and biodiversity outcomes (Southon, Jorgensen, Dunnett, Hoyle, & Evans, 2018, Reyes-Riveros et al., 2021) or between biodiversity and climate outcomes (Butt, Shanahan, Shumway, Bekessy, Fuller, Watson, Maggini, & Hole, 2018, Raymond et al., 2023). Very few studies discuss the relationship between UGI climate and well-being outcomes, let alone jointly address UGI outcomes for climate, biodiversity, and well-being (Choi et al., 2021). This is a critical knowledge gap, as dismissing the complex interactions between different UGI outcomes, and the varying levels of public support for policies addressing such outcomes, may result in unintended social or ecological consequences, ultimately undermining efforts to manage UGI for any given outcome across the BCS-nexus.

Public participation geographic information systems (PPGIS) can help navigate this complexity by providing a spatial understanding of how UGI is valued, where, and by whom, enabling the integration of spatially explicit social values and preferences for UGI into urban planning (Rall, Hansen, & Pauleit, 2019). Together with compatibility analyses, PPGIS can be used to identify potential for land-use synergies and conflicts (e.g., Brown, Reed, & Raymond, 2020, Kangas et al., 2022), to map the well-being benefits of nature in cities (Fagerholm, Eilola, & Arki, 2021), and to assess support for environmental policy and management (Engen et al., 2018). In the context of the BCS-nexus, PPGIS can help spatially target specific UGI climate, biodiversity and well-being outcomes in cities and help assess synergies and balance trade-offs between them. PPGIS can thus provide a nuanced understanding of where to manage UGI for specific outcomes across the BCS-nexus, while engaging residents of different socio-economic backgrounds in this process.

This paper aims to investigate how support for UGI policies addressing different climate, biodiversity, or well-being outcomes varies across urban residents and socio-spatial urban contexts. To achieve this, we first assess to what extent urban residents support, or oppose, the implementation of UGI policies that favor the climate benefits of UGI, or trade-offs with biodiversity or well-being that may be associated with such policies. We then assess public support for such policies spatially and identify hotspots and cold spots of support for climate, biodiversity, or well-being outcomes in the urban landscape. Finally, we explore the reasons underlying the variation in support for policies addressing specific UGI outcomes by linking this variation with different ways of valuing and using UGI, and the socio-economic context of urban residents. Through this, we contribute to a holistic understanding of how UGI can help cities respond to topical concerns of climate change, biodiversity loss, and well-being in a manner that is, if not socially acceptable for all, at least recognizes the plurality, contestation, and potential conflict between different expectations placed on UGI.

2. Materials and methods

2.1. Study area and sampling

The data for this study was collected during 13.9.2021–1.11.2021 in Helsinki, Finland, in survey format through the online participatory mapping platform Maptionnaire (https://maptionnaire.com). The survey was piloted in spring 2021 in Kumpula, a city district in central Helsinki, with an independent pilot study with a sample of 487 respondents (Lampinen et al., 2022). The pilot study served the purpose of testing and iterating the contents of the survey used to collect data underlying the work presented in this paper. To distribute the survey among city residents in Helsinki, we followed a mixed-mode approach containing elements of random and convenience sampling. First, we distributed the survey via postal invitations to a random sample of 1 000 households across Helsinki, followed by a reminder letter to participate sent two weeks after the initial invitation. We then advertised the survey on social media platforms (e.g., Facebook groups of local residential associations), complemented by outreach through online newspapers.

2.2. Survey content

The survey gathered a wide range of aspatial and spatial data regarding the relationship of the respondents with UGI in Helsinki (for full survey content, see Appendix A). At the beginning of the survey, all participants were provided with information about the research project and given the option to participate under informed consent; respondents could withdraw from the survey at any point if they so wished. The participants could choose a language of their choice for responding (Finnish, Swedish, or English).

The questions in the survey included open-ended, multiple-choice, and Likert-scale questions, as well as mapping tasks prompting the respondent to identify and map values for places in Helsinki relevant to theme of the survey. When mapping, the participants could choose from a number of map backgrounds, including satellite imagery. A minimum zoom-level of 14 (where 1 cm on the map corresponded to roughly 330 m in reality) was set to ensure each participant mapped at the approximate same accuracy.

The results presented in this paper are based on Likert-scale survey items concerning respondent support for UGI policies addressing different dimensions of the BCS-nexus. Five items concerned policies that favor the climate-benefits of UGI (hereafter "carbon-oriented UGI policies", see Table 1.). These were formulated based on the literature on carbon sequestration and broader climate mitigation benefits of UGI. While the potential of UGI in offsetting the carbon emissions of cities through carbon sequestration or storage is moderate at best (Strohbach, Arnold, & Haase, 2012), UGI is instrumental in helping cities mitigate and adapt to broader effects of climate change, such as extreme weather effects, or more pronounced urban heat island effects (Gaffin, Rosenzweig, & Kong, 2012, Iungman et al., 2023). For this reason, we formulated these policies to on one hand contribute to carbon sequestration, but also provide broader climate benefits upon implementation. The respondents were asked to assess their support for each policy separately in their local green spaces and at the scale of the entire city.

The results are also based on similar Likert-scale items concerning support for carbon-oriented UGI policies despite trade-offs to UGI biodiversity, aesthetic appearance, or recreation potential, that may follow such policies (Table 1). These items were formulated based on literature on the relationships between different dimensions of the BCS-nexus in the context of UGI. The items juxtaposed carbon and broader climate benefits of UGI with the biodiversity, aesthetic appearance, or recreation potential of UGI, with three items concerning each trade-off (Table 1). For example, an item assessing support for increasing the proportion of tree-covered areas in the city, a policy understood to favor carbon sequestration, included a trade-off to biodiversity in the form of potential open habitat loss. For a concise review of literature underlying the validity of juxtaposing carbon with other UGI outcomes, see Appendix B.

The results are also based on spatial mapping questions and aspatial questions related to respondent socio-demographic status and their access to different types of UGI in Helsinki. The spatial questions prompted the respondents to map both their domicile and a minimum of one green space personally important to them in Helsinki, and to elaborate the reason for this with a pre-selected list of social values they associate with that place. This list of values was based on the pilot-study and included a range of intrinsic and relational values, such as natural, restorative, or learning value (Lampinen et al., 2022).

2.3. Creating and validating key constructs

Before data analysis, we calculated four compound constructs of public support for UGI policy addressing different climate, biodiversity, or well-being outcomes. This involved **i)** averaging and reversing responses to groups of items theoretically salient in capturing the intended attitudinal variation and **ii)** validating the newly created constructs with exploratory factor analysis (EFA) and the greatest lower bound (GLB) (Ten Berge & Socan, 2004) for construct reliability.

Responses to items assessing support for carbon-oriented UGI policies at the scale of the local neighborhood and at the scale of the entire city were averaged to form a single construct describing support for said policies. This was motivated by strong positive correlation ($r = 0.93$) between the two sets of items. We hereafter refer to this construct as "*Support for carbon-oriented UGI policies*".

Responses to three groups of three items assessing support for carbon-oriented UGI policies even at the expense of trade-offs to UGI biodiversity, aesthetic appearance, or recreation potential, were averaged within each item triplet. To better highlight which respondents prioritize UGI biodiversity, aesthetic appearance, or recreation potential as opposed to carbon mitigation, the responses to these items were also reversed. We hereafter refer to these three constructs as "*Policy priorities of UGI biodiversity / aesthetic appearance / recreation potential*".

Table 1
Constructs and underlying survey items used to assess public support for carbon-oriented UGI policies, and policy priorities of UGI biodiversity, aesthetic appearance, or recreation potential. Note that items underlying the construct "Support for carbon-oriented policies" were responded to at the scale of both the local neighborhood of the respondent, and at the scale of the entire city. All items could be responded to with a five-point scale of Strongly disagree, Disagree, Neutral, Agree, and Strongly agree.

Construct	Underlying Likert-scale survey items
Support for carbon-oriented UGI policies	*Managing urban green spaces for increased density of vegetation. For example, urban forests would have more trees and shrubs.*
	Relaxing the intensity of management in urban green spaces. For example, mowing park lawns less frequently, not raking all the leaves from park lawns.
	Maintaining as much of the existing vegetation and native soils as possible during new urban development. For example, instead of surrounding newly built houses with built green spaces, housing and infrastructure should be placed around existing vegetation to the extent it is possible.
	Compensating for lost carbon storages upon urban development. For example, a forest cut down in a specific location should be accompanied by tree planting elsewhere.
	Prioritizing the development of new housing into already built-up areas rather than expanding them into existing green spaces. For example, existing low-density housing should be replaced by tall, dense housing.
Policy priority: UGI biodiversity	*Forests in Helsinki should be managed so as to maximize their carbon uptake, even if this is detrimental for* e.g. *old growth forest species.*
	Meadows, brownfields, and other unused land in the city should be forested even if this leads to loss of open habitat.
	Even non-native vegetation can be favored in urban green spaces if it stores carbon more efficiently than native vegetation.
Policy priority: UGI aesthetics	*Forests in Helsinki should have dead and decaying wood in them, even if this looks neglected and untidy.*
	New plantings in public parks should be selected for their ability to sequester and store carbon, not for their aesthetic appeal.
	Public green spaces should be managed with low-emission methods, even if this leads to a messier appearance.
Policy priority: UGI recreation potential	*Newly built urban green spaces should have the lowest carbon footprint possible, even if this means that they can not be used for all recreation purposes.*
	To reduce vegetation and soil disturbance in urban forests efficient in CSS, access to and movement in them should be limited.
	Wetlands along rivers and the seaside should be protected and restored to a larger extent, even if this leads to a loss of recreational area within the city.

The above constructs were supported by exploratory factor analysis, which indicated that items assessing support for the implementation of carbon-oriented UGI policies at the scale of local neighborhood and at the scale of the entire city could be condensed into a single factor for each pairwise comparison. Similarly, the three sets of three items assessing policy-priorities of UGI biodiversity, aesthetics, or recreation potential, could be expressed by a single underlying factor, respectively (see Appendix F for EFA output).

The greatest lower bound (GLB) (Ten Berge & Socan, 2004) for construct reliability varied from 0.98 (support for carbon-oriented UGI policies) to 0.72 (policy priority of aesthetic appearance), 0.70 (policy priority of recreation potential) and 0.48 (policy priority of biodiversity). Finally, we tested if the constructs differed across the respondents in a statistically significant manner from one another with Kruskal-Wallis non-parametric ANOVA.

2.4. Spatial analyses

The purpose of spatial analyses was to assess how support for carbon-oriented UGI policies, or the different policy priorities of aesthetic appearance, recreation potential, or biodiversity, varied spatially across the study area. To achieve this, we used the spatial point data on green spaces mapped by each respondent, clipped to include points mapped within the administrative borders of Helsinki, buffered with 100 m. This buffer was chosen to enable potential mapping inaccuracy in green spaces close to the city border. We assessed spatial variation in the focal constructs through green space points rather than respondent domiciles due to the exceedingly higher number of mapped green spaces ($n = 17\ 463$) than domiciles ($n = 3\ 002$). We performed a spatial join to link the construct scores of each respondent to the green spaces they mapped and identified statistically significant spatial hot and cold spots in support for carbon-oriented UGI policies, and policy priorities of biodiversity, aesthetic appearance, or recreation potential, with Optimized Hotspot Analysis using Getis-Ord Gi*-statistic (Getis & Ord, 1992).

We also assessed spatial overlap between quartiles of high and low support for carbon-oriented UGI policies and high and low policy priorities of biodiversity, aesthetic appearance, or recreation potential, with bivariate maps and Jaccard coefficients of overlap. For the purpose of these analyses, we aggregated the points to a grid with 225 m as cell width; this width was identified in the optimized hotspot analyses described above. The cell-based scores for each construct were derived by averaging the scores in all points mapped within each grid cell. All spatial analyses were conducted in ArcGIS Pro 3.0.

2.5. Aspatial analyses

The purpose of aspatial analyses was to understand the relationships between support for carbon-oriented UGI policies, the different policy priorities of aesthetic appearance, recreation potential, or biodiversity, and the socio-spatial urban context of the respondents. To achieve this, we used multiple linear regression to explain variation in all four constructs with socio-demographic variables, the values mapped to green spaces, and self-reported measures of access and objective measures of exposure to specific UGI types. The *p*-values in the models were corrected against false-discovery rate (Verhoeven, Simonsen, & McIntyre, 2005). The data on respondent exposure to UGI was obtained with spatial analyses of UGI within 300 m, 700 m, and 1000 m (Grunewald, Richter, Meinel, Herold, & Syrbe, 2017, Konijnendijk, 2022) of respondent domiciles, as expressed in an open-access database of UGI across Helsinki (HSY (Helsinki Region Environmental Services) (2022) (Helsinki Region Environmental Services), 2022).

3. Results

3.1. Survey response rate, respondent characteristics, and representativeness

A total of 3 237 respondents took part in the survey, with females (n = 2 308, 71.3%) being over-represented in the sample compared to males (n = 725, 22.4%) more so than in the population of Helsinki (52.5%). Roughly a half of respondents (54.2%) were between 35 and 65 years of age, with younger and older respondents being slightly underrepresented compared to Helsinki. The number of respondents possessing at least upper secondary education was higher (98.9%) relative to Helsinki (76.8%) (City of Helsinki 2021b). Unemployment rates for all age groups were lower among respondents compared to Helsinki (City of Helsinki 2021b), likely explaining the higher median yearly income of respondents (40 573 €), compared to population in Helsinki (38 736 €) (OSF (Official Statistics of Finland) (2022) (Official Statistics of Finland), 2022) (for full description of representativeness, see Appendix C). On average, respondents mapped 9.6 important green space points (for description of point distribution, see Appendix D).

3.2. Support for carbon-oriented UGI policies

Public support for carbon-oriented UGI policies was overall moderate to high among survey respondents (median response = 4.0; mean = 3.98; st dev 0.53; on a scale of 1–5 where 1 = "Strongly disagree" and 5 = "Strongly agree"), but differed according to suggested trade-offs to UGI biodiversity, aesthetic appearance, or recreation potential (Kruskal-Wallis test statistic $H(2) = 2275.17$, $p = <0.01$). Carbon-oriented UGI policies that could cause trade-offs to UGI aesthetics were met with varying degrees of support or neutrality (median = 4; mean = 3.89; st dev 0.78), as was the case with trade-offs to UGI recreation potential (median = 3.3; mean = 3.17; st dev 0.87). Carbon-oriented UGI policies that could cause trade-offs to biodiversity were largely rejected (median = 2.3; mean = 2.47; st dev 0.73).

Statistically significant hot- and cold spots emerged across Helsinki regarding support for carbon-oriented UGI policies and policy priorities of aesthetic appearance, recreation potential, or biodiversity (Fig. 2). Bivariate maps and Jaccard coefficients of overlap between the highest and lowest quartiles of each construct indicated varying, though primarily low, overlap between areas of high support for carbon-oriented UGI policies and priority areas of aesthetic appearance, recreation potential, or biodiversity (Table 2, Appendix G Fig. 1**a-c**). For example, priority areas (i.e. the highest quartile of support) of aesthetic appearance overlapped very weakly with the highest quartile of support for carbon-oriented UGI policies (6.93), but did so to a greater extent regarding the lowest quartile for support for carbon-oriented UGI policies (33.45). Overlap between priority areas of aesthetic appearance, recreation potential and biodiversity was likewise moderate, peaking between priority areas of aesthetic appearance and recreation potential (42.61) (Table 3, Appendix G Fig. 1d-**f**).

3.3. Relationships between support for carbon-oriented UGI policies, different policy priorities, and the socio-spatial urban context

Support for carbon-oriented policies, or for prioritizing UGI biodiversity, aesthetic appearance, or recreation potential, in UGI policy was significantly, though only moderately, related to the socio-demographic context of the respondent, their exposure to and self-reported access to specific UGI types, and the values they mapped to green spaces (Fig. 3**,** Appendix E). For example, male respondents, those of high income, and those with frequent self-reported access to private yards, reported low support for implementing carbon-oriented UGI policies and prioritized the aesthetic appearance of UGI. On the other hand, respondents with frequent self-reported access to allotment gardens or urban forests, those living in highly forested urban areas, and those valuing green spaces for their natural and wildness values, reported high support for carbon-oriented UGI policies. Respondents who prioritized recreation potential in UGI policy were characterized by high income and valued green spaces for sports and relaxation opportunities. Respondents who prioritized biodiversity in UGI policy valued green spaces for their natural value and reported frequent access to urban forests.

4. Discussion

This paper illustrates how public support for UGI policies advancing climate, biodiversity, and well-being outcomes in cities varies strongly among urban residents not only across different ways of valuing and accessing green spaces, or between socio-demographic groups, but also spatially across different urban contexts. Put simply, different residents support different climate, biodiversity, or well-being outcomes in different urban contexts, and for different reasons. This provides an important contribution to the rapidly developing literature on nexus-approaches to global sustainability challenges (Liu et al., 2018, Pascual et al., 2022). To date, practical efforts to jointly address climate, biodiversity, and well-being challenges in cities with the help of UGI have largely been missing, and while much attention has been given to

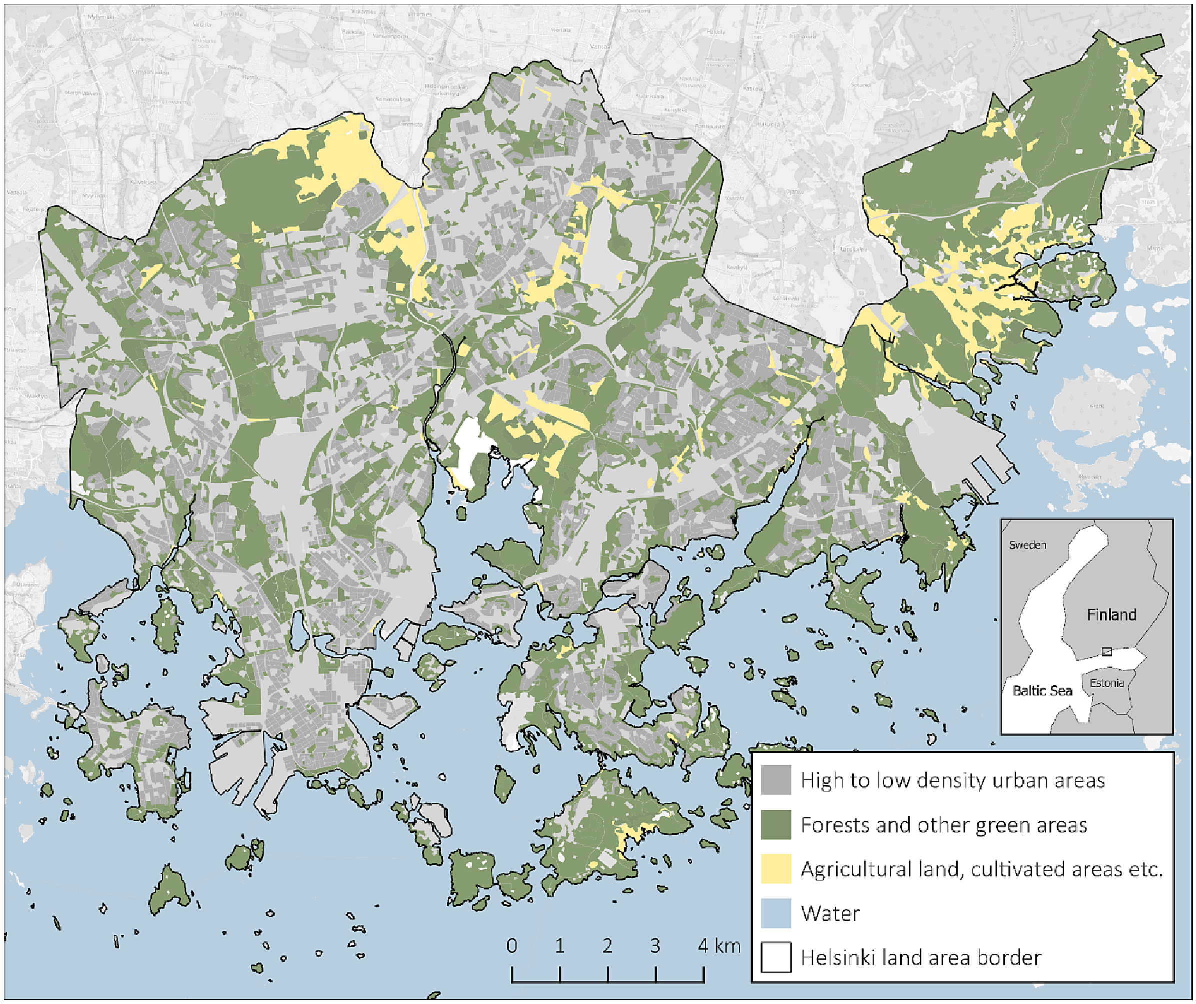

Fig. 1. Map of the study area. Dominant green infrastructure types in Helsinki are based on the Urban Atlas 2018 of the European Environmental Agency. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

leveraging co-benefits between UGI well-being and biodiversity outcomes, these have primarily been treated in isolation of UGI climate outcomes. Our results, derived with participatory methods, highlight how framing UGI as a solution to broad political targets of climate change mitigation or reversing biodiversity loss must acknowledge and navigate through diverse understandings of the purpose of green spaces in cities, plural ways of valuing them, and different levels of access them.

4.1. Joint consideration of climate, biodiversity, and well-being outcomes provides a holistic understanding of how UGI can help respond to topical policy concerns in cities

We found that urban residents overall tend to support UGI policies that advance carbon sequestration and broader climate benefits attributed to urban green infrastructure. This support, however, varied according to what residents prioritized as key outcomes of UGI management, namely biodiversity, or well-being outcomes such as recreation and aesthetic appearance. Importantly, residents in our sample were willing to compromise the aesthetic and recreation values of UGI in support of climate benefits but remained reluctant to similarly compromise UGI biodiversity values.

These results provide empirical evidence against simplistic, technocratic approaches to maximizing carbon sequestration (Seddon et al., 2019) and highlight how important it is to acknowledge potential trade-offs that such approaches may entail. The results also illustrate how participatory approaches to UGI planning can unveil diverse priorities among urban residents for UGI policy (Fagerholm et al., 2021, Nordh et al., 2022), ultimately helping urban planning to acknowledge and adapt to such diversity. The reluctance of residents to compromise the biodiversity values of UGI mirrors previous results on perceived policy priorities among stakeholders, which highlight the primacy of biodiversity either over well-being (Castro, Vaughn, Julian, & García-Llorente, 2016) or over climate change mitigation (Mäntymaa, Artell, Forsman, & Juutinen, 2022). Simplistic attempts to distinguish “which is more important” should, however, be avoided, as the consequences of policy addressing any outcome across the BCS-nexus are variable and depend on the context (Eriksson & Klapwijk, 2019).

The result that different UGI outcomes were supported to different extents is understandable, as the benefits derived from UGI, whether related to climate, biodiversity, or well-being, are often valued and prioritized differently, both across green space types and stakeholder groups, but also along geographic, temporal, and political gradients (e.g. Castro et al., 2016, Drillet et al., 2020). In general, tangible benefits related to well-being (e.g., personal health) and to broader cultural services (e.g., contact with nature), are highly valued (Jim & Chen, 2006) and often ranked more important among urban residents than regulating or provisioning services (Casado-Arzuaga, Madariaga, & Onaindia, 2013). In addition, well-being benefits (e.g., recreation) tend to remain in high demand in densely populated urban areas, while ecological benefits (e.g., water regulation) more so in suburban areas (Li et al., 2020).

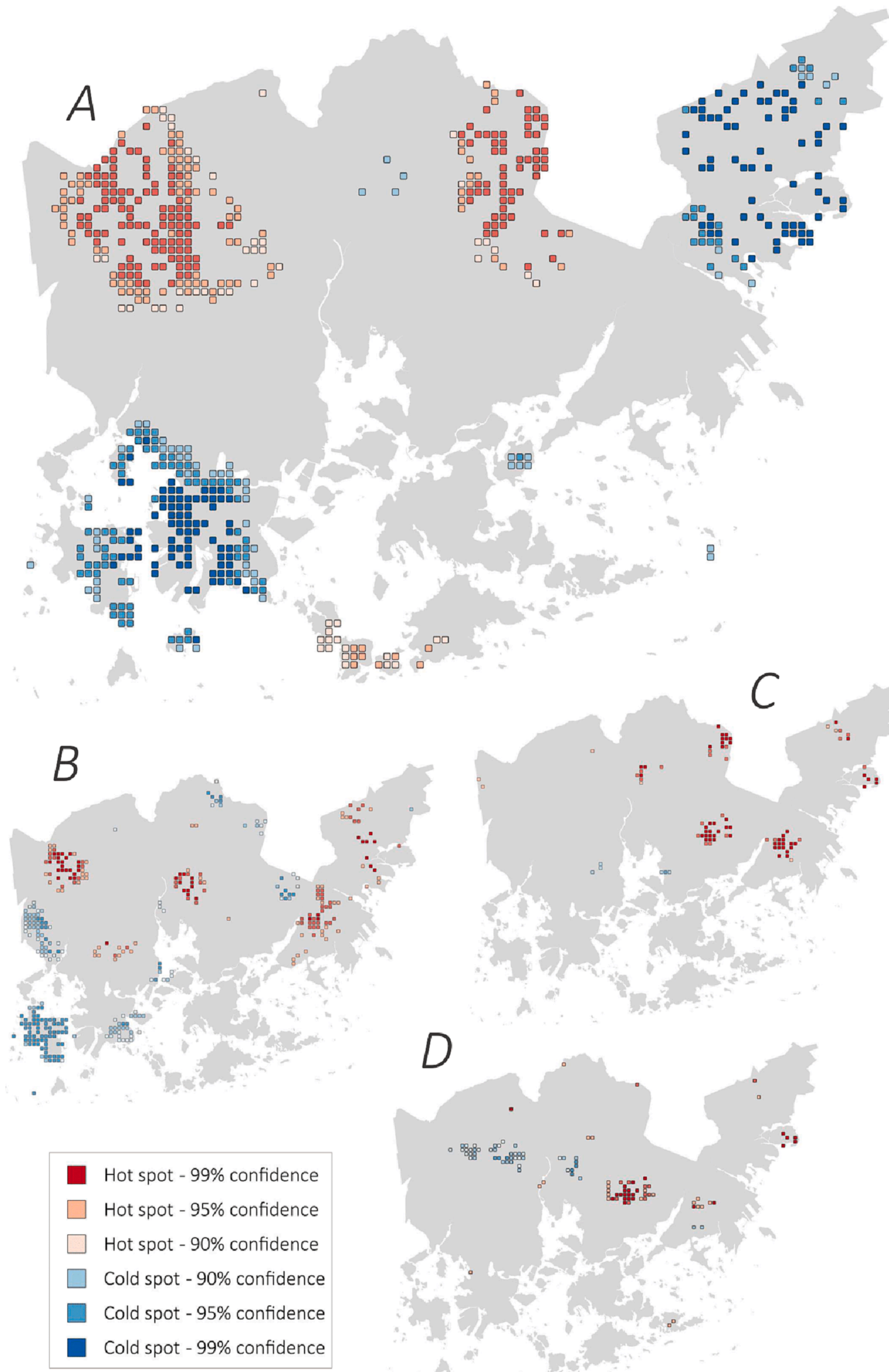

Fig. 2. Statistically significant hot and cold spots of A) support for carbon-oriented UGI policies, and policy priorities of B) biodiversity, C) aesthetic appearance, or D) recreation potential. For scale, each grid cell is 225 m in width.

Table 2
Jaccard coefficients of overlap (potential range: 0–100%) between the highest and lowest quartiles of support for carbon-oriented UGI policies and policy priorities of biodiversity, aesthetic appearance, or recreation potential.

			Support for carbon-oriented UGI policies	
			Highest quartile	Lowest quartile
Policy priority	UGI biodiversity	Highest quartile	16.84	20.37
		Lowest quartile	21.21	18.18
	UGI aesthetic appearance	Highest quartile	6.93	33.45
		Lowest quartile	29.03	6.70
	UGI recreation potential	Highest quartile	8.30	28.70
		Lowest quartile	34.45	9.80

4.2. Spatial priority areas of public support help target climate, well-being, and biodiversity outcomes across the city

We found that distinct hot and cold spots of public support for carbon-oriented UGI policies emerged across diverse urban contexts in Helsinki. The same applied to policy priorities of UGI aesthetic appearance, recreation potential, and biodiversity. These results provide a unique spatial representation of the perceived synergies and trade-offs between the distinct dimensions of the BCS-nexus in cities that participatory methods, such as PPGIS, can help assess. Identifying priority areas for specific UGI outcomes can help reach current (City of Helsinki 2021a) and future targets (European Commission, 2022) for conservation and climate change mitigation. Importantly, identifying priority areas of public support for specific UGI outcomes by engaging with residents can help spatially balance and target management addressing such outcomes in a manner sensitive to concerns of social acceptability among the residents.

Distinct differences in urban structure and UGI availability characterize the hot and cold spots of support for carbon-oriented UGI policies. The largest hot spots extend over forested, medium- to low-density city districts that have primarily been built in the decades following the 1950′s. Both hot spots also lie close to the green wedges of the city, either the Central Park, or the Viikki-Kivikko -green wedge (Hautamäki, 2021). The larger out of two extensive cold spots covers the southern and western parts of downtown Helsinki. These are among the most densely built city districts (HSY (Helsinki Region Environmental Services) (2022) (Helsinki Region Environmental Services), 2022) as well as among the most expensive to live in, and include historical public parks, cemeteries, and recreation areas close to the city center and the adjacent shoreline. Another large cold spot covers the north-eastern section of the city, the Östersundom major district. Recently annexed to the city, Östersundom is likewise a wealthy area, and among the most sparsely built in the city, with little to no urban fabric but large tracts of forest and agricultural land.

Theories of landscape preference (Nassauer, 1995, Nassauer, Wang, & Dayrell, 2009) can help explain why support for specific UGI outcomes varies so strongly across contrasting urban contexts in Helsinki. Most of the UGI policies discussed in this study would result in changes in the form and appearance of UGI through contributing to, e.g., denser and structurally more complex vegetation. We argue that policies contributing to a disrupted, and effectively messier, UGI appearance will likely face opposition in UGI located in more affluent, centric, and densely built urban areas. In these areas, cues to care (Nassauer, 1995) such as mown lawns and heavily managed ornamental vegetation are an integral part of the scenic beauty and historical identity of the area. Conversely, at the sparsely built semi-rural urban fringe, such as in Östersundom, policy contributing to increased density of housing, one of the policy options presented to the respondents, may similarly be undesirable.

We also found that priority areas of support for carbon-oriented UGI policies, and for policy priorities of UGI aesthetic appearance, recreation potential, or biodiversity, overlapped with one another only weakly, with the exception of aesthetic appearance and recreation potential. This result suggests that trade-offs across the different dimensions of the BCS-nexus may not always need to be made in the same location. The low overlap different outcomes also suggests that UGI multifunctionality (Rode, 2016) in terms of carbon, biodiversity, and well-being outcomes depends on the scale of inspection and may best be supported not at the scale of individual green spaces, but at a larger scale of a network of UGI with individual functions across the city. This mirrors ecological studies assessing how relationships between carbon stocks and biodiversity vary according to spatial scales of inspection (Sabatini et al., 2019).

4.3. Values for and access to UGI, and socio-economic context, explain variation in support for climate, well-being, and biodiversity outcomes in UGI

We also found that residents who value UGI for natural and wilderness values, live in highly forested areas, or access forests frequently, tend to support carbon-oriented UGI policies. Male respondents, those of high income, and those who primarily access private gardens, opposed such policies, and prioritized the aesthetic appearance or recreation opportunities of UGI over its potential for carbon sequestration or broader climate benefits. These results illustrate how different ways of valuing and utilizing UGI, together with socio-economic context, manifest into plural and sometimes conflicting understandings of which dimension of the BCS-nexus to manage UGI for. The results also mirror previous work that shows how different types of UGI is valued (Palliwoda & Priess, 2021) and used differently (Raymond, Gottwald, Kuoppa, & Kyttä, 2016, Fagerholm et al., 2021, Korpilo et al., 2021), and how specific values for and uses of UGI translate to specific views concerning what such UGI should be managed for (Fischer et al., 2020, Lampinen et al., 2021).

Variation in support for carbon-oriented policies by access to public

Table 3
Jaccard coefficients of overlap (potential range: 0–100%) between the highest and lowest quartiles of policy priorities of biodiversity, aesthetic appearance, or recreation potential.

		Policy priority: UGI biodiversity		*Policy priority: UGI aesthetic appearance*		*Policy priority: UGI recreation potential*	
		Highest quartile	Lowest quartile	Highest quartile	Lowest quartile	Highest quartile	Lowest quartile
Policy priority: UGI biodiversity	Highest quartile	–	–	14.61	17.15	15.95	22.80
	Lowest quartile	–	–	17.18	16.76	18.38	19.82
Policy priority: UGI aesthetic appearance	Highest quartile	14.61	17.18	–	–	42.61	3.75
	Lowest quartile	17.15	16.76	–	–	4.48	40.49
Policy priority: UGI recreation potential	Highest quartile	15.95	18.38	42.61	4.48	–	–
	Lowest quartile	22.80	19.82	3.75	40.49	–	–

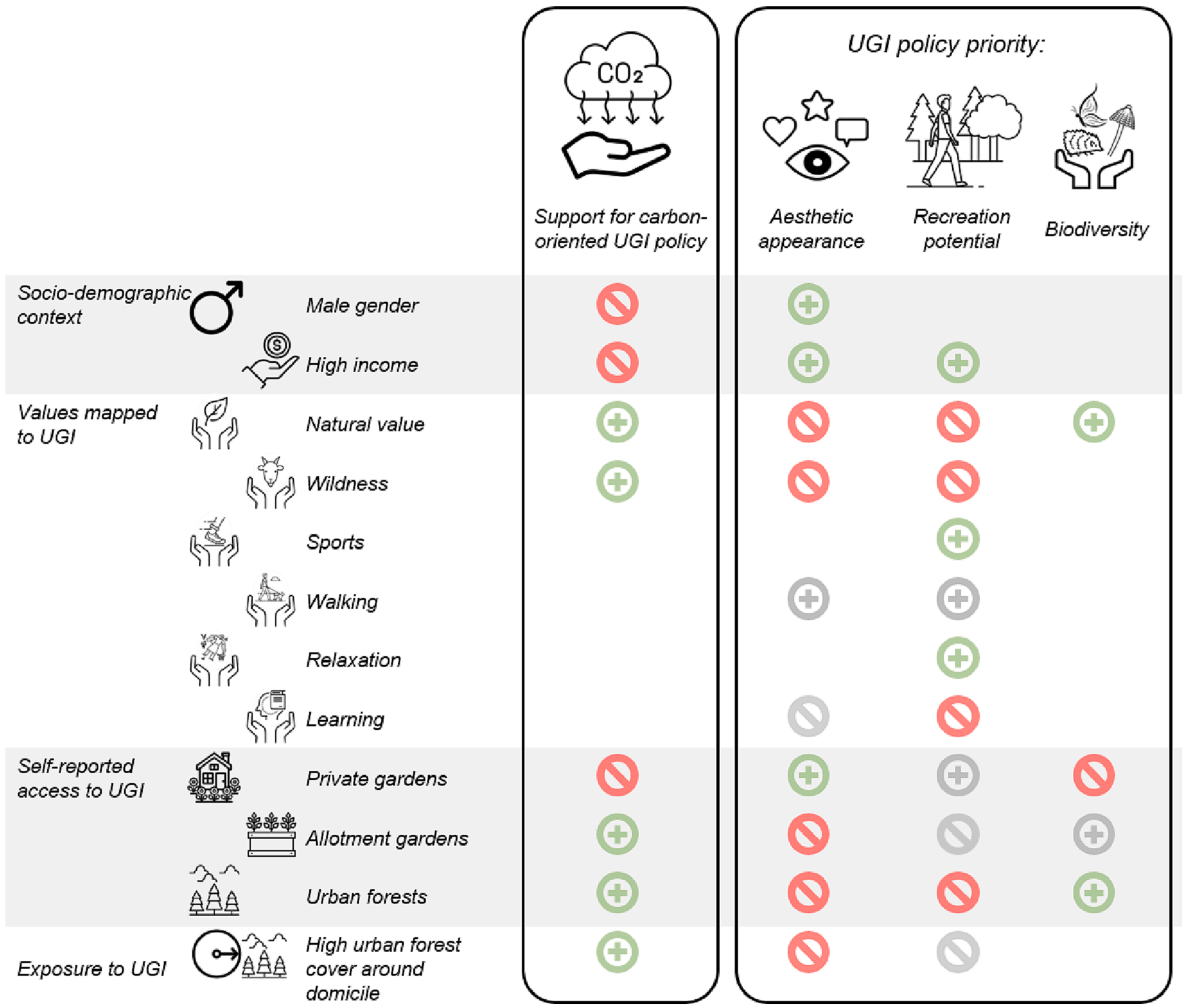

Fig. 3. Graphical summary of relationships between the socio-demographic context of survey respondents, support for carbon-oriented UGI policies, and specific policy priorities of UGI aesthetic appearance, recreation potential, and biodiversity. Symbols in the table describe the outcomes of linear regression models relating response variables (columns) to predictor variables (rows). Red symbols indicate statistically significant (p-value ≤ 0.05) negative and green symbols significant positive relationships between the response and predictor variables. Gray symbols indicate near-significant relationships (p-value ≤ 0.09). For full description of models, see Appendix E. Icons based on open-access material at: https://thenounproject.com/. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

or private UGI is revealing. Respondents more dependent on public UGI, such as forests, were more supportive of policies to advance carbon sequestration and broader climate benefits, while respondents with frequent access to private gardens opposed them. Urban forests provide immense social-ecological benefits (Tyrväinen, Pauleit, Seeland, & de Vries, 2005), are instrumental for the broader intellectual and emotional fulfillment of urban residents (Peckham, Duinker, & Ordóñez, 2013), and support residential recreation disproportionately compared to other urban land use types (Fagerholm et al., 2021). Forests are also common to Helsinki (City of Helsinki 2021a), and it is thus understandable that both access and exposure to them emerges as a key determinant for policy support. On the other hand, the low support for carbon-oriented UGI policies among those who often access private yards may reflect a disbelief that yards could meaningfully help address environmental concerns in cities (García-Antúnez, Lindgaard, Lampinen, & Olafsson, 2023). Similar disbelief in how property owners' actions, especially concerning the environmental management, could contribute to climate change mitigation, has been identified in Finland (Laakkonen et al., 2018).

Different values for and different levels of access to UGI are often tightly associated with socio-economic context (Ordóñez-Barona, 2017), which may translate to profound, and persistent, differences in green infrastructure size and quality between affluent and disadvantaged urban areas. Especially gender is fundamental in explaining different preferences for and uses of UGI: For example, women tend to place more importance on benefits derived from UGI than men (Ode Sang, Knez, Gunnarsson, & Hedblom, 2016), to prefer more natural, as opposed to ornamental, UGI designs (Caula, Hvenegaard, & Marty, 2009), and to show stronger support for biodiversity-friendly UGI management interventions than men (Fischer et al. 2021). On a more general level, older, white, and conservative men in Western countries tend to report lower concern over climate change and to oppose environmental regulation more strongly than females (Tranter & Booth, 2015). It is thus understandable that males in our results expressed lower support for policy to advance carbon sequestration in UGI.

Overall, our results highlight how participatory methods can not only be used to elicit community preferences for UGI policies across the BCS-nexus, but to also provide insight on the social and perceptual reasoning underlying such preferences, ultimately contributing to more comprehensive, and just, UGI planning (Rall et al., 2019).

4.4. Limitations and future directions

Despite the multi-mode sampling strategy, our sample comprises respondents who are more often female than male, slightly wealthier, more educated, and more often employed than what could be expected based on the background population in Helsinki. Similar over-representation of certain socio-demographic groups is commonly seen in similar surveys in the Nordic countries (Fagerholm et al., 2021, Fagerholm et al., 2022). Our results, while they reflect those obtained in other studies, call for further studies with a more balanced set of respondents.

In addition, public support for environmental policies often varies according to environmental awareness and knowledge of the context of the policies (Drews & Van den Bergh, 2016, Lampinen & Anttila, 2021). Future work relating respondent knowledge of the dynamics of carbon in the context of UGI with the level of support they report for UGI policies modifying those dynamics is thus warranted. This would help explain to what extent campaigns to elevate public awareness could foster stronger support for managing UGI for greater benefits to carbon mitigation.

Finally, while the survey items underlying the construct of biodiversity as policy priority are theoretically valid, the construct itself has relatively low internal consistency. Biodiversity as a concept is inherently multidimensional, and consequently the relationships between UGI climate benefits and biodiversity are context-dependent and variable. In our survey, we purposefully formulated items that capture this multidimensionality, and attribute the low consistency of the construct to this.

5. Conclusions

This paper has shown that a joint consideration of climate, biodiversity, and well-being outcomes in UGI policy provides a more nuanced, though also more complicated, understanding of how UGI can help address pressing sustainability challenges in cities. The spatial priority areas we have identified help integrate spatially explicit social values and preferences for UGI into such efforts. The diverse and interrelated links between values for UGI, access to UGI, and the socio-demographic context of the respondents, however, illustrate how complex the understandings of what UGI should be managed for, and why, can be. Together, these results suggest that successfully leveraging UGI for simultaneous benefits across the biodiversity-climate-society -nexus, i.e., reaching the so-called “triple-wins” (Pritchard, 2021, Key et al., 2022), is likely to depend strongly on the ecological and social contexts in which such attempts take place. Public participation GIS, as exemplified in our results, can help elucidate and potentially manage some of this complexity, providing a replicable way to introduce concerns of social acceptability into the practice of planning and managing UGI for any outcome across the BCS-nexus. This will ensure that the ambitious global policy targets of reversing biodiversity loss and reaching carbon-neutrality, the greatest challenges cities of today face, translate to planning and management solutions that are fair, socially acceptable, and leave no one behind (United Nations (2017), 2017).

CRediT authorship contribution statement

Jussi Lampinen: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Supervision, Data curation, Writing – original draft, Writing – review & editing, Project administration. **Oriol García-Antúnez:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Alex M. Lechner:** Methodology, Writing – original draft, Writing – review & editing. **Anton Stahl Olafsson:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Natalie M. Gulsrud:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Christopher M. Raymond:** Conceptualization, Methodology, Resources, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data underlying this publication is available in: https://zenodo.org/record/7664925#.Y_25q3ZBx3g

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2023.104856.

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