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## **Prioritizing the provision of urban ecosystem services in deprived areas, a question of environmental justice**

### **Abstract**

The distribution of urban ecosystem services (UES) is often uneven across socioeconomic groups, leading to environmental justice issues. Understanding the distribution of UES across a landscape can help managers ensure an equitable distribution of services. While many past studies have focused on the distribution of green spaces in relation to socioeconomic variables, this research analyzes the distribution of UES provided by these green spaces. This research quantified air pollution removal, atmospheric carbon reduction, and surface runoff mitigation provided by urban trees in Strasbourg city (France). The provision of these three UES was studied at the census block scale by creating an index of UES delivery, which was contrasted with a constructed social deprivation index. Our results show that there is no significant association between the delivery of UES and social deprivation. Some deprived populations benefit from high UES delivery. Results also suggest that mapping associations between UES delivery and social deprivation should be integrated with future development plans to enhance the equitable distribution of UES. This study provides insights into the French context where studies about the distribution of UES at a small-area level remain lacking.

**Keywords:** Deprivation, Environmental justice, Urban ecosystem services, Urban trees

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**1. Introduction**

Numerous studies have stressed the importance of quantifying urban ecosystem services (UES) at different scales and integrating them into decision-making processes (Ernstson et al. 2010; Kremer et al. 2016; Yang et al. 2018). However, while the concept of UES represents a bridge between social and ecological systems within a city, little is known about the relationship between social systems and ecosystem services delivery at the local level (Amini Parsa et al. 2019). This issue is increasingly addressed within the environmental justice (EJ) framework, given the recognition of urban green spaces (UGS) and their UES as local solutions to both local (e.g. air pollution, intense precipitation events) and global environmental burdens (e.g. climate change) (Zhao and Sander. 2015; Amini Parsa et al. 2019; Escobedo et al. 2019) and the growing conviction that uneven exposure to environmental burdens and benefits among social groups affects city sustainability (Baró et al. 2019). The concept of EJ was mainly developed in the USA in the 1970s, with a focus on the relationship between socioeconomic groups and the distribution of environmental burdens and benefits, assuming that disadvantaged communities are most exposed to environmental risks (Greenberg and Cidon. 1997; Agyeman et al. 2002; Kruize et al. 2007; Brown et al. 2012; Raddatz and Mennis. 2013; Boyce et al. 2016). The application of EJ framework to UES focuses on their immediate distribution at the local scale (e.g. city-scale, block group, neighborhood) where ecosystem services delivery and benefits are realized (Baró et al. 2019) and hence can support policies of sustainability to maintain their long-term production in a fair and just manner (de Groot et al. 2010; Boone and Fragkias. 2013).

An important scientific corpus has been constructed around environmental justice linked to UGS (Grove et al. 2006; Heynen et al. 2006; Pham et al. 2012). For example, the distribution of green cover in Edinburgh, Glasgow, Leicester, Oxford and Sheffield (UK) and San Juan

26 (Puerto Rico) has been found to be linked with urban characteristics like housing type, detached  
27 housing and age of construction (Tratalos et al. 2007; Martinuzzi et al. 2018). In Terre Haute  
28 (IN, USA), positive correlations were found between leaf area, population density, and median  
29 income (Jensen et al. 2005). However, knowledge about the distribution of UES from an EJ  
30 perspective remains limited (Wilkerson et al. 2018; Baró et al. 2019). For instance, few studies  
31 have investigated the link between income level and temperature reduction (Jenerette et al.  
32 2011), and the variation of amenities according to economic status and ethnic origin (Landry  
33 and Chakraborty. 2009). Dobbs et al. (2014) found that UES provision in Melbourne (Australia)  
34 was positively related to the degree of human development, assessed as the ratio between  
35 education level and income. In Bogota (Colombia), Escobedo et al. (2015) found that the  
36 wealthiest population had the greatest access to particulate matter removal by trees. In Europe,  
37 EJ applied to UES is an emerging subject that has been investigated only in few urban areas,  
38 notably Berlin (Lakes et al. 2014), Barcelona (Baró et al. 2016; Baró et al. 2019) and Porto  
39 (Graça et al. 2017).

40 In France, investigations of UES within the EJ framework are rather scarce. Cohen et  
41 al. (2012) assessed indirectly UES distribution in Paris through perception and species  
42 indicators. In 2013, the national program of ecosystem functions and services assessment  
43 (“L’évaluation française des écosystèmes et des services écosystémiques”: EFESE) was  
44 launched. It addressed the disparity in the distribution of green spaces in French cities by  
45 referring to some indicators like accessibility and attendance (EFESE 2018). However, the  
46 distribution of UES across a socioeconomic gradient has not been considered.

47 In line with such evidence, it is essential to investigate more case studies to draw a more  
48 complete and general picture about the interactions between socioeconomic factors and  
49 ecosystem services depending on local contexts. Providing empirical research about how  
50 socioeconomic factors influence ecosystem services can enrich research in this field. It may

51 also facilitate orienting urban planning toward increased sustainability and equity. Hence, our  
52 paper contributes to the literature of environmental justice related to UES by providing a case  
53 study combining biophysical indicators that directly measure urban ecosystem services and  
54 socioeconomic indicators in a context of French cities.

55 Therefore, the main goal of this study is to conduct a quantitative assessment of UES  
56 from a distributive justice perspective in Strasbourg city (France) and analyze if there are social-  
57 spatial inequalities related to their provision. Distributive justice of ES is defined as the equal  
58 access to ES among different social groups (Sievers-Glotzbach 2013; Schüle et al. 2019).

59 We focused on ecosystem services provided by trees located in public green spaces and  
60 along streets as these areas are managed via public funding. We aimed to analyze the  
61 distribution of UES delivery across a deprivation gradient defined by both social and material  
62 disadvantages of local communities (Havard et al. 2008). Our study had three specific  
63 objectives: 1) identify and assess socioeconomic variables that define deprivation, 2) quantify  
64 three UES (air purification, runoff mitigation, atmospheric carbon reduction) and combine them  
65 into one UES delivery index, and 3) investigate the relationship between social deprivation and  
66 UES delivery to highlight potential environmental inequalities within the city.

67

## 68 **2. Methods**

### 69 **2.1. Study area**

70 This study was conducted in Strasbourg city, in Northeastern France (48°35'N and  
71 7°45'W). The city covers an area of 7830 ha and supports about 275 700 inhabitants with a  
72 population density of 35 inhabitants per ha (INSEE, 2016). The city is covered by 400 ha of  
73 parks and about 1600 ha of protected alluvial forests that are major carbon sinks in the city. The  
74 historic core of the city is surrounded by the green belt which is 650 m wide and supports 370  
75 ha of gardens, vacant areas, and green spaces. Strasbourg occupies the 7<sup>th</sup> place in terms of

76 number of m<sup>2</sup> of tree cover per inhabitant (32 m<sup>2</sup> /inhabitant) while the first place is occupied  
77 by Montpellier city (43 m<sup>2</sup> of tree cover / inhabitant; about 5700 ha; 268 456 inhabitants.).

78         Strasbourg is projected to develop more than 1000 ha of green and vacant spaces  
79 between 2017 and 2030. This development would lead to the release of carbon stored in soils  
80 and vegetation and weaken strategies for mitigating climate change. Increasing cumulative  
81 rainfall along with substantial impervious surfaces and a dense hydrographic network makes  
82 the city vulnerable to flooding (ADEUS 2018). Air pollution is also an environmental burden  
83 in Strasbourg, as NO<sub>2</sub> exposure is increasing and PM<sub>10</sub> exceeds prescribed daily limits (Atmo  
84 Grand-Est 2018).

85         The city contains 14 neighborhoods subdivided into 116 census blocks called IRIS  
86 (Fig.1a). To ensure relevant analysis of social and ecological mismatches in Strasbourg, IRISs  
87 with a limited population (less than 250 inhabitants) were excluded. According to Havard et al.  
88 (2008), the excluded blocks with very low population numbers do not present sufficient  
89 socioeconomic information. In total, 94 IRISs were included in our study sample. The average  
90 population per IRIS was 2619 inhabitants with a mean IRIS area of 59 ha (44 inhabitants per  
91 ha).

## 92         **2.2.Quantification of social deprivation**

93         Studies of UES from an EJ perspective are often based on literature reviews to select  
94 socioeconomic variables to define social deprivation (e.g. McPhearson et al. 2013; Dobbs et al.  
95 2014; Baró et al. 2019). In this work, we instead built a composite deprivation index based on  
96 quantitative data and statistical analyses.

97         Data on socioeconomic variables that are often used to reflect social deprivation within  
98 UES environmental justice frameworks (e.g. Pham et al. 2012; Cohen et al. 2012; McPhearson  
99 et al. 2013; Graça et al. 2018) were obtained from the 2013 national census (INSEE 2016).

100 From these original data, eight socioeconomic variables providing inter-related  
101 indicators of social deprivation were determined: (1) Median household income (in euros), (2)  
102 Density of household with standard of living below poverty line (= number of household with  
103 standard of living below poverty line / IRIS area in ha), (3) Density of rent-controlled housing  
104 (HLM) (= number of HLM / IRIS area in ha), (4) proportion of immigrants in the population  
105 (= number of immigrants / total number of IRIS inhabitants), (5) ratio of house owners to  
106 tenants (= number of owner-occupied primary residences / number of non-owner occupied  
107 primary residences), (6) ratio of unemployed to active people (= number of unemployed people  
108 aged 15 and older / number of employed people aged 15 and older), (7) ratio of blue collar to  
109 white collar (number of blue collar workers aged 15 and older / number of white collar workers  
110 aged 15 and older), and (8) ratio of households without car to households with cars (= number  
111 of households without a car / number of households with a car).

112

### 113 **2.3. Quantification of UGS and UES**

114 Three UES provided by public urban trees were selected: atmospheric carbon reduction,  
115 surface runoff mitigation, and air pollution removal. The three UES are considered as the most  
116 important in terms of distributional EJ (Amini Parsa et al. 2019; Baró et al. 2019). While  
117 production and benefits of surface runoff mitigation and air pollution removal are mostly local  
118 effects, atmospheric carbon reduction affects global climate regulation (Fisher et al. 2009).  
119 Numerous other local urban ecosystem services that impact human well-being are affected by  
120 local leaf area and biomass, such as building energy use and thermal comfort (Graça et al.  
121 2018). Although it affects global climate regulation, it is of interest to study the carbon storage  
122 and sequestration by trees in urban areas since they are more vulnerable to climate change and  
123 where adaptation strategies should be developed (Amini Parsa et al. 2019). Producing

124 information about the distribution of this UES may contribute to enhanced climate justice even  
125 at the local scale (Srang-iam 2011).

126

127 The three UES were assessed using i-Tree Eco model that provides information about  
128 forest structure and benefits (Nowak et al. 2008; [www.itreetools.org](http://www.itreetools.org)). i-Tree Eco guidelines (i-  
129 Tree Eco User's Manual 2013) were followed to define the sample size and field survey  
130 protocol to collect municipal urban forest data. The sampling design and data collection were  
131 carried out by delimiting and stratifying public UGS within land-use classes, assessing tree  
132 cover within public UGS, generating field samples, and collecting field data

133 The city and its public green spaces were stratified into 8 land-use classes based on  
134 1:10000 land-cover database of the Alsace region provided for 2008 by the "Cooperation for  
135 Geographic Information System in Alsace" (CIGAL). Using the 2010 map of public green  
136 spaces provided the City Council of Strasbourg (EMS), 228 circular 11 m-radius plots (0.04 ha)  
137 were selected. Study plots were distributed randomly within public green spaces using random  
138 plot generation functionality of Arcgis (by generating x and y coordinates) and following the  
139 model documentation (see Selmi et al. 2016).

140 The field survey was conducted during the leaf-on season of 2013. At each plot, general  
141 information (date, plot address, GPS coordinates, land use, tree and shrub cover, ground cover  
142 and plantable space) were recorded, as well as individual tree data (species, diameter at breast  
143 height (DBH), total tree height, crown width, height to base of live crown, crown light exposure,  
144 crown dieback percent, percent crown missing).

145 Local hourly pollution data were obtained from the regional Air Quality Agency (Atmo-  
146 Est). These data were measured at six monitoring stations located within the study area over a  
147 one-year period (from July 2012 to June 2013). Concentrations of carbon monoxide (CO),  
148 nitrogen dioxide (NO<sub>2</sub>), sulfur dioxide (SO<sub>2</sub>), ground-level ozone (O<sub>3</sub>), particulate matter of



149 less than 2.5  $\mu\text{m}$  ( $\text{PM}_{2.5}$ ) and particulate matter between 2.5  $\mu\text{m}$  and 10  $\mu\text{m}$  ( $\text{PM}_{10 \text{ coarse}}$ ) were  
150 calculated as averages values from the six monitoring stations. Weather data (wind speed,  
151 precipitation, temperature, etc.) were retrieved from “Météo France” (two stations within the  
152 study area) and one station of the National Oceanic and Atmospheric Administration (NOAA)  
153 located at Strasbourg city.

154 The collected field and environmental data were combined in i-Tree Eco v5 to assess  
155 basic structural information (e.g., tree density, species composition) and three UES: air  
156 purification (dry deposition indicator), atmospheric carbon reduction (carbon storage and  
157 sequestration indicators) and surface runoff mitigation (avoided runoff indicator). The average  
158 rates of all UES per tree cover (i.e.,  $\text{g m}^{-2}$  or  $\text{m}^3 \text{m}^{-2}$ ) were calculated for each land-use class.  
159 Following UES environmental justice literature (Dobbs et al. 2014; McPhearson et al. 2013;  
160 Baró et al. 2019), the aggregated index was calculated to quantify UES at each IRIS following  
161 the formula:

162 
$$\text{UES}_i \text{ (g) (IRIS scale)} = \sum (\text{tree cover per land-use class } j \text{ (m}^2\text{)} \times \text{Average of UES}_i \text{ per}$$
  
163 
$$\text{tree cover per land-use class } j \text{ (g m}^{-2} \text{ or m}^3 \text{ m}^{-2}\text{)}).$$
 The IRIS value was then divided by the area  
164 of the corresponding IRIS to obtain a relative measure of that UES metric ( $\text{UES m}^{-2}$ ).

165

## 166 **2.4. Statistical analysis**

167 Separate Principal Component Analyses (PCA) were conducted on the three sets of  
168 variables (socioeconomic, UGS, and UES) to summarize the original variables into a few  
169 components. Only components with eigenvalues exceeding 1 were retained (Vyas and  
170 Kumaranayake 2006). PCA provided three composite indices of social deprivation, UGS  
171 parameters and, UES delivery (see results).

172

173 A classification was further conducted according to social deprivation and UES delivery  
174 indices to identify vulnerable areas (i.e. areas with high deprivation and low UES delivery).  
175 The three classes (high, moderate and low) were identified based on the mean of UES and  
176 deprivation indices  $\pm \frac{1}{2}$  standard deviation (Faburel et Guymard 2008). The combination of  
177 deprivation and UES classifications provided nine categories that were mapped using  
178 Geographic Information using Esri's ArcGIS for Desktop 10.5.

179 Since study units were locations, spatial autocorrelation, and hence statistical non-  
180 independence among observations (Legendre and Legendre 1998; Rangel et al. 2006) could  
181 occur. Spatial autocorrelation among indices of deprivation, UES parameters, and UES  
182 delivery was checked for using Moran's correlograms (Legendre and Legendre 1998). The  
183 studied IRISs were organized into 10 equiprevalent classes of geographic distance, with a lag  
184 ranging from 0.527 to 2.897 km and sample size of 872 pairs of IRISs per class. For each  
185 distance class, a Moran's I autocorrelation coefficient was calculated and tested for significance  
186 using 999 permutations. A correlogram was then obtained by plotting the Moran's I values  
187 against the upper boundaries of the corresponding distance classes, and the significance of the  
188 whole correlogram was assessed by applying the Bonferroni correction for multiple tests  
189 (Legendre and Legendre 1998). These spatial autocorrelation analyses were carried out using  
190 SAM software 4.0 (Rangel et al. 2006).

191 The significance of social deprivation as a predictor of green space cover and UES  
192 delivery was investigated using simple linear regressions. These regressions were performed  
193 using Ordinary Least Square (OLS) models assuming independence among model residuals.  
194 Spatial models were also run that considered model residuals as correlated and their covariance  
195 as a function of the geographic distance between pairs of sites; Generalized Least Square (GLS)  
196 models (Cressie 1993; Rangel et al. 2006). The competing non-spatial and spatial models were  
197 then compared according to their AICc (Akaike Information Criteria corrected for small sample

198 size) and  $R^2$ . The best model was the one having the lowest AICc and highest  $R^2$  values (Rangel  
199 et al. 2006). These regression analyses were performed using SAM software 4.0 (Rangel et al.  
200 2006).

### 201 **3. Results**

#### 202 **3.1. General results about social deprivation and UES delivery**

203 The first component extracted from a PCA on the original socioeconomic variables has  
204 an eigenvalue of 5.26 and explains 66% of the variance of the original data set, corresponding  
205 to an increasing axis of social deprivation (Table 1). However, the second component has an  
206 eigenvalue less than 1 (0.79) and is not retained.

207 Twenty-eight IRISs are characterized as having the best living condition, where only  
208 12% of households live below the poverty line, 88% of the population has a job and only 4%  
209 of houses are rent-controlled. Conversely, the high deprivation class contains 33 IRISs that are  
210 characterized by a high average of households who live below the poverty line (38%) and a  
211 high percentage of immigrants (47%).

212 Descriptive statistics of UGS and UES parameters for the 94 IRIS are shown in Table  
213 1. Average green spaces cover and tree cover across all IRIS are 14.7% and 5.7 % respectively.  
214 Average species number and tree density are 114 species and 23 trees ha<sup>-1</sup> respectively. The  
215 conducted PCA reduces UGS variables into one component accounting for 75% of the variance  
216 (eigenvalue = 3.02), while the second component has an eigenvalue of 0.73. The first  
217 component is positively correlated with all original variables, thus providing a composite index  
218 of UGS characteristics (Table 1).

219 UES provided by public urban trees in Strasbourg city during 2013 are estimated to  
220 128000 t and 4000 kg C year<sup>-1</sup> of stored and sequestered carbon respectively, 88 t year<sup>-1</sup> of  
221 removed air pollutants including 1.2 t year<sup>-1</sup> of CO, 13.8 t year<sup>-1</sup> of NO<sub>2</sub>, 55.9 t year<sup>-1</sup> of O<sub>3</sub>;  
222 11.8 t year<sup>-1</sup> of PM<sub>10</sub>, 4.5 t year<sup>-1</sup> of PM<sub>2.5</sub> and 1.0 t year<sup>-1</sup> of SO<sub>2</sub> (Note: PM<sub>10</sub> estimates exclude

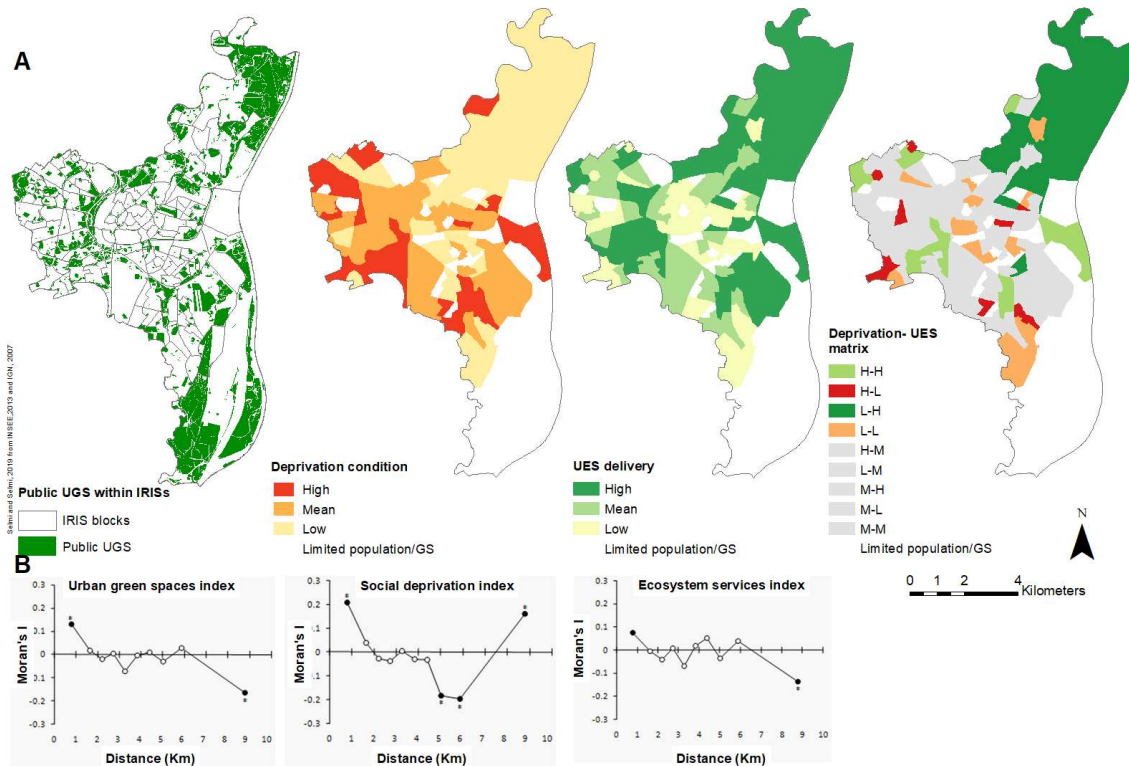
223 PM<sub>2.5</sub> particles) and 24 160 m<sup>3</sup> year<sup>-1</sup> of avoided runoff. A PCA summarizes the investigated  
224 UES into a single composite index (first component) that explains 99% of the total variance  
225 and has an eigenvalue of 8.92. In contrast, the second component has an eigenvalue of 0.07.  
226 The composite index derived from this PCA is positively correlated with all original variables  
227 (Table 1), indicating that high scores correspond to areas with increased delivery of UES.

228 **Table 1. List of assessed socioeconomic, green space and ecosystem service variables among IRISs, with descriptive statistics and correlations (Pearson**  
 229 **correlation coefficient) with the indices derived from the Principal Component Analyses (sample size = 94 IRIS).**

Variables		Range	Mean $\pm$ SD	Correlation test		Constructed index
				<i>r</i>	<i>P</i>	
Socio-economic variables	Median household income (euros)	10 847–38,290	19 228 $\pm$ 5495	-0.799	< 0.0001	Deprivation index
	Density of household with standard of living below poverty line (number ha <sup>-1</sup> )	0–0.04	0.01 $\pm$ 0.01	0.941	< 0.0001	
	Density of rent-controlled housing (HLM) (number ha <sup>-1</sup> )	0–89.61	10.89 $\pm$ 16.01	0.730	< 0.0001	
	Proportion of immigrants in the population	0.05–0.40	0.20 $\pm$ 0.08	0.808	< 0.0001	
	Ratio of house owners to tenants	0–3.99	0.53 $\pm$ 0.59	-0.575	< 0.0001	
	Ratio of unemployed to active people	0.06–0.95	0.27 $\pm$ 0.18	0.916	< 0.0001	
	Ratio of blue collar to white collar	0.05–60.68	4.38 $\pm$ 9.19	0.765	< 0.0001	
	Ratio of households without car to households with cars	1.25–7.14	2.49 $\pm$ 0.99	0.893	< 0.0001	
UGS variables	Cover of green areas (%)	0–68.30	16.80 $\pm$ 15.30	0.917	< 0.0001	Urban vegetation index
	Number of species	17–671	114 $\pm$ 108	0.602	< 0.0001	
	Tree density (trees ha <sup>-1</sup> )	0.25–182.29	23.22 $\pm$ 27.77	0.941	< 0.0001	
	Tree cover (%)	0–44	5.70 $\pm$ 7.50	0.962	< 0.0001	
Atmospheric carbon reduction	Carbon storage (kg ha <sup>-1</sup> )	0.32–36 058	7160 $\pm$ 8195	0.994	< 0.0001	
	Carbon sequestration (kg ha <sup>-1</sup> year <sup>-1</sup> )	0.01–1126	203 $\pm$ 230	0.976	< 0.0001	
Surface runoff mitigation	Avoided runoff (m <sup>3</sup> ha <sup>-1</sup> )	0–9.76	1.54 $\pm$ 1.85	0.994	< 0.0001	
UES variables	CO removal (g ha <sup>-1</sup> )	0–447	79 $\pm$ 91	0.999	< 0.0001	Ecosystem services delivery index
	NO <sub>2</sub> removal (g ha <sup>-1</sup> )	0–5146	912 $\pm$ 1047	0.999	< 0.0001	
	O <sub>3</sub> removal (g ha <sup>-1</sup> )	0–20774	3682 $\pm$ 4226	0.999	< 0.0001	
	PM <sub>10</sub> removal (g ha <sup>-1</sup> )	0–4374	775 $\pm$ 890	0.999	< 0.0001	
	PM <sub>2.5</sub> removal (g ha <sup>-1</sup> )	0–1676	297 $\pm$ 341	0.999	< 0.0001	
	SO <sub>2</sub> removal (g ha <sup>-1</sup> )	0–385	68 $\pm$ 78	0.999	< 0.0001	

231           Twenty-four IRISs have a high level of UES delivery; 90% of tree cover and 82% of  
232 green spaces are concentrated in these 24 IRISs. IRISs with high UES delivery produce about  
233 88% of the total amount of UES in Strasbourg followed by IRISs with moderate delivery (10%)  
234 and low delivery (2%). Relative UES delivery (normalized per area) is important in high  
235 delivery areas except for air pollution removal, which is slightly higher in low delivery areas.  
236 This difference is due to the variations of tree cover. For instance, in high delivery class  
237 sequestered carbon is about 696 kg ha<sup>-1</sup> and removed pollution is about 6 g m<sup>-2</sup> (of tree cover).  
238 In contrast, trees sequestered about 42 kg ha<sup>-1</sup> of carbon and removed about 7.5 g m<sup>-2</sup> of air  
239 pollutants in low delivery class. However, the total amount of pollutant reduction is fifty times  
240 greater in the high delivery class than the low class. This is due to the greater area and greater  
241 percentage of tree cover (25 % of high delivery class is covered by trees while cover percentage  
242 within low delivery class not exceed 2 %). Low-delivery areas are typically located in the  
243 historic center and the Midwestern area of the city, which is dominated by industrial areas with  
244 low tree cover (Fig. 1a).

245



246

247 **Figure 1. (A) Ecosystem services delivery, deprivation and combined (deprivation-UES) distribution maps**

248 **within Strasbourg. H-M through L-M were mapped with the same symbol as we want to highlight**

249 **extreme combinations. (B) Moran's I correlograms of the three indices in the 94 studied IRISs. Significant**

250 **Moran's I values at the 0.05 level are highlighted in bold. Asterisk-marked symbols represent Moran's I**

251 **values significant at the Bonferroni corrected level of  $0.05/10 = 0.005$**

252 **3.2. Deprivation and UES delivery matrix**

253 Comparisons of deprivation condition with UES delivery (Fig. 1a, Table 2) show that 9

254 IRISs are vulnerable (high deprivation and low UES delivery: H-L) where 97% of its housing

255 is apartment-type and only 1% of the area is covered by trees. Eleven IRISs are in deprived

256 condition and moderate UES delivery (H-M). These two classes (H-L and H-M) are located in

257 central districts and the extreme western fringe of the city (Fig. 1A). Conversely, 8 IRISs have

258 a high quality of life with low deprivation and high UES delivery (L-H). They are located on

259 the northern side of the city where 31 % of the total area was covered by trees. Population across

260 the two classes is almost equally distributed with 10% and 9.8% of the total population living  
 261 in vulnerable areas (H-L) and in areas with great quality of life (L-H) respectively.

262 Eight IRISs are considered as highly deprived and high producers of UES (H-H) with  
 263 13% of the total population living in these 8 IRISs. 14 IRISs have a low deprivation condition  
 264 and low UES production (L-L) where 13% of total inhabitants of the city is concentrated.

265 **Table 2. Distribution of IRIS across the deprivation-ES delivery matrix. Parentheses in the first**  
 266 **row represent the percentage of IRISs and the parentheses in the second row represent the**  
 267 **percentage of the population**

<b>Deprivation ES</b>	<b>Low</b>	<b>Moderate</b>	<b>High</b>	<b>Total</b>
<b>Low</b>	14 (32.6) (39.1)	20 (46.5) (31.6)	9 (20.9) (29.7)	43
<b>Moderate</b>	11 (40.7) (65.7)	5 (18.5) (13.8)	11 (40.7) (20.7)	27
<b>High</b>	8 (33.3) (34.7)	8 (33.3) (38.7)	8 (33.3) (26.6)	24
<b>Total</b>	<b>33</b>	<b>33</b>	<b>28</b>	<b>94</b>

268

269 **3.3. Spatial autocorrelation and relationships between social deprivation, green**  
 270 **space and UES parameters**

271 Moran's I correlograms show that the social deprivation, UGS, and UES indices exhibit  
 272 significant spatial autocorrelation (Fig. 1B). Of particular importance is the positive spatial  
 273 autocorrelation in the first distance class, i.e. pairs of IRISs less than 0.527 km from each other  
 274 (social deprivation index:  $I = 0.207$ ,  $P < 0.001$ ; UGS index:  $I = 0.131$ ,  $P < 0.001$ ; UES index:  
 275  $I = 0.074$ ;  $P = 0.043$ ). IRISs close to each other show more similar levels of social deprivation,  
 276 UGS and UES delivery than predicted by a random distribution of these variables, reflecting  
 277 the 'contagious' nature of these parameters in the studied city.

278

279 This significant spatial autocorrelation would suggest that nearby IRISs could not be  
 280 considered as independent sampling units when investigating the relationships of social  
 281 deprivation with UGS and UES parameters. This finding is supported by the results of



282 regression analyses, which show that models accounting for spatial covariance among  
283 observations provide better fit to the data than standard models that assumed independence  
284 among model errors, based on AICc and R<sup>2</sup> values (see below). These regression models show  
285 negative but still non-significant associations of social deprivation with both UGS (non-spatial  
286 model: AICc = 272, R<sup>2</sup> = 0.1%;  $\beta \pm SE = -0.020 \pm 0.104$ ;  $t = -0.193$ ,  $P = 0.8470$ ; spatial model:  
287 AICc = 237, R<sup>2</sup> = 33%;  $\beta \pm SE = -0.107 \pm 0.103$ ;  $t = -1.043$ ,  $P = 0.3000$ ) and UES (non-spatial  
288 model: AICc = 277, R<sup>2</sup> = 0.1%;  $\beta \pm SE = -0.034 \pm 0.104$ ;  $t = -0.327$ ,  $P = 0.7450$ ; spatial model:  
289 AICc = 247, R<sup>2</sup> = 26%;  $\beta \pm SE = -0.099 \pm 0.114$ ;  $t = -0.870$ ,  $P = 0.3870$ ).

290

#### 291 **4. Discussion**

292 We examined the distribution of UES delivery and whether it is associated with social  
293 deprivation condition across census blocks in Strasbourg. Developing a spatial assessment  
294 approach at this level is of interest because the majority of UES are produced at the local scale,  
295 except for climate regulation which is provided at a larger scale (city, region, country) (Baró et  
296 al. 2019). Thus, priorities of decision-making may change by acting on low provision areas and  
297 protecting high provision ones. In agreement with Escobedo et al. (2011) and de Groot et al.  
298 (2010), we argue that urban green patches are most affected by planning and management  
299 decisions at the census block scale. However, the implication of different scales should be  
300 considered because the relevance of UES could change among social groups and scales  
301 depending on needs and local context. Also, managing urban vegetation and related ecosystem  
302 services should be addressed in an integrative way by considering all impacts across temporal,  
303 political, economic, and spatial scales (Escobedo et al. 2011, Andersson et al. 2019).

304 Unlike other studies carried out in Australia (Dobbs et al, 2014) and USA (Landry and  
305 Chakraborty 2009), our results show no significant relationship between UES delivery and  
306 social deprivation. This finding is in line with those previously reported in Barcelona (Baró et

307 al. 2019), where no association was found between ES distribution and household income. The  
308 explanation of our results may rely on two assumptions. The first one is related to the fact that  
309 our analysis was conducted on public green spaces where planting and managing decisions are  
310 made regardless of the socioeconomic status of the neighborhood. This is in line with findings  
311 of Kuras et al. (2020) that suggest that neutral relationship between socioeconomic status and  
312 biodiversity, in general, occurs in public land uses. This raises the question whether local  
313 policies are not interested in establishing a participatory approach or the residents do not feel  
314 concerned by planting strategies of their neighborhood. More investigations are needed to  
315 understand interactions between planners, managers and citizens and how they influence  
316 greening decisions. The second potential explanation could be a possible difference in the speed  
317 of change of green spaces compared to the socioeconomic situation of the population  
318 concerned. Indeed, the spatial distribution of green spaces is not likely to evolve at the same  
319 speed as the socioeconomic parameters of the population, as has previously been highlighted in  
320 a New Zealand study on the relationship between green spaces and public health (Richardson  
321 et al. 2010).

322         Nevertheless, there is one issue that raises particular concern related to the urban  
323 mutation in Strasbourg at the mid and long terms, namely the gentrification (Gerber 1999;  
324 Blanchard 2019). Municipal investments want to make the city uniform in terms of quality of  
325 life. This uniformity can make it greener, but may increase property values which can displace  
326 socioeconomically disadvantaged classes and exclude them from access to amenities  
327 (Anguelovski et al. 2018). In New York (USA), the restoration of Prospect Park resulted in a  
328 change of the socioeconomic status around the park toward socially advantaged population,  
329 while in Barcelona, it was shown that gentrification took place in old industrial and desirable  
330 neighborhoods, but not in the socially deprived neighborhood (Anguelovski et al. 2018).

331 Studying this process in Strasbourg will provide relevant information about the impact of  
332 planning strategies (including greening strategies) on creating (or not) new inequities.

333

334 The trend of negative association between ES delivery and social deprivation in  
335 Strasbourg city may be visible over a more extended period, with taking into account the  
336 consequences of gentrification and interactions between the city and surrounding villages.  
337 Further research should investigate shifts in historical expansion of the city, population  
338 demography, socioeconomic status across neighborhoods to better understand the link between  
339 UES delivery and deprivation conditions over time. This research could help substantiate the  
340 idea of Pickett et al. (2008), who argued that the ecological dynamic within a city is slower than  
341 the social dynamics. Thus, the ecological structure of a particular neighborhood may reflect a  
342 previous social structure, not the existing one.

343 Our approach not only demonstrates the absence of a relationship between ES delivery  
344 and social deprivation, but also detects their spatial distribution including vulnerable areas (i.e.  
345 low ES provision and high social deprivation) and advantaged areas (i.e. high ES provision and  
346 low social deprivation). In our case, it is also important to notice that descriptive analyses show  
347 that the number of deprived neighborhoods with high UES is not negligible, which is consistent  
348 with findings in other European cities like Porto (Graça et al. 2017), Barcelona (Baró et al.  
349 2019) and Paris (Cohen et al. 2012). This neutral relationship may be explained by the planning  
350 trends that facilitate greening actions and thus, UES provision across time (Kuras et al. 2020).  
351 In Strasbourg, major urban projects were carried out in the urban fringe between 1950 and 1970  
352 that represented the core of the social housing urban fabric of the city. At that time, those  
353 neighborhoods were designed toward a predefined percentage of 10 to 40% of green spaces  
354 (POS 1979), which explains the observed high level of UES delivery. Consequently, other  
355 mechanisms like urban policies and landscape structure seem to have an impact on UES

356 delivery and should be studied to identify factors that spatially influence ecosystem services  
357 distribution.

358         As demonstrated by other findings (Dobbs et al. 2014; Wilkerson et al. 2018), studying  
359 the link between landscape structure and UES distribution gives insights on the consequences  
360 of planning strategies on ecosystem services provision. These strategies, which have to be  
361 sustainable, should include actions to improve the quantity, the distribution and the connection  
362 between green spaces to equitably increase ecosystem services provision and hence to ensure a  
363 balance between social and ecological health within the city.

364         UGS within socially-deprived neighborhoods where high population density occurs  
365 may be faced with over-use. In addition to maintaining current UES potential, management  
366 planning in those neighborhoods could focus on environmental quality drivers like recreational  
367 facilities, diversified vegetation features, and maintenance types. Moreover, daily experiences  
368 and perceptions of users could be taken into account to help green spaces services meet resident  
369 needs (Hoffmann et al. 2017). Improved residents' awareness about nearby UGS and its  
370 services could encourage support for its development and maintenance. It could also help build  
371 community cohesion by recognizing local community power and expertise, which facilitates  
372 the involvement of residents into the local decision-making process (Lovell and Taylor 2013).

373         High and moderate UES provisions were generally located within the green belt of the  
374 city that is entirely included within the so-called "Urban Natural Park". This park resides within  
375 the deprived districts "Elsau", "Koenigshoffen" and "Montagne verte" and surrounds the  
376 central core of the city. One issue of concern is that 20% of the green belt could be built in the  
377 future. Protecting this resource by reducing development can help preserve the current UES  
378 flow. Enhancing the connectivity of green spaces within the green belt could also connect  
379 neighborhoods of different socioeconomic levels, improve social mixing, and provide equitable  
380 access to UES among different social categories. New urban projects in proposed development

381 areas should address the gentrification risk to ensure equal opportunities to a healthy  
382 environment among various socioeconomic classes. Urban policies could go beyond  
383 distributional justice to procedural justice to involve different social classes in making  
384 connections among neighborhoods.

385         Spatial results of areas with high or low UES delivery could be crossed with the zoning  
386 of the local urbanism plan (PLU) to better inform on the risk of environmental degradation if  
387 future development occurs. For instance, few high UES provision patches were located within  
388 areas assigned to future urbanization. In this case, strategies to maintain UES provision in these  
389 areas could be investigated (Baró et al. 2016). Conversely, areas assigned to urbanization with  
390 low UES provision could represent an opportunity to create sustainable urban projects that  
391 support social mix, meet social needs, and enhance UES. According to existing literature,  
392 addressing these issues is still challenging for urban renewal policies (Anguelovski and  
393 Martinez Alier 2014; Chen and Yonh Hu 2015).

394         Studying UES from the EJ perspective may produce information stating an equitable  
395 distribution of services provided by UGS. While approaches that can holistically quantify UES  
396 are needed (Dobbs et al. 2014; Riley and Gardiner 2019), it may also be of interest to analyze  
397 only the most easily measured variable, most relevant for local policies, or the most needed by  
398 citizens and use it as a proxy for all UES only if a strong correlation is found between them,  
399 which is our case. Although the correlation is demonstrated for the three quantified services,  
400 the link between these services and others such as cultural services or temperature reduction  
401 services should be explored to have a relatively global vision of the potential of vegetation to  
402 produce benefits for the population. Furthermore, decision-makers could go beyond  
403 characterizing the non-significant disparity in UES distribution and move into identifying  
404 vulnerable neighborhoods and establishing priorities.

405 In sum, our study does not reveal a direct relationship between socioeconomic status  
406 and the distribution of UES provision in Strasbourg city. To have a complete vision of UES  
407 and meet local needs, studies could investigate the impact of socioeconomic factors on the  
408 demand of UES and the relationship between supply and demand of UES (Baró et al. 2015;  
409 Larondelle and Lauf 2016). Wilkerson et al. (2018) report that socially advantaged population  
410 prioritizes recreational services instead of regulation services or production services. Given our  
411 results, does social deprivation mean high demand for UES in Strasbourg city? How does  
412 socioeconomic status influence perception and behaviors?

### 413 **5. Research limitations**

414 The estimation of UES production by i-Tree Eco was analyzed by land-use classes and  
415 disaggregated into the IRIS level. This limitation could be overcome with an increased sampling  
416 that would provide enough plot data to analyze results by IRIS. Multiple models run with locally  
417 specific weather, and pollution data could increase local specificity of the analyses, but these  
418 data are currently lacking.

419

420 This study focused on the IRIS level with varying area. Variables were converted to  
421 density, proportion, and ratios for all IRISs to normalize the area. Dividing the city into equal  
422 spatial units could be interesting to reduce the sensitivity of results to IRISs areas. A multi-scale  
423 study could be more effective to understand different synergies between UES and to connect  
424 local and regional actors.

425 Only tree cover and green spaces densities were analyzed. However, other factors could  
426 influence the provision of UES such as age, diameter, green spaces area, and the total number  
427 of trees (Dobbs et al. 2014). Further research is needed to understand better interactions between  
428 structural variables, ES flow and socioeconomic status. Similarly, only regulation services were  
429 examined in this study. These services mainly depend on tree cover as it presents the ecological

430 reservoir that ensures their production. However, the distribution of other categories of services  
431 such as cultural services may not be associated with tree cover but rather with perception, use,  
432 accessibility, etc. (Riley and Gardiner 2019).

433 In this study only public green spaces have been considered. However, private green  
434 spaces, such as private gardens, cemeteries, allotment gardens and schools' gardens, may also  
435 contribute to total UES provision in the city. Although these private green spaces are not easily  
436 controlled by urban managers, their connection with public spaces to benefit from their  
437 ecological potential would be an interesting path to explore through the environmental justice  
438 framework. In addition, it would also be interesting to verify whether there is compensation  
439 between the UES produced by private spaces and the UES produced by public green spaces  
440 (i.e. verify whether the neighborhoods with low public green spaces and low ES provision have  
441 more access to private gardens and their associated ES).

442

443 Finally, the main challenge of this study was the combination of socioeconomic and  
444 ecological indicators. Composite indicators were created and classified into low, moderate, and  
445 high clusters according to mean and standard deviation values. The aim was to simplify the  
446 information, but it would be interesting to study the impact of each socioeconomic indicator on  
447 each UES. Extensive research is also needed to define a mapping method that is transferable  
448 and easy for decision-makers to use.

449

## 450 **6. Conclusion**

451 This study used a spatially explicit approach to visualize the distribution of UES across  
452 socioeconomic conditions in Strasbourg, France. Using tools that connect UES to a social  
453 context is useful to identify priority areas where enhancing UES and social justice are needed.  
454 Urban policies could prioritize areas with high deprivation and low UES provision by defining

455 strategies that improve the quality and/or the number of green spaces, optimize UES and foster  
456 the connection between population and local green spaces. Distributive environmental justice  
457 studies could be followed by investigations of interactional and procedural justice that aim to  
458 highlight the personal experiences of populations and their involvement in the decision-making  
459 process. Comparing results with perceived access to UES according to the socioeconomic  
460 condition of the population can help to identify the well-being demand in the city. A key  
461 challenge of this work is to integrate outcomes of UES mapping into decision-making processes  
462 that support future urban planning strategies and are consistent with social needs and  
463 environmental restoration of the city. Considering environmental justice patterns associated  
464 with UES in current urban policies may impact the interactions between society and semi-  
465 natural ecosystems within the city in the future.

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