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Landscape ecological enhancement and environmental inequalities in peri-urban areas, using flora as a socio-ecological indicator – The case of the Greater Paris area

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Abstract

1 The peri-urban areas of European metropolises offer a diversity of vegetated spaces – forests,
 2 agricultural land, abandoned or preserved natural areas – that receive ecological attention from
 3 city dwellers. This attention varies locally depending on the socio-economic characteristics of
 4 the population and raises the question of ecological inequalities in accessing different types of
 5 landscapes. Once the target of a green belt project that was never carried out, the peri-urban areas
 6 of the Paris region have undergone different trajectories according to local biophysical, social
 7 and political characteristics. This article shows how these characteristics interconnect and
 8 explain the ecological enhancement or abandonment of landscapes in a complex urban region
 9 using flora as an indicator. To do so, (1) we build a landscape analysis at different scales, (2) we
 10 collect botanical data at 252 sites and analyse it through statistical multivariate analysis, and (3)
 11 we correlate the plant communities' spatial distribution to socio-economic contexts and planning
 12 projects. The results show that the socio-political dimension is decisive for understanding how
 13 and why vegetated areas are enhanced or abandoned and helps to correlate ecological
 14 preservation and socio-economic contexts locally. Flora reflects these dynamics: the type of
 15 management of forest or arable lands, as well as a mixed deprivation/luxury effect on flora. Peri-
 16 urban vegetated landscapes are a target for local political projects that may lessen environmental
 17 inequalities, or conversely and more insidiously, may perpetuate them.

18

Highlights:

- 20 • Landscape preservation in peri-urban areas depends on socio-ecological contexts
- 21 • Using Paris as a case study, we present a landscape typology at different scales
- 22 • Analysis of botanical data reveals contrasted socio-economic trends.
- 23 • This highlights the environmental inequalities around European cities.

24

25 Keywords: biodiversity, luxury effect, plant geography, green belt, landscape analysis.

26

27 **1. INTRODUCTION**

28

29 Green spaces on the outskirts of European metropolises are invested with ecological (Vejre,
 30 Jensen, & Thorsen 2010; McGregor & Simon 2012; Albert & Von Haaren 2017), recreational
 31 (Žlender & Ward Thompson 2017; Komossa, van der Zanden, & Verburg 2019) and social
 32 (Tyrväinen, Mäkinen, & Schipperijn 2007; Sylla, Lasota, & Szewrański 2019) purposes and
 33 practices. These issues are more interconnected than it would appear and the efforts to enhance a
 34 landscape's ecological value are likely to vary from one place to another within a single peri-
 35 urban area. Peri-urban vegetated areas – agriculture land, forests, abandoned or protected natural
 36 areas – extend over larger areas than urban ones, and within more complex spatial patterns,
 37 where city and rural characteristics intermingle (Dolan, Stephens & Moore 2015). Here,
 38 landscape preservation is more dependent on regional planning policies on open spaces (Kühn,
 39 2003) and is facing urban sprawl (Couch, Leontidou & Petschel-Held, 2007; Koprowska,
 40 Łaskiewicz & Kronenberg, 2020) in a very contrasted way, in Europe especially (Shaw *et al.*,
 41 2020). The socio-ecological and political trends behind peri-urban landscapes are yet to be
 42 clarified, especially in the context of environmental inequality (Wolch, Byrne, & Newell 2014).
 43 In such contexts, demographic and social trends may play a strong role in influencing landscape

44 enhancement and planning (Ravetz, Fertner, & Nielsen 2013) and contribute to new
45 demographic trends such as green gentrification (Anguelovski *et al.*, 2019). The importance of
46 socio-economics for urban green spaces and flora is now well known (Hope *et al.*, 2003; Luck *et*
47 *al.*, 2009; Johnson & Swan 2014), and the cultural and social characteristics of the population
48 may also play a role (Kinzig *et al.*, 2005; Grove *et al.*, 2006; Riechers, Barkmann, & Tschardtke,
49 2018). Some recent studies even investigated a “luxury effect”, whereby wealthier populations
50 have an impact on plant composition (Leong, Dunn & Trautwein, 2018). These benefits resonate
51 in the current period, when the population has been confined to their homes during the COVID-
52 19 lockdown measures. This may highlight a new reality of environmental inequality, yet to be
53 studied: having access to a garden or an open view on forests or rural landscapes could play a
54 role in how well people endure the pandemic event.

55 In 1983, the Regional Council of Île-de-France – the region that covers the urban area of
56 Paris and its peri-urban margins – put forward a proposal for a green belt for the Paris metropolis
57 to preserve open spaces from urban sprawl. Later on, the proposal’s objectives shifted towards
58 environmental and recreational ones (Barbieri, 2002). The green belt model had gained
59 popularity worldwide after the Second World War (Amati, 2008), with the most famous example
60 being London’s green belt, which is still in place today (Amati & Yokohari, 2006). Other forms
61 such as the “Green Heart” of the Dutch Randstad have also been successful in preserving open
62 spaces, through strong legal restrictions (Koomen, Dekkers & van Dijk, 2008). In Île-de-France,
63 however, due to a lack of law enforcement and an awkward intermediate positioning between
64 city and countryside (see Figure 1), the project never succeeded in curbing urban development
65 (XXX 2016, masked for blind review). Although the idea of a green belt is still present in
66 regional urban plans (Conseil Régional de l’Île-de- France et Préfecture de la Région d’Île-de-
67 France 2013), no proper green belt policy has been implemented. The consequence is that peri-
68 urban green spaces have followed local trajectories in terms of landscape enhancement measures,
69 depending on their biophysical characteristics but also on inhabitants’ practices and elected
70 representatives’ aims and projects.

71 This paper endeavours to show how, alongside ecological considerations, social and
72 political trends also explain why some landscapes are enhanced and others are not in the green
73 belt context, allowing us to better understand some aspects of environmental inequality
74 mechanisms in accessing vegetated spaces. Following other biogeographical studies with an
75 “interdisciplinary work across the ecological / social divide” (Francis, Lorimer & Raco 2012),
76 our approach is to focus on flora to reveal these local dynamics and discuss their mixed political,
77 social and ecological objectives. This is a contribution to current debates on whether rules or
78 ideas should prevail in landscape preservation (Korthals Altes, 2018). This also places the luxury
79 effect approach (Leong *et al.*, 2018) into a socio-ecological geography of plants and landscapes
80 in European peri-urban areas. This is then a first step towards revealing the unequal access to
81 vegetated spaces for city dwellers (Anguelovski *et al.*, 2019, Haase *et al.*, 2017; Kabisch &
82 Haase, 2014; Łaskiewicz *et al.*, 2018) and how politics deal with those inequalities depending
83 on local socio-ecological contexts.

84 For Paris, some studies have focused on the biodiversity effects of local management
85 practices (Muratet *et al.*, 2007; Politi Bertoncini *et al.*, 2012). More similar to our intentions,
86 others have attempted to connect plant ecological characteristics to social dynamics through
87 statistical correlation inside the city itself (Cohen *et al.*, 2012). Our approach is more exploratory
88 as we offer a more qualitative interpretation. Firstly, we rely on a landscape typology at different
89 scales, and secondly, we analyse plant spatial organisation from 252 botanical surveys and

90 confront them to ecological, social and political interpretations. Our paper will first focus on the
 91 study areas and on data collection and analysis. It will then present the findings, including the
 92 multivariate analysis of plant data at different landscape scales. Lastly, the discussion section
 93 will focus on the socio-ecological influences on landscape preservation and planning.

94

95 2. MATERIALS & METHODS

96

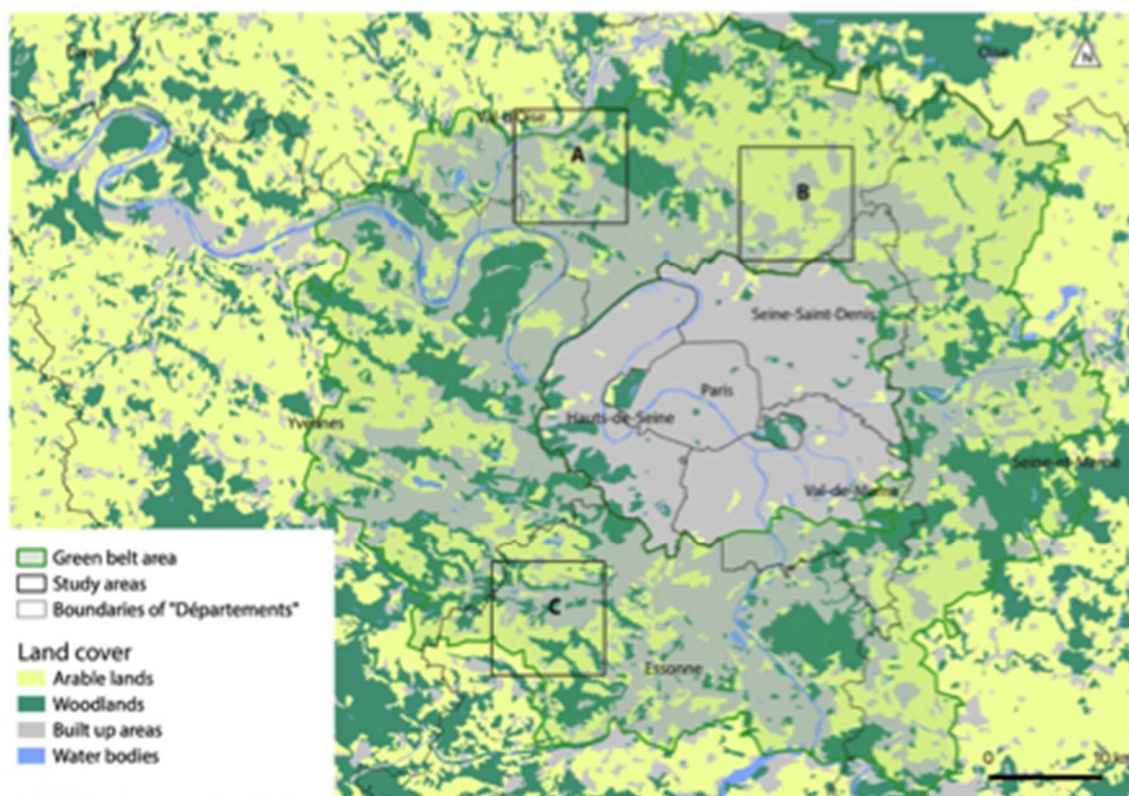
97 2.1. Selection of study areas

98

99 2.1.1. A landscape analysis of peri-urban green spaces

100

101 The green belt area is 20 km wide and connects municipalities situated between 10 and 30 km
 102 from the centre of Paris. Regional authorities based this demarcation on a land cover criterion as
 103 municipalities of the green belt area had to be composed of 40 to 60% open spaces, i.e.,
 104 woodlands, agriculture, natural areas or wastelands. It is therefore unsurprising to observe a high
 105 level of heterogeneity in land occupation and very fragmented landscapes (see Figure 1).
 106 Although it is very common in urban ecology, we did not use an urban-rural gradient approach
 107 (Dunn and Heneghan 2012) as it was not our intention to answer this issue but rather to focus on
 108 the socio-ecological characteristics of the vegetated spaces in the context of the green belt itself.



109

110 **Figure 1:** Study areas, situation map and land cover of the Île-de-France green belt (A:
 111 Pierrelaye-Oise-Montmorency; B: Plaine de France; C: Vallée de Chevreuse). Source of
 112 information: IGN 2011 (land cover and *département* limits) and IAU-Idf 2013 (green belt
 113 boundaries).

114
 115 The whole area covers 2,660 km², so we had to select specific study areas. To do so, we applied
 116 a selection based on landscape analysis inspired from landscape ecology (Forman & Godron
 117 1986) and the later proposals by M. Godron himself (Godron 2012):

- 118 • *A supra-landscape scale* (10x10km). This level refers to regional dimensions, which refer
 119 both to the role of human beings and the weight of topographic arrangements. Two types
 120 of data were used to highlight a typology: land use patterns as mapped in 2011 by the
 121 *Institut Géographique National* (IGN) at a 1:100,000 scale (see Figure 1), and
 122 topography using a digital terrain model (DTM) from the online database Earth Explorer
 123 provided by the US Geological Survey (USGS). Four main types were identified in this
 124 supra-landscape context, using geographic information system software (ArcGIS®) and
 125 heterogeneity indices (Shannon diversity index) from the Fragstat® software: sectors
 126 structured by valleys, sectors of plateaus or plains dominated by agricultural activity,
 127 sectors dominated by forest cover, and finally, very heterogeneous sectors.
- 128 • *A landscape scale* (1x1km). For each supra-landscape types, we identified landscapes and
 129 made a representative selection (see Figure 2). To achieve this, we relied on land use
 130 patterns established at a local scale by photo-interpretation of aerial photographs at a 50
 131 cm resolution from the IGN (see Figure 2), and on topographical units (hills, valleys,
 132 plateaux, etc.) using the same DTM data. Three types of vegetation cover were mapped:
 133 woodlands, bushy/arbustive cover, and herbaceous cover.
- 134 • *An infra-landscape scale* composed of landscape elements. The identification of these
 135 elements relies on landscape ecology proposals (within a landscape, it distinguishes a
 136 matrix, patches and corridors) applied directly on fieldwork: for instance, landscape B1
 137 (figure 2) is composed of an arable land matrix, fallow lands are patches and paths create
 138 bushy/grassy corridors. No prior quantitative study has been carried out due to seasonal
 139 constraints. However, correlation was studied *a posteriori*. Table 1 shows, on the one
 140 hand, that the selected landscape elements are representative of the land cover observed
 141 by photo interpretation. On the other hand, it shows the relevance of the fieldwork
 142 analysis in distinguishing landscape elements not visible in the aerial photograph,
 143 especially for arable land where grass corridors or bushes are hardly visible in aerial
 144 photographs. These highly fragmented peri-urban spaces constantly raise the question of
 145 ecotones and edges. Botanical surveys were sampled from these landscape elements. This
 146 selection was therefore made according to a qualitative approach crossing photo
 147 interpretation analysis and field observation. The goal was to have a representative
 148 selection of landscape elements for a given landscape. The sampling consists of a
 149 selection of types at each level, leading to a selection of representative study areas.

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Table 1: Correlation between vegetation types at study areas scale and vegetation types at survey sites (the greener the colour, the higher the percentage)

| Study area A | Study area B | Study area C |
|--------------|--------------|--------------|
|--------------|--------------|--------------|

| | | % of each vegetation cover on the aerial photograph | % of surveys per land cover | % of each vegetation cover on the aerial photograph | % of surveys per land cover | % of each vegetation cover on the aerial photograph | % of surveys per land cover |
|------------------|-----------------------|---|-----------------------------|---|-----------------------------|---|-----------------------------|
| Vegetation cover | Woodlands | 64 | 53 | 21 | 20 | 71 | 66 |
| | Bushy/arbustive cover | 22 | 13 | 40 | 25 | 18 | 11 |
| | Herbaceous cover | 14 | 16 | 39 | 29 | 11 | 14 |
| Other land cover | Arable land | - | 11 | - | 24 | - | 4 |
| | Others | - | 7 | - | 2 | - | 5 |
| <i>Total (%)</i> | | <i>100</i> | <i>100</i> | <i>100</i> | <i>100</i> | <i>100</i> | <i>100</i> |

158

159 *2.1.2. Landscape criteria and social indicators for the selection of study areas*

160

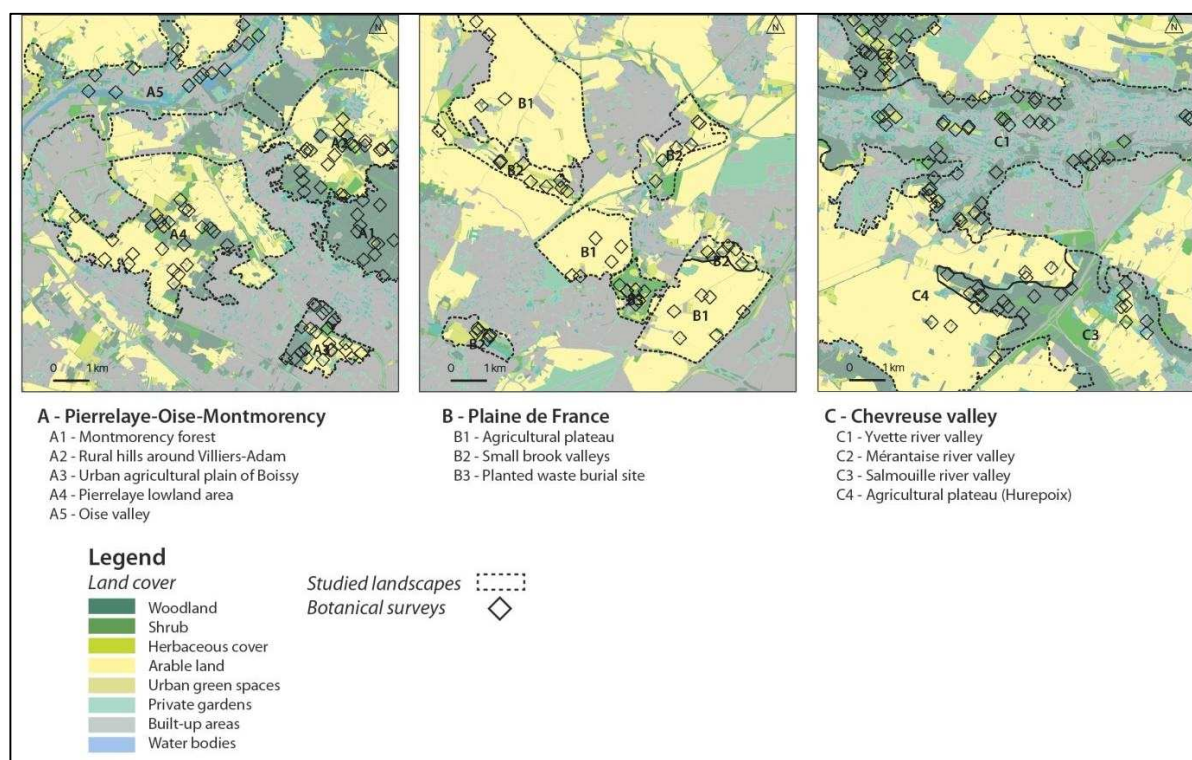
161 Three study areas have been selected (see Figure 1) at a supra-landscape scale following the
 162 latter methodology. It also took into consideration socio-economic indices such as median
 163 household income at the municipality level, obtained from the French statistical institute
 164 (INSEE).

165 A. The Pierrelaye, Oise Valley and Montmorency Forest sector stands out for its forest
 166 cover and for its heterogeneity in terms of land use, topography and socio-economic
 167 characteristics. Five landscapes were identified: (A1) the Montmorency forest, (A2) the rural
 168 hills around the village of Villiers-Adams, (A3) the urban agricultural plain of Boissy (A4) the
 169 Pierrelaye lowland area, and (A5) the Oise Valley. The socio-economic conditions are
 170 contrasted: median household income is estimated by INSEE at 19,084 euros for Pierrelaye and
 171 28,511 euros in Villiers-Adam. 101 botanical surveys were carried out.

172 B. The Plaine de France sector is particularly representative of the contexts where
 173 agricultural occupation dominates in plateau situations, in a fairly homogeneous sector from a
 174 socio-economic point of view, with municipalities with one of the lowest median household
 175 income levels (13,434 euros for Garges-lès-Gonesse, 16,322 euros for Goussainville, for
 176 example). Here, we identified three landscape types: (B1) the agricultural plateau, (B2) the small
 177 brook valleys, and (B3) artificial hills at old waste burial sites. Because of very scarce vegetation
 178 cover, only 51 botanical surveys were carried out.

179 C. Finally, the Chevreuse Valley is characteristic of valley situations, incorporated into
 180 agricultural plateaus. This sector also covers the perimeter of the *Haute-Vallée de Chevreuse*
 181 Regional Natural Park and shows a privileged socio-economic context: 32,938 euros for the
 182 municipality of Gif-sur-Yvette or 30,598 for Orsay. Four landscapes were identified: (C1) the
 183 large and urbanised valley of the river Yvette, (C2) the grassland valley of the river Mérintaise,
 184 (C3) the agricultural wooded valley of the river Salmouille, and (C4) the agricultural Hurepoix
 185 plateau. A hundred botanical surveys were carried out in this last field case (see Figure 2).

186



187
 188 **Figure 2:** Studied landscapes at each study area, related land cover and situation of the botanical
 189 surveys. Source: IGN 2013 (aerial photographs) and IAU-Idf (base for the land cover map).

190

191 2.2. Plant data collection

192

193 252 botanical surveys were carried out in summers 2014 and 2015. All biological types were
 194 taken into account, including woody plants (phanerophytes, chamephytes), perennial herbaceous
 195 plants (hemicryptophytes or geophytes) or annuals (therophytes). Only bryophytes (mosses)
 196 were excluded from the surveys.

197 The ecological characteristics of the plants were determined based on the work of French
 198 biologist Philippe Julve, who runs a programme called CATMINAT (“*Catalogue des Milieux*
 199 *Naturels*”, or Catalogue of Natural Habitats) and has established an online database named
 200 “basflor” (see: <http://perso.wanadoo.fr/philippe.julve/catminat.htm>). His work is also integrated
 201 into another national online database, Tela Botanica (<https://www.tela-botanica.org/>).

202 The minimal area method is borrowed from Sigmatist phytosociology developed by
 203 Braun-Blanquet (Guinochet 1973; Kent 2011): by starting at the very centre of the vegetated
 204 area/landscape element, we identify the species (a single specimen is enough) by gradually
 205 moving away from our starting point in concentric circles. The process continues as long as new
 206 species are being encountered. If no new species are found, then the survey stops. Similarly, if
 207 we reach the edges of the plot and the floral procession changes accordingly, we interrupt the
 208 survey: we are in another plot, or else in an ecotone situation. However, some surveys were
 209 carried out in ecotone situations where they were of significant landscape importance: extensive
 210 bushes/scrubs between afforestation and open areas; shrubbery/herbaceous strips at the edge of
 211 forest plots; or hedges or grass strips in agricultural land. In the case of narrow and linear plant
 212 formations such as herbaceous strips or hedges, a linear path is used instead of concentric circles

213 until the end of the landscape element is reached or until the floral procession is completely
214 changed.

215 The size of the surveys varies according to the size and shape of the landscape elements,
216 and also according to the type of vegetation cover. Surveys carried out in forest areas are more
217 extensive than those of grassland, for instance. The very principle of the minimum area governs
218 this logic. In forests, tree species occupy larger areas, while herbaceous species are much more
219 concentrated in grassland-type formations. A correlation test (Pearson) was carried out on the
220 101 surveys in the first study area to verify whether the variability of the areas had an effect on
221 the number of species collected. This was not the case. The determination coefficient R^2 obtained
222 was 0.036 and therefore shows that there was no correlation between the size of the surveys and
223 the number of species.

224

225 **2.3. Defining plant geography through statistical multivariate analysis**

226

227 A first level of analysis consists in using simple statistical indicators at the landscape level
228 (Table 2): percentage of rare species, percentage of exotic species and Shannon diversity index, a
229 common index to measure species diversity at survey site (Kent 2011), applied here at the
230 landscape scale composed of several surveys.

231 A second level of analysis is to identify the geography of plants in the peri-urban
232 landscapes of Paris. To do so, we used statistical multivariate analysis, a common tool in plant
233 data analysis (Kent 2011; Wildi 2013): (a) correspondence factor analysis (CFA) and (b)
234 Hierarchical Cluster Analysis (HCA) with XLSTAT® software. The plant data obtained from the
235 botanical surveys is arranged in a table of presence/absence of species in the survey sites. The
236 objective of such a ranking is to highlight the species that are present together in the same place
237 and conversely the places that host the same species. As the large number of low- frequency
238 species recorded (1 to 3 appearances) blurs the statistical analysis, we retained the species
239 encountered 4 times or more, i.e., 321 species out of 532. Species encountered fewer than 4
240 times are thus excluded from the statistical analysis.

241 (a) *CFA* - Unlike cluster analyses (see below), CFA does not provide plant groups but
242 helps interpret the plant data by highlighting organising factors (Wildi, 2013). The interpretation
243 of the CFA results is based on various indicators. Some are arithmetic: global inertia of the data,
244 or the eigenvalue of each factor axis, which is in relation with the percentage of inertia. Some are
245 geometric: statistical individuals are projected on a two-axis chart (see Figure 3). In order to
246 analyse this geometric projection, we use two indicators: the statistical contribution of each
247 individual to the given axis (measured as a percentage), and the geometric quality of the
248 projection.

249 (b) *HCA* - Hierarchical Cluster Analysis (HCA) is a statistical method that aims to
250 identify groups within a statistical dataset (Hennig *et al.*, 2015). It leads to the identification of a
251 typology. HCA progressively groups together individuals and then intermediate groups
252 according to their similarities in terms of the species present together. In our case, the first level
253 is made up of 252 individuals and the last level is made up of a single individual. Between the
254 two, HCA provides a series of groupings that are as homogeneous as possible and increasingly
255 fewer in number, in the form of a dendrogram or hierarchical tree. To see the details of this
256 work, we refer to the reading of a previous published work (XXX 2017, masked for blind
257 review). Six groups were selected as relevant.

258

259 3. RESULTS

260

261 3.1. General trends in Paris peri-urban flora

262

263 517 species were specifically identified, to which we must add 15 genus-level identifications.
 264 General ecological trends can be determined with simple indicators to depict the flora found in
 265 Île-de-France's green belt. We specify these trends at the landscape level (see Table 2).

266 *Frequency* – A first analysis consists of highlighting the most frequent species, present in
 267 more than a third of the 252 surveys. In decreasing order: *Urtica dioica*, *Fraxinus excelsior*,
 268 *Rubus cæsius*, *Galium aparine*, *Hedera helix*, *Acer pseudoplatanus*, *Cratægus monogyna*, *Rubus*
 269 *fruticosus*, *Geum urbanum*, *Corylus avellana*, *Dactylis glomerata*, *Sambucus nigra*, *Cirsium*
 270 *arvense*, and *Glechoma hederacea*. These common species are well adapted to peri-urban
 271 contexts under such temperate climates, and draw a picture of a flora strongly determined by
 272 anthropisation. What these species have in common is their ecological plasticity (see
 273 <https://www.tela-botanica.org/> for the ecological characteristics of each species).

274 *Species diversity* - The 517 species represent 32% of the 1,620 species that botanists have
 275 identified in Île-de-France (Jauzein and Nawrot, 2011). 7,756 plant specimens were counted in
 276 total, an average of 31 species per survey, with a minimum of 6 and a maximum of 82. Shannon
 277 diversity index is used here at the landscape scale in order to differentiate species diversity at the
 278 landscape level (Table 2). Chevreuse landscapes are particularly diverse. On the contrary, the
 279 Montmorency forest has the lowest index. Extensive rural landscapes share similar indexes
 280 whereas intensive arable land and landfill sites have lower indexes.

281 *Chorology* – 12% of the species are cosmopolitan and confirm the importance of
 282 anthropogenic factors in structuring the flora of the Paris outskirts, in particular the tendency to
 283 favour plastic species from an ecological point of view. This is confirmed by the fact that 49% of
 284 the species have a very large Eurasian or European range, including most of the very frequent
 285 species. 16% of species in Île-de-France reach their southern (circumboreal or holarctic) or
 286 eastern (Atlantic) limits. 7% exceed it on a continental scale, here species of Mediterranean
 287 origin, perhaps in relation to the urban environment and the heat island effect (Yow 2007). 7%
 288 are introduced and can be considered exotic (see Table 2). They participate in the international
 289 homogenisation of flora. Some of these species are recognised as invasive and represent one of
 290 the biological issues in urban contexts: for example, *Ailanthus altissima* (Motard *et al.*, 2011),
 291 *Reynoutria japonica* (Maurel *et al.*, 2010) *Buddleja davidii* (Tallent-Halsell & Watt, 2009).

292 *Rarity* – Botanists Jauzein and Nawrot (2011) have stated the rarity of species at the Île-
 293 de-France scale. We have classified our own plant data according to this nomenclature, which is
 294 based on an index of the presence of taxa within 1,318 municipalities or similar entities,
 295 weighted for the largest municipalities. The results are expressed in percentage at the landscape
 296 level (Table 2). Some of the rarest species encountered refer to rare habitats: *Carex digitata* is
 297 very sensitive to forest exploitation (*Ibid.*) and found in small clearings on wooded slopes;
 298 *Catabrosa aquatica* is very sensitive to prairie drainage or stream correction, and is restricted to
 299 wetlands; *Carex rostrata*, is found on nutrient-poor peaty substrates, where it can suffer from
 300 eutrophication; the blueberry (*Vaccinium myrtillus*) is limited to the moors on superficial
 301 substrates with cold mesoclimates. Others grow in fairly common environments: *Atropa*
 302 *belladonna*, for example, is not very widespread in Île-de-France and is present in perennial
 303 glades and on the forest edge; *Crepis bursifolia* extends from the Mediterranean, facilitated by its
 304 ruderal character; ruderal fallow lands for *Elytrigia campestris* or *Sisymbrium loeselii*;

305 *Sisymbrium altissimum*, well adapted to urban wasteland, is present in the urban heart of the
 306 Paris conurbation.

307
 308 **Table 2:** Percentage of rare species, exotic species and Shannon diversity index at the landscape
 309 level.

| Supra-landscapes | Landscapes | Land use characteristics | % of rare species | % of exotic species | Shannon diversity index |
|---------------------------------|--------------------|---|-------------------|---------------------|-------------------------|
| A - Pierrelaye-Oise-Montmorency | Montmorency forest | Deciduous forest | 3,76 | 3,76 | 4,34 |
| | Villiers-Adam | Arable land with wooded patches | 2,12 | 2,12 | 4,95 |
| | Boissy | Mixte arable/forest land in urban context | 4,35 | 5,16 | 4,90 |
| | Pierrelaye | Abandoned arable land with shrub patches | 5,80 | 5,65 | 4,97 |
| | Oise valley | River sides | 1,88 | 5,21 | 4,85 |
| B - Plaine de France | Plateau | Intensive arable land | 2,08 | 3,02 | 4,79 |
| | Brook valleys | Small brook valleys | 1,08 | 3,00 | 4,86 |
| | Waste burial site | Land fields with wastes | 3,48 | 8,26 | 4,67 |
| C - Chevreuse valley | Yvette valley | Mixte forest/wetlands/residential areas | 1,63 | 2,52 | 5,31 |
| | Mérantaise valley | Mixte forest/wetlands/pastures | 1,70 | 2,17 | 5,09 |
| | Salmouille valley | Deciduous forest and agriculture patches | 1,44 | 1,88 | 5,10 |
| | Plateau | Intensive arable land | 1,27 | 1,69 | 4,72 |

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313 3.2. A strong correlation with the local contexts

314

315 3.2.1 Towards a peri-urban plant geography

316

317 We applied a CFA to the 252 surveys to gain a general view of the spatial factors driving plant
 318 geography in the context of the green belt area.

319

320 **Table 3:** Eigenvalues and percentages of inertia of the first factor axis of the CFA

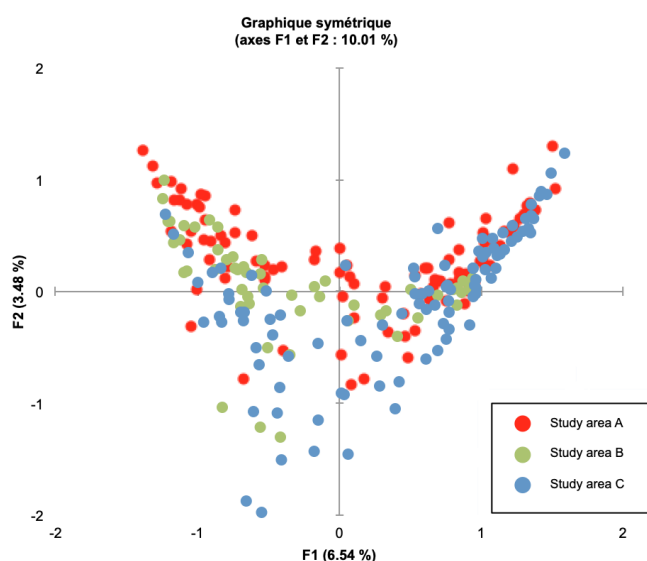
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| | F1 | F2 | F3 | F4 | F5 |
|-------------|-------|--------|--------|--------|--------|
| Eigenvalues | 0.631 | 0.336 | 0.288 | 0.206 | 0.193 |
| Inertia (%) | 6.536 | 3.475 | 2.979 | 2.130 | 2.001 |
| % cumulated | 6.536 | 10.012 | 12.991 | 15.121 | 17.122 |

322

323 With an eigenvalue of 0.631, factor number 1 is a good measure of the degree of structuring of
 324 the data matrix and hence the geography of plants, and there is a clear opposition within all the
 325 surveys, that is visible in the geometric projection (see Figure 3). The first factor F1 represents
 326 6.536% of the total eigenvalue, a relatively low result, however. The flora is generally
 327 unstructured. This result confirms the heterogeneous nature of land cover that had been observed
 328 at the landscape level. Observation of the position of the surveys on axis 1 makes it possible to
 329 spatialise the plant data, showing a dichotomy between surveys carried out in the context of
 330 agricultural land around Pierrelaye, Plaine de France and Plateau du Hurepoix, and surveys that
 331 correspond to the wooded hills around the Yvette valley. The CFA confirms the effect of the
 332 landscape, both statistically and logically: two main types of plant contexts are opposed, on the
 333 one hand forest contexts, on the other open herbaceous contexts and between the two, a variation
 334 of bushy or shrubby vegetation. Factor 1 is directly related to the landscape heterogeneity of the
 335 green belt. In a way, human intervention is also reflected in this axis, where the developed parts
 336 and built landscapes are located at both ends of the axis, while the intermediate part refers to
 337 abandoned vegetation and spontaneous reclamation.

338



339

340 **Figure 3:** Geometric projection of surveys from each study area on the factor axis F1-F2 (A
 341 (red): Pierrelaye-Oise-Montmorency; B (green): Plaine de France; C (blue): Chevreuse Valley).

342

343 Factor F2 also plays a significant role in the structure of the matrix. Factor axis 2 carries 3.475%
 344 of the total inertia. With an eigenvalue of 0.336, its weight is not very high but it remains
 345 interpretable. As for the surveys, contributions are quite high. Of the 18 individuals that
 346 contribute the most to the axis, 15 extend it on the negative quadrant. They are all located in the
 347 Yvette, Méranaise or Salmouille valley landscapes in study area C. Individual species found at
 348 those sites contribute to the negative elongation of the axis: they are hygrophilous, present in
 349 riparian or wet grassland contexts. Factor 2 shows a gradient related to soil moisture. Following
 350 the anthropogenic dimension, soil moisture is the most important biophysical factor.

351

352 3.2.2. Plant communities in relation with landscape types

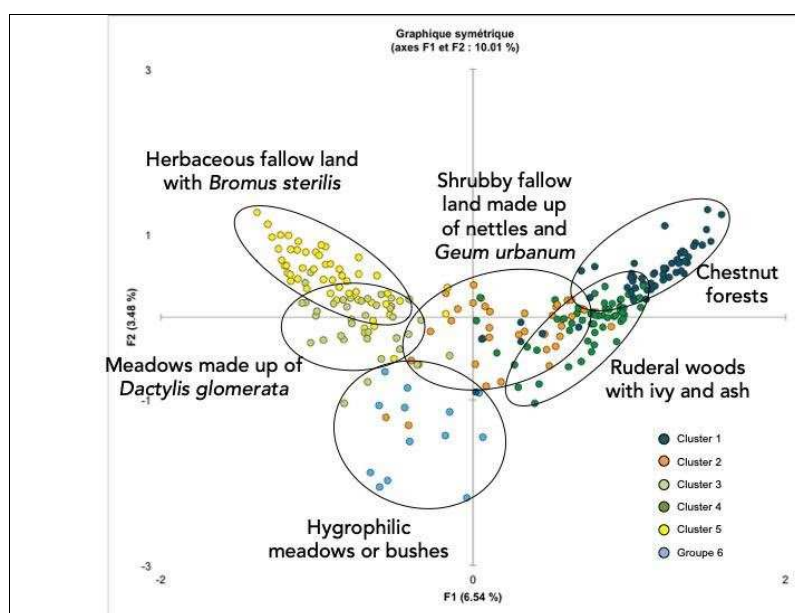
353

354 In a previous article (XXX 2017, masked for blind review), we applied a hierarchical cluster
 355 analysis to the same plant data in order to reveal vegetation types or plant communities. Six
 356 clusters were chosen according to the cluster analysis dendrograms:

- 357 1. Chestnut forest vegetation
- 358 2. Shrubby fallow land made up of nettles (*Urtica dioica*) and *Geum urbanum*
- 359 3. Ruderal woods with ivy (*Hedera helix*) and ash (*Fraxinus excelsior*)
- 360 4. Herbaceous fallow land with *Bromus sterilis*
- 361 5. Meadows made up of *Dactylis glomerata*
- 362 6. Hygrophilic meadows or bushes

363 Here (see Figure 4), we associate those types with the geometrical projection obtained from
 364 the CFA applied to the 252 surveys. This helps specify the designation of vegetation types and
 365 related landscapes.

366



367
368 **Figure 4:** Axes 1 and 2 of the CFA and the six clusters derived from the HCA
369

370 3.3. Correlation between ecological, social and political contexts

371 3.3.1. Testing the correlation between species diversity and median household income

372 Here we present a statistical correlation, as it is often the case when studying socio-economics
373 and biodiversity (Leong *et al.*, 2018). However, contrary to most of those studies, the basic
374 spatial entity is not municipality but landscape, which is consistent with the initial objectives of
375 the study that consisted in identifying the spatial organisation of vegetation. Socio-ecological
376 factors were derived from the multivariate statistical analysis (see Section 3.2 above.). In that
377 way, our approach is inductive, not deductive.

378 We applied Pearson correlation test to landscape entities comparing on the one hand
379 Shannon diversity index and on the other hand median household income for 2013. The latter is
380 a mean of every median household income for municipalities occupying a given landscape
381 (Table 4).

382 **Table 4:** Comparison of Shannon diversity index and median household income at landscape
383 level
384
385
386

| Supra-landscapes | Landscapes | Shannon diversity index | Median household income (€) |
|---------------------------------|--------------------|-------------------------|-----------------------------|
| A - Pierrelaye-Oise-Montmorency | Montmorency forest | 4,34 | 26044 |
| | Villiers-Adam | 4,95 | 26029 |
| | Boissy | 4,90 | 25337 |
| | Pierrelaye | 4,97 | 23345 |
| | Oise valley | 4,85 | 24021 |
| B - Plaine de France | Plateau | 4,79 | 19990 |
| | Brook valleys | 4,86 | 19230 |
| | Waste burial site | 4,67 | 16681 |
| C - Chevreuse valley | Yvette valley | 5,31 | 30107 |
| | Mérantaise valley | 5,09 | 33578 |
| | Salmouille valley | 5,10 | 27753 |
| | Plateau | 4,72 | 27327 |

387
388

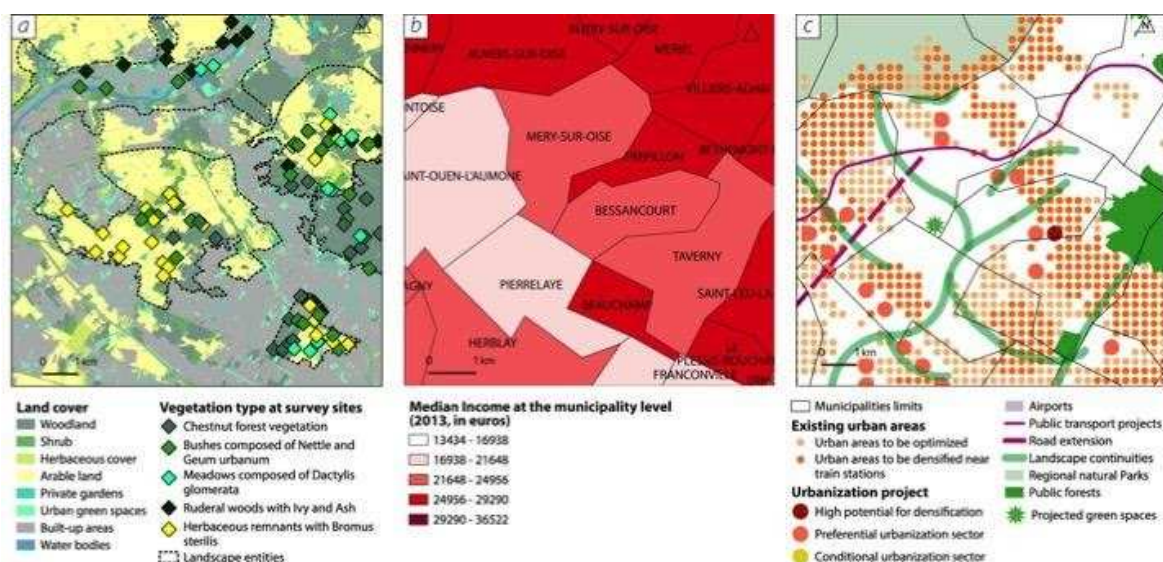
389 The determination coefficient R^2 obtained from Pearson test is 0.50. It indicates a positive
390 correlation between the two sets of data for some data but not for all. The correlation is
391 particularly visible for Chevreuse Valley (C) where high median household incomes correspond
392 to a high level of diversity, in relation with certain types of vegetation communities, for instance
393 those of wetlands. On the contrary, low incomes of Plaine de France (B) correspond to lower
394 levels of diversity. However, supra-landscape A is more contrasted and even reveals
395 contradictions: Montmorency forest has the lowest diversity index but the highest income in the
396 area. As this will be discussed further on, it is related to how public forests are managed.

397 It is therefore relevant to have a closer look at plant communities corresponding to those
398 landscapes in order to have a more precise analysis of which types of green spaces correspond to
399 particular types of socio-economic contexts, in relation with planning contexts and projects.

400

401 3.3.2 Case study A: Pierrelaye-Montmorency-Oise River

402



403

404 **Figure 5:** Map panel for case area A with vegetation type at survey sites (a), median household
 405 income at municipality level (b, according to INSEE) and development and planning projects
 406 and measures (c, according to the 2013 Île-de-France regional plan).

407

408 Figure 5 allows us to link plant communities to ecological, social and planning contexts:

- 409 • Chestnut forest vegetation corresponds to higher sand grounds and is managed through
 410 public forest policies (A1), or as a remnant of former forest occupation (A4).
- 411 • Ruderal woods with ivy and ash correspond to agricultural/urban or forest/urban edges
 412 representing a type of vegetation that currently delineates landscape entities, whether or
 413 not in preserved areas (A3 and A5).
- 414 • Herbaceous fallow land with *Bromus sterilis* is concentrated in the less privileged
 415 Pierrelaye context in abandoned arable land along agricultural paths. This area is
 416 undergoing both environmental projects and an urbanisation process.
- 417 • Meadows are linked to rural landscapes (A4) or urban management by mowing and have
 418 recreation or landscape purposes in privileged areas.
- 419 • The shrubby fallow land made up of nettle (*Urtica dioica*) or *Geum urbanum* represents
 420 abandoned patches of agricultural lands or urban areas, scattered all around in
 421 agricultural or urban remnants.

422 Hygrophilic meadows and bushes are absent despite the presence of the river Oise: plant
 423 composition along the riverside is very anthropic, mixing garden species and very urban
 424 management of a landscape corridor.

425 There is a spatial correlation between municipalities with the lowest median household
 426 income and projected urbanisation. The wealthier areas are more rural and are located close to
 427 existing environmental amenities (regional natural park or public forest) and excluded from new
 428 urban development.

429

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435 *3.3.2. Case study B: Plaine de France*

436

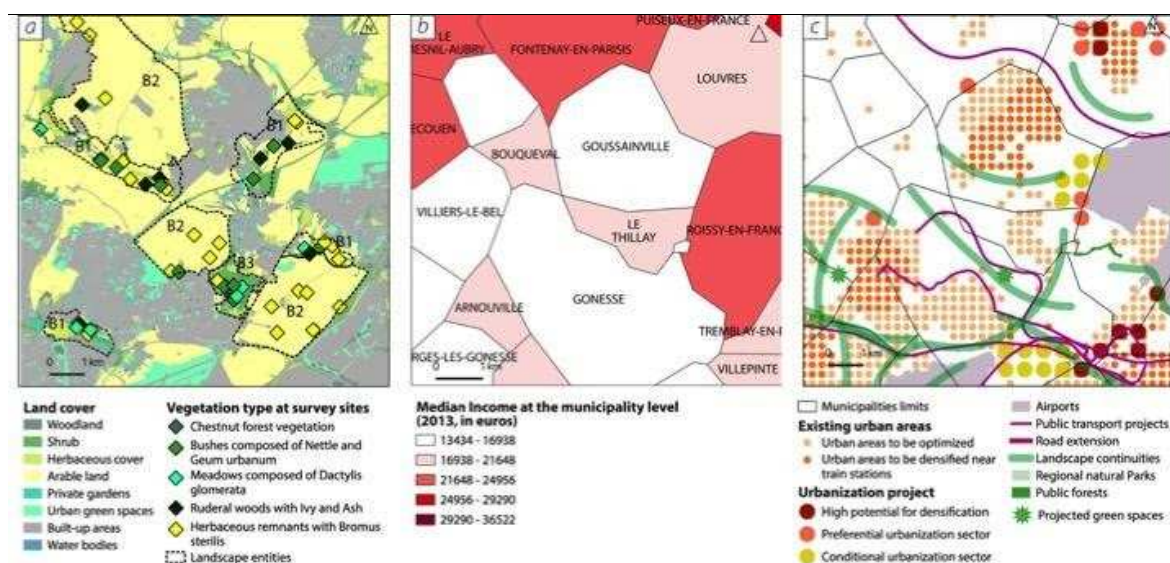


Figure 6: Map panel for case area B with vegetation type at survey sites (a), median household income at municipality level (b, according to INSEE) and development and planning projects and measures (c, according to the 2013 Île-de-France regional plan).

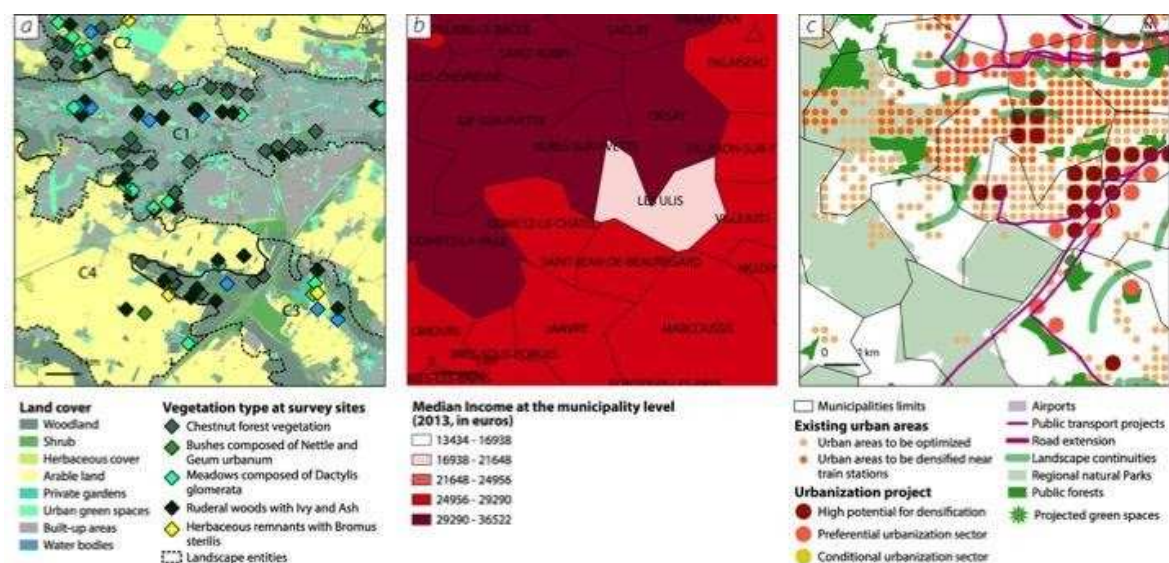
Only four types of communities appear here:

- Ruderal woods with ivy and ash are very scarce and only remain on the slope of the brook valley, where agriculture was unable to develop.
- Herbaceous fallow land with *Bromus sterilis* are among the largest and are located in agricultural settings: they mostly consist of vegetation along agricultural paths, and some fallow land.
- Meadows are linked to landscape maintenance by mowing or horse/cattle breeding, with landscape objectives more than agricultural ones.
- The shrubby areas composed of nettle and *Geum urbanum* are very present, too, and are related to abandoned patches or very ruderal contexts such as in landscape B3.

The two types of habitats that are the most frequent targets for ecological enhancement projects – forests and wetlands – are not present here because of the long history of agricultural use but also due to a lack of attention to potential areas along the brook valleys: wetlands do appear here, but the plant composition is a mix of hygrophilic plants with ruderal plants, so wetlands belong to the herbaceous or shrubby fallow land or wasteland. The whole area is very much under urban pressure although there are a few proposals to create new natural areas. This is the case of landscape B3, a newly-created park in the Gonesse municipality.

3.3.3. Case study C: Chevreuse Valley

469



470
471 **Figure 7:** Map panel for case area C with vegetation type at survey sites (a), median household
472 income at municipality level (b, according to INSEE) and development and planning projects
473 and measures (c, according to the 2013 Île-de-France regional plan).
474

475 Plant communities, social context and planning projects converge to depict a privileged area.
476 - Chestnut woods are linked to the topographical context and to forestry management in response
477 to recreational activities and ecological preservation (landscape continuities).
478 - Ruderal woods with ivy and ash are patches scattered in the urban or agricultural fabric, and
479 they contribute to the green quality of both landscapes
480 - Herbaceous fallow land with *Bromus sterilis* is scarce and located in an agricultural setting:
481 fallows or paths.
482 - Meadows are linked to landscape maintenance by mowing or horse breeding.
483 - Hygrophilic meadows and bushes are located at the bottom of the valley, and are preserved for
484 flood regulation and/or biodiversity conservation
485 - The shrubby fallow land made up of nettle and *Geum urbanum* is very rare (only two cases).
486 Vegetated landscapes here are heavily managed and preserved for ecological purposes
487 and recreational uses. They are part of the identity of this wealthy area where urban development
488 is very much concentrated in the eastern areas and restricted in the wealthier areas.
489

490 4. DISCUSSION

491
492 Our results raise three levels of discussion in the perspective of a socio-ecological geography of
493 vegetated landscapes in peri-urban areas: the importance of forest and agricultural management
494 in relation with the proximity of the city, the relationship between flora diversity and socio-
495 economics through phenomenon such as the so-called “luxury effect”, environmental inequalities
496 mitigation at a local level.
497

498 4.1. Forest and agricultural management in relation with the proximity of the city

499

500 Peri-urban landscapes are dependent on the management objectives applied to forest and
 501 agricultural areas. There are several issues at stake: economical (agriculture or forestry),
 502 ecological (preservation of environments and resources) and social (use of these areas).

503 First of all, our results highlight the role of state-owned forests in the Parisian context.
 504 Chestnut forest communities are the result of management by the National Forestry Office based
 505 on the principle of multifunctionality of spaces (Moigneu, 2005): timber exploitation issues are
 506 combined with recreational and ecological issues. Urban forests play an important role in the
 507 various green infrastructure projects and provide a multitude of ecological services (Escobedo *et*
 508 *al.*, 2019). Parisian peri-urban forests fulfil the same role (XXX *et al.*, 2017, mask for blind
 509 review). The paradox is that these forest communities do not have the highest biological
 510 diversity, due to unfavourable acidic soils but also to very advanced management by public
 511 authorities (timber exploitation, cleaning of the under-growth, planting, tree pruning). Focusing
 512 on forests in peri-urban areas for ecological projects is first of all focusing on the landscape, as it
 513 provides amenities to city dwellers. Studies have shown, in the Czech Republic for example
 514 (Čepelová & Münzbergová, 2012), and our results are in line with this, that smaller, more
 515 marginal wooded areas, closer to human activities, present a better species diversity, although
 516 this shows ruderal species that are more common in the urban context (*Rubus caesius*, *Hedera*
 517 *helix*, *Fraxinus exelcior*, *Sambucus nigra*, etc.). Inaccessible, seemingly disordered, sometimes
 518 occupied by informal activities (squatting, waste disposal), these small woods do not, on the
 519 other hand, meet the landscape expectations of the inhabitants. In this respect, they are close to
 520 the socio-ecological dynamics of vacant lots (Rega-Brodsky *et al.*, 2018).

521 Secondly, arable land and its spontaneous vegetation are also dependent on the intensity
 522 of farming. From this point of view, arable land is poorly integrated into the city, as shown in
 523 study area B (Plaine de France): the flora of these areas is rudimentary, not very visible and not
 524 very desired. The relationship between attachment and charismatic species has been shown by
 525 McGinlay *et al.* (2017). In particular, characteristic nitrophilic species such as *Urtica dioica* and
 526 *Galium aparine* are found in abundance in *Bromus sterilis* communities which dominate the
 527 landscape here, echoing the European synanthropic flora (Küzmič *et al.*, 2016). In addition, the
 528 intensive agricultural activity leaves no space for recreational activities by city dwellers. For this
 529 to be the case, there is a need for green infrastructure projects that promote a more ecological
 530 approach and integrate landscape considerations that city dwellers appreciate. This is the case
 531 around Paris with the PNR (Desponds, 2007), it is also verified with the green belt policy for
 532 London (Amati & Yokohari, 2006) or the green heart policy in the Netherlands (Rij *et al.*, 2008).
 533 As the more extensive rural landscapes in area A show, this has positive effects on flora, since
 534 segetal species, which have been damaged by intensive agriculture (Fonderflick *et al.*, 2020), are
 535 gradually returning, as are poppies (*Papaver roheas*), for example.

536

537 4.2. Relationship between flora diversity and socio-economics

538

539 In addition to multifunctional landscape management, the social perspective is essential to
 540 understand landscape and flora dynamics in peri-urban areas. Behind the positive results
 541 obtained by some areas in terms of biodiversity are specific socio-economic contexts. This has
 542 been shown through the concept of “luxury effect” on flora, for example in Phoenix, where plant
 543 diversity and inhabitants’ affluence are correlated (Hope *et al.*, 2003). In South Africa, Lubbe *et*
 544 *al.* (2010) verified this on the flora of gardens: the highest species diversity is obtained by
 545 gardens in the most affluent neighbourhoods, the lowest by those in the most disadvantaged

546 neighbourhoods. A new paradox then arises with regard to the flora: in the first case, it is exotic
 547 flora that is mainly present, while local flora - more correlated to the environment - is more
 548 present in the second case. Although climate is very different – temperate to oceanic for Paris,
 549 climate having a mitigating effect (Meléndez-Ackerman *et al.*, 2014) – we observe similar trends
 550 with regard to spontaneous flora. In the Chevreuse Valley, for example, among the wealthier
 551 sectors of the urban area (Table 3), species escaping from gardens (*Prunus laurocerasus*,
 552 *Aesculus hippocastanum*, *Symphoricarpos albus*...) or planted (poplars) contribute to enriching
 553 the landscape and show "an inverse luxury effect for native plants" (Leong *et al.*, 2018), in
 554 correlation with the environmental impact of gardens (Cameron *et al.*, 2012). Thus, for more
 555 disadvantaged areas, in Plaine de France for example (Table 2), it is the local, more common
 556 flora that prevails (*Fraxinus excelsior*, *Hedera helix*, *Sambucus nigra*, *Rubus fruticosus*) in
 557 relation to a ruderal context, which is also less wooded, another dimension of the luxury effect
 558 (Leong *et al.*, 2018).

559 A luxury effect can also be observed in the most natural spaces. In the case of Paris, it
 560 goes hand in hand with local policies supporting biodiversity that also respond to long-standing
 561 landscape policies in favour of a certain type of living environment, i.e., for well-off populations
 562 (Leong *et al.*, 2018): the luxury effect is not only a result of the effect of inhabitants on the
 563 vegetation, but also the result of a decision to come and live in a place that is already locally
 564 enhanced, and even built for that purpose. In underprivileged areas, there is a desire to create
 565 new areas of biodiversity, as can be seen in the surveys carried out on former waste landfill sites
 566 in Plaine de France (B3). However, given the unfavourable initial context, the floral procession
 567 is less qualitative, leaving space for invasive species. There, biodiversity preservation projects
 568 serve as an argument that aims to improve the image of the territory, for social purposes.
 569

570 4.3. Mitigating environmental inequalities at a local level

571
 572 The socio-ecological geography of plants reveals the importance of local territories. This leads to
 573 a reflection on environmental inequalities and on the means to mitigate them. It is not just a
 574 question of having access to a green space (Kabisch *et al.*, 2016). Our results show that there are
 575 many different types of green spaces, not all of which meet either the ecological challenges or
 576 the landscape expectations of city dwellers. This raises the question of regional harmonisation
 577 policies that seek to mitigate those inequalities. Otherwise, each territory follows its own path
 578 according to its own socio-economic context. As Leong *et al.* (2018) observe, "the luxury effect
 579 may be reduced in more socialist cities, where income inequality is reduced, and urban planning
 580 is more focused on the equitable distribution of city resources". The liberal rules of the
 581 residential market allow a displacement of the richest populations to the most attractive places.
 582 Green spaces are a very strong argument, as shown by market prices (Sander & Polasky, 2009)
 583 or the hedonic pricing methods (Sylla *et al.*, 2019). New trends emerge such as green
 584 gentrification, i.e., "new or intensified urban socio-spatial inequalities produced by urban
 585 greening agendas and interventions, such as greenways, parks, community gardens, ecological
 586 corridors, or green infrastructure" (Anguelovski *et al.*, 2019). This is true for some of our studied
 587 areas – the Chevreuse Valley, the Montmorency forest, the Oise Valley – where there are
 588 strategies, visible in planning projects (see paragraph 3.3. above), "for attracting commercial and
 589 residential investments and bringing in more socially – and ethnically – privileged residents"
 590 (Anguelovski *et al.*, 2019). This was stated by then minister for the interior and planning,
 591 Nicolas Sarkozy, in 2007, cited by H. Brédif, (2009), about a university development project

592 near the Chevreuse Valley: "I want the place where we are today to become one of those places
593 where a company is prepared to spend a fortune to set up, one of those places that students from
594 all over the world dream of, one of those places that are themselves a reference on a curriculum
595 vitae. I believe that this world-renowned university centre that Europe is looking for is becoming
596 a reality right here".

597 The planting of a forest on 2000 hectares of polluted arable land in the Pierrelaye plain
598 (landscape A4 on figure 2, see SMAPP 2018 for details), where waste had accumulated and
599 travellers had settled, has a similar kind of objective where "competitive landscapes" serve
600 global competition, without considering the vulnerability of the local population (Anguelovski *et*
601 *al.*, 2019). Another paradox is that the Pierrelaye area, since it has a high level of plant diversity,
602 is among our selected landscapes with the rarest species, and shows a high level of connectivity.
603 The environmental and social relegation of the Pierrelaye plain does not result in degradation of
604 its biodiversity and the forest project can be considered a "sustainable fallacy" (Schuetze &
605 Chelleri, 2016).

606 In order to circumvent these issues, it is certainly necessary to develop a strategy at the
607 local level, as the failure of regional green infrastructure projects has shown, for example in
608 Seoul (Schuetze & Chelleri, 2016). This requires the development of smaller areas, for instance,
609 vacant lots (Anderson & Minor, 2017; Čepelová & Münzbergová, 2012) and enabling the
610 populations of the most disadvantaged neighbourhoods to experience the flora differently, for
611 example, by foraging (Shackleton *et al.*, 2017). This scale of action sees a reconfiguration of the
612 approach of the commons in the city, where nature areas and the resources they contain are
613 designed by the community according to socially situated uses, in a perspective of environmental
614 justice that really mobilises the needs of the inhabitants, regardless of their socio-economic
615 profile or origin (Schlosberg, 2007).

616

617 **CONCLUSION**

618

619 The objective of this article was to show the need to articulate botanical data, socio-economic
620 data and the design of landscape projects. This is a prerequisite for understanding why ecological
621 enhancement takes place in some places and not in others. More broadly, the issue of regulating
622 environmental inequalities raises the question of scales of policies. The Parisian case shows that
623 the inefficiency of the regional green belt policy has led to a diversity of contexts in which many
624 of the effects described elsewhere, such as the luxury effect on flora and the dynamics of green
625 gentrification, can be identified.

626 This approach, which is a bridge between social sciences and ecological sciences, also
627 makes it possible to nuance the positive and consensual discourses around biodiversity and
628 landscape preservation. As we discussed, many contradictions arise. The Greater Paris area is
629 emblematic of those intermediate urban/rural landscapes with very fragmented spaces that are
630 found in other French metropolises and elsewhere in Europe. By identifying landscape entities
631 and revealing contradictions, our proposal offers a more adapted methodology in contrast with
632 studies in countries where demographic history and trends have created very precise socio-
633 economic delineations, such as the US. For Europe, and Paris particularly, spatial development is
634 very contrasted, with some landscapes being preserved for many decades, whereas others are
635 under constant development pressure. This situation calls for a landscape assessment through
636 longer periods of time.

637 To meet these challenges, we believe that regional policies should not be abandoned in
 638 order to maintain coherence, while inhabitants' local practices should be given greater emphasis.
 639 The interweaving of socio-economic and ecological phenomena has to continue to be better
 640 studied to clearly identify the criteria for the ecological and social success of landscape projects
 641 in peri-urban areas involving vegetated spaces

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