Evaluation of floristic diversity in urban areas as a basis for habitat management

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ABSTRACT

Questions: How can floristic diversity be evaluated in conservation plans, to identify sites of highest interest for biodiversity? What are the mechanisms influencing the distribution of species in human-dominated environments? What are the best criteria to identify sites where active urban management is most likely to enhance floristic diversity?

Location: The Hauts-de-Seine district bordering Paris (France).

Methods: We described the floristic diversity in one of the most urbanized French districts through the inventory of ca. 1000 sites located in 23 habitats. We built a new Index of Floristic Interest (IFI), integrating information on richness, indigeneity, typicality and rarity of species, to identify sites and habitats of highest interest for conservation. Finally, we explored the relationship between site IFI and Land Use Patterns

Results: We observed a total of 626 vascular plant species. Habitats with highest IFI were typically situated in “semi-natural” environments or environments with moderate human impacts. We also showed that neighboring (urban) structures had a significant influence on the floristic interest of sites: for example, the presence of collective dwellings around a site had a strong negative impact on IFI.

Conclusions: Our approach can be used to optimize management in urban zones; we illustrate such possibilities by defining a ‘Site Potential Value’, which was then compared with the observed IFI, to identify areas (e.g. river banks) where a better management could improve the district’s biodiversity.

Key-words: Index of Floristic Interest, Land Use Pattern, Spatial distribution, Urban biodiversity, Habitat units, Human impact, Conservation, Environmental planning

INTRODUCTION

Biodiversity in urban areas has long been neglected by ecologists, because urban ecosystems were regarded as highly disturbed and supporting relatively common species. Although the latter assertion is generally true (Kühn & Klotz 2006), considering urban biodiversity and the mechanisms that control its dynamics is of major importance for conservation biology. First, urbanization is a central component of land-transformation processes worldwide and one of the leading causes of species extinction (McKinney 2006). Cities are often located at the crossroads of major communication routes and may act as 'hotspots' of invasive species, which generally thrive in disturbed habitats. Understanding the mechanisms underlying the dynamics of invasive species, and biodiversity in general, in urban habitats is thus central to slow down the loss of biodiversity inside and outside cities. In addition, a majority of the world's human population lives in urban areas (Grimm et al. 2000), where the existence of healthy green zones supporting a variety of plant and animal species has been shown to contribute to human welfare (Tzoulas et al. 2007).

As a result of conservation and human welfare concerns, extensive studies of biodiversity, especially flora, have started to emerge in urban areas. A number of these studies were specific to a single habitat or land-use type, such as woodlands (Goodfellow & Peterken 1981; Godefroid & Koedam 2003), wetlands (Mushet et al. 2002), wastelands (Muratet et al. 2007) or parks and gardens (Hermy & Cornelis 2000; DeCandido 2004; Thompson et al. 2004). However, a growing number of studies also addressed the distribution of common flora across all urban zones (see Pysek 1998 for a review) using standardized sampling (e.g. Berlin, Germany, Zerbe et al. 2003; Brussels, Belgium, Godefroid 2001; Plymouth, England, Kent et al. 1999; Birmingham, England, Angold et al. 2006; Rome, Italy, Ricotta et al. 2001; and Almeria, Spain, Dana et al. 2002). These studies showed that cities harbor relatively high plant diversity due to the co-existence of a large variety of habitats. However, urbanization is also generally associated with increased frequency of alien species and loss of some habitat-specialist plants, such as wetland species.

Although these large-scale inventories of urban floristic diversity carry key information to understand the dynamics of biodiversity in urban areas, they remain mostly descriptive, i.e. they do not investigate the mechanisms responsible for observed patterns. The first studies in mechanistic urban ecology are recent (reviewed in Shochat et al. 2006) and concern animal populations mainly. Studies examining the floristic composition in the different land use types and assessing the impact of urban structures on floristic diversity are scarce (Kent et al. 1999; Roy et al. 1999; Maurer et al. 2000; Zerbe et al. 2003; Godefroid & Koedam 2007). Such knowledge is however necessary to incorporate biodiversity in urban planning and favour the maintenance of diverse urban ecosystems (Lofvenhaft et al. 2002). In the present study, we examine plant diversity in one of the most urbanized French districts (Hauts-de-Seine) and explore the potential influence of urbanization and urban structures on such diversity. We undertook a comprehensive habitat mapping (as in Sukopp & Weiler 1988) and performed about 1000 inventories to evaluate the floristic interest of sites and habitats. Our aims were:

(1) To describe species distribution over the whole region and locate areas of highest interest for plant diversity. Following previous studies describing site quality (Ratcliffe 1977; Wittig & Schreiber 1983; Swink & Whilelm 1994; Maleyx 2001; Godefroid et al. 2003 and reviewed in Spellerberg 1992), we defined a new Index of Floristic Interest (IFI), combining information on richness, indigeneity, typicality and rarity of species present in a site or habitat. The use of IFI allowed us to rank habitats according to their contribution to the district's biodiversity.

(2) To evaluate the influence of urbanization on the floristic diversity of sites. Using data from the Land Use Pattern, we explored the relationship between site floristic interest and the presence of various urban structures around sites.

(3) To identify habitats and sites where active urban management is most likely to enhance floristic diversity. Using the available knowledge on the influence of urban structures on floristic interest, we built an index of Site Potential Value (SPV) that can be used to direct urban planning.

MATERIALS AND METHODS

Study area

The Hauts-de-Seine district (French administrative ‘département’) is a crescent-shaped area of 176 km² (Fig.1) bordering the west of Paris (48°50’ N; 2°14’ E). The climate is oceanic with continental trends (mean annual temperature: 11.7°C and annual rainfall: 641mm). Hauts-de-Seine is composed of (1) a plain, (2) small hills, which reach 180 m at their highest point and are least favorable to urbanization and (3) a plateau, divided into 5 sub-regions by small valleys, relics of ancient waterways. The Seine River borders the northern part of the district for 39 km. This district is one of the most densely populated areas of France (8118 vs. 95 people/km² on average in France, INSEE 1999). Built zones have covered about 70% of the territory for over 20 years (IAURIF 2003).

Sampling design and inventories

Using an exhaustive map of green spaces in Hauts-de-Seine (“cadastre vert”, Dewilde & Lafréchoux 2001), we calculated the total area occupied by each of 10 types of green spaces in the district. Inventory sites were sampled at random within each type; the area inventoried in each green space type was proportional to its total area in the district (proportional stratified sampling). Inventory sites were generally defined as the total area covered by a given plant community (used as a proxy for habitat type), and thus ranged from 3.39 to 116 415 m², except in forests where sites were forester-defined stands (from 806 to 40 842 m²). Following Westhoff & Werner (1983) and Kendle & Forbes (1997), each habitat type was assigned to one of three levels of anthropogenic impact: “semi-natural”, “intermediate" or “anthropogenic” (Table 1).

Between 2001 and 2005, we inventoried a total of 986 sites, in which we recorded all present wild vascular species once, in spring, summer or autumn. Species were classified as "indigenous" or "naturalized" according to a list compiled by professional botanists of the National Botanical Conservatory of the Parisian region (CBNBP 2008). Naturalized species are non-indigenous species that now behave like indigenous species (Richardson et al. 2000). We dismissed cultivated or casual species that may reproduce occasionally in an area, but which do not form self-replacing populations and are unlikely to contribute significantly to community processes.

Quantifying floristic interest: Index of floristic interest

Species richness (Rich), the total number of species observed in a given location, is a widely used measure of biodiversity to evaluate habitat or site interest for conservation. However, not all species are equivalent and some of their characteristics should be incorporated to describe site interest accurately. Rare species, for example, often receive special attention in conservation programs. We measured the rarity of a species as the proportion of district sites in which it was not observed. Species rarity varied between 0.999 (e.g. for *Callitriche stagnalis* Scop. and *Serratula tinctoria* L., inventoried only once in 986 sites) and 0.365 (e.g. for *Taraxacum campylodes* G.E.Haglund inventoried in 626 sites). A site rarity index (Rar) was calculated as the average rarity over all species. We also considered two other characteristics that potentially influence conservation choices: indigeneity (Ind), the proportion of indigenous species (see definition above) and typicality (Typic), the proportion of typical species in each site. Typical species are habitat-specific species that were observed in a single habitat type in the Hauts-de-Seine (e.g. *Myriophyllum spicatum* L. was observed in aquatic habitats only -nine sites- and *Calluna vulgaris* (L.) Hull in Oak groves only -eight sites).

These four indices were significantly but weakly correlated across sites (Spearman rank correlation coefficient between 0.04 and 0.39), so that the information they carry is largely complementary. Using a one way ANOVA, we showed that there were strong differences among seasons of inventory for all indices (P <0.005); to correct for the season effect, the four indices were thus incorporated as follows to build the "Index of Floristic Interest" (IFI):

$$IFI = \frac{1}{4}(Rich/Richmax + Typic/Typicmax + Ind/Indmax + Rar/Rarmax)$$

where each index is standardized by its maximum value observed in a given season, which removes differences in IFI among seasons. By construction, IFI lies between 0 and 1 (highest floristic interest) and can be defined at the site or habitat (mean across sites) level.

Impact of urbanization on floristic interest

Characteristics of urbanization

Using a Geographic Information System, we calculated the area of inventory sites and their distance from the center of Paris, which is negatively correlated with intensity of urbanization (linear regression, *proportion of built up land* = 1.18 – 0.05 x *distance*, r^2 = 0.83, P <0.0001). The Land Use Pattern (LUP, IAURIF 2003) is composed of 83 different classes, which were grouped into nine major classes for the present study (Table 2). Using MapInfo software (MapInfo corporation 2004), we defined a buffer around each site and estimated the proportion of each class within this buffer. To select the most relevant scale at which urbanization influences site floristic interest, we varied the buffer radius between 100 m and 2 km by steps of 100 m.

Relationship between floristic diversity and anthropogenic variables

To assess the impact of broad-sense environment and urbanization on floristic interest, we explored the relationships between the floristic interest of sites (IFI) and (1) habitat type, (2) site age, defined as the number of years during which the site LUP class remained the same (3) distance from the center of Paris, (4) the (Arcsine square-root transformed) proportion of the nine LUP classes in a buffer around the site. Because the IFI (species richness notably) strongly depends on site area, the latter was added as a quantitative covariate in the model.

Hierarchical partitioning (Walsh & McNally 2004) and randomization (500 times) were conducted on r^2 values to isolate variables with a significant independent effect on the IFI (the signs of the correlations were given by simple linear regressions) and to correct for multicollinearity (McNally 2002).

Observed vs. potential floristic interest

Using observed IFI values at 986 sites and inverse distance weighted (IDW) interpolation, we interpolated the IFI values in the non-sampled areas as a weighted average of a defined number of neighborhood sites within a 1.5 km-radius. The weight assigned to each neighborhood site decreased with increasing distance to the unsampled areas. This generated a map of “interpolated floristic interest”. Although interpolation might be problematic in highly structured landscapes, we showed that interpolation successfully predicted IFI in a subset of 186 sites used as ground-truthed samples (R= 0.364, p<0.001, mean over five replicates).

We also built a map of potential floristic interest by extracting LUP classes with a significant effect on observed IFI and weighting their proportion by the R squares obtained from hierarchical partitioning. The Site Potential Value (SPV) was thus defined as follows:

$$SPV = \sum_i (-1)^j r_i^2 \times \mathrm{Arcsin}\sqrt{area_i}$$

where $area_i$ is the proportion of area covered by LUP class i in a 200 m radius buffer; j = 1 (2) for LUP classes with a negative (respectively positive) effect on observed IFI values. SPV was calculated for all inventoried sites and interpolated to the whole district (using IDW as described above) to generate the map of “potential floristic interest”. To assess whether SPV truly carried information on the actual floristic interest, we confronted it with ground-truthed samples by calculating SPV from a subsample of our dataset (n = 800 sites sampled without replacement) and comparing predicted SPV values to observed IFI values in the remaining sites (n = 186 sites). This operation was repeated five times.

RESULTS

Over 986 sites we observed a total of 626 plant species, including 522 indigenous species and 104 (16.6%) naturalized species. Within habitats, the observed number of species varied between 19 (aquatic vegetation) and 365 (wastelands, Table 1).

Habitat Floristic interest

To estimate the floristic interest of each habitat, we scored each index and the IFI separately (Fig.2). Generally, the ranking of habitats varied across the four indices of floristic diversity. However, habitats of high floristic interest were mostly found in intermediate or semi-natural environments, as expected, whereas anthropogenic habitats were usually species-poor and contained more common and non-indigenous species. For example, the largest species richness was observed in wet thickets (42.3 species on average), a semi-natural habitat. In total, semi-natural and intermediate habitats hosted 477 and 523 species, respectively, whereas 315 species only were found in anthropogenic habitats. Except for the aquatic habitat, typicality was rather uniform across habitats, whereas the rarity index was much more discriminating: semi-natural habitats generally had a higher mean rarity index than anthropogenic habitats (0.90 vs. 0.83 on average), with the exception of gravestones and cracks of walls.

When habitats were ranked with respect to IFI, which synthesises all four indices, aquatic habitats came first despite their low specific richness (2.6 species per site, Fig.2), because they host species of high interest for conservation (rare, typical, indigenous species). Anthropogenic habitats such as base of walls or spaces between paving stones had a significantly lower interest. Among the thirteen habitats with highest IFI, four represented less than 3% of total inventoried area (namely aquatic vegetation, wet thickets, wastelands after culture, and embankments) and are thus likely to be also rare at the district scale.

Impact of urbanization on site floristic interest

When examining the relationship between site floristic interest and the proportions of each urbanization class (Table 2) in a buffer around the site, the buffer radius of 200 m generated the best fit (Appendix S1) and was thus retained for subsequent analyses. At the site level, the Index of Floristic Interest (IFI) varied between 0.29 and 0.76. Quite expectedly, variation among sites was explained by differences in site area, distance from the center of Paris and habitat type (Fig.3): site interest was high in large sites, located away from Paris and in more natural habitats. All land use classes had a significant influence on the floristic interest of a site. In particular, increasing proportions of collective dwellings around a site were correlated with a lower site floristic interest. In contrast, the presence of water (rivers, ponds…), and, to a lesser extent, woods, open and rural areas, vacant urban areas and building sites had a positive impact on the site IFI, whereas transport, activities, individual dwellings and facilities in the neighborhood seemed to have a negative influence (Fig.3).

Observed and potential floristic interest

As expected, the regions of highest observed or interpolated floristic interest were found near the Seine River (Fig.4.I, A) or in forests (Fig.4.I, B), whereas highly urbanized or industrial areas exhibited low IFI (Fig.4.I, C). The Site Potential Value, calculated from known contributions of LUP classes surrounding sites, proved to carry meaningful information regarding site floristic interest, as shown by a significant relationship between SPV calculated from a subsample of sites and observed IFI ($R=0.204$, $p<0.0001$; mean over 5 replicates), although this relationship varied across habitats (not shown). Therefore, site potential value generally exhibited the same patterns as interpolated IFI but proved very useful to identify specific sites with a high, but unrealized, potential (Fig.4). For example, all of the Seine River banks and two parks with ponds generally exhibited a moderate observed IFI together with some of the highest values of potential IFI (Fig.4.II, D).

DISCUSSION

As in most conservation plans, preserving biodiversity in urban zones requires to describe the existing patterns of species and habitat diversity, and identify areas of highest conservation interest (“comprehensive biotope mapping”, Sukopp & Weiler 1988). However, biodiversity cannot be efficiently managed without a good knowledge of the mechanisms affecting species distribution, which, in highly human-dominated urban habitats, can be very different from the usual ecological mechanisms acting in “natural” ecosystems. In the present study, we inventoried habitats and plant species in a highly urbanized French district to (1) describe species distribution, (2) locate sites and habitats of high interest, by building a new index of floristic interest (IFI) and (3) evaluate the influence of urbanization on the floristic interest of sites. We discuss the implication of these findings for the conservation of plant diversity in the Hauts-de-Seine.

Distribution of floristic diversity in the Hauts-de-Seine

In the Hauts-de-Seine district, we recorded 626 vascular plant species in 23 habitats. In face of similar studies in European urban areas, the observed species richness of the Hauts-de-Seine is comparatively low. For example, Pysek (1993) inferred the mean floristic richness of urbanized zones as a function of city area, using inventories from 55 cities of Central Europe. Applying this regression to the Hauts-de-Seine (176 km²), we expect 763 species over the whole district, i.e. about 20% more than what was observed in the present study (626 species). This suggests that plant diversity in the Hauts-de-Seine is slightly lower than the average of other European cities considered in Pysek (1993), but the difference might be attributable to: (1) differences in sampling effort, which is known to strongly influence the observed species richness (Hayek & Buzas 1997) and (2) differences in urbanization level (the Hauts-de-Seine is part of the highly urbanized heart of Paris area (2720 km^2), whereas the zones studied in Pysek (1993) comprised entire city areas including less highly developed outskirts).

On average, we found that the Hauts-de-Seine district hosted 16.6% of naturalized species. This was rather high compared with the national rate (9.4%, Vitousek et al. 1996) but comparable to an equivalent study in Brussels, where 19.8% of the vascular flora consisted of naturalized species (Godefroid 2001). Higher levels of naturalized species in urban areas are a general pattern (Kowarik 1995; Pysek 1998; Godefroid 2001), which can be explained by the presence of a complex network of roads, railways, rivers, and airports, contributing here to the dispersal and settlement of species such as *Conyza sumatrensis*, *Solidago canadensis* and *Erigeron annuus*.

Throughout the inventories, we observed five protected (one nationally and four regionally) species, three of which (*Cardamine impatiens*, *Cuscuta europaea*, and *Thelypteris palustris*) grow in wet habitats. Their presence legally justifies the preservation of wet zones, one of the most threatened habitats of urban areas. In Brussels, Godefroid (2001) showed that species of very humid to swamp soils were progressively replaced by more mesophilic taxa. In New-York, DeCandido et al. (2004) also found that humid habitats were most disturbed, and 9.9% of hosted species were rare or imperiled. These findings suggest that conservation of rare species is relevant also in cities.

The Index of Floristic Interest

Characteristics of IFI

The Index of Floristic Interest incorporates four equally weighted variables (species richness, typicality, indigeneity and rarity). The choice is necessarily subjective, but we believe that we have accounted for the most classical criteria used in conservation studies, where they are often considered alone. Therefore, in contrast to most approaches, where site floristic interest is generally estimated via species richness alone, IFI provides information on both the number and “quality” of present species. The three “quality” variables were chosen for their relevance to conservation issues (e.g. Godefroid & Koedam 2003), but also because they can be simply and objectively measured. Other indices exist to evaluate habitats or sites, but they usually include subjective criteria, such as potential value, intrinsic appeal (Ratcliffe 1977), or inhabitant attitudes (Maleyx 2001) to account for social value. The “coefficient of conservatism” is a good index of site floristic quality, accounting for plants’ tolerance to disturbance and fidelity to specific habitat integrity (Swink & Wilhelm 1994). However, it is assigned by experts, familiar with plant habitats of a specific region, and thus cannot be applied uniformly across regions. Other criteria, such as the recorded history of a site (Ratcliffe 1977) provide potentially useful information but may not be available for some sites and regions. In contrast, provided clear definitions are agreed upon (notably for indigeneity), IFI should be a simple, objective and repeatable index, devoid of subjective estimations. In addition, and most importantly, it can be readily used at a minimal cost in numerous cities where floristic presence/absence data already are available (though poorly published) in botanical gardens or conservatories, thanks to the work of amateur or professional botanists. As such, this index can prove a useful tool to evaluate the biodiversity of sites and habitats and identify locations of highest priority for conservation (see below).

Nonetheless, besides the simple fact that information is always lost in the process of summarizing different variables, IFI suffers one noticeable shortcoming inherent to its construction. Although the different variables incorporated in IFI are generally little correlated to one another, rarity and typicality exhibit non negligible levels of correlation (spearman $\rho = 0.39$, $P < 0.0001$). This is due to the fact that, at a small spatial scale, rare species (e.g. observed in a single site) are also categorized as ‘typical’. This suggests that IFI is to be used for comparison between sites of regions at least as large as a French district (a few hundreds of km^2), as typicality and rarity are meaningless at too small spatial scales.

Evaluation of habitat interest

By synthesizing information on the quantity and quality of species, IFI proved a useful tool to identify such patterns and define conservation priorities, two tasks that could not have been correctly achieved by considering single variables and notably species richness alone. For example, the aquatic vegetation was the poorest habitat in terms of species number, but exhibited the highest rates of rare typical and indigenous species. Wet zones are thus a habitat of high interest for conservation, which is highly threatened by urbanization and is now poorly represented in the district (Table 1).

Here we focused on a single group, but floristic diversity is only one part of the evaluation process in nature conservation. Analysis of other groups could provide a better image of ecosystems and their conservation status. Moreover, the index of floristic interest was created from the point of view of the scientific conservationist only, it would be very helpful to integrate sociological (Hope et al. 2003; Kinzig et al. 2005) and economic dimensions to evaluate the effectiveness of management choices.

Site interest and the mechanisms controlling floristic diversity in urban areas

The Index of Floristic Interest was calculated in each of 986 sites, but also interpolated to the whole district (Fig.4.I). Although interpolation should be interpreted with caution in highly fragmented urban landscapes, we believe it is relevant here, because IFI was spatially autocorrelated across sites within 3km (results not shown) and because the average minimum distances among site centers was small (150 m), so that IFI at a given site was correctly predicted by interpolation from neighboring sites.

To evaluate the impact of urbanization on biodiversity on a finer scale, we characterized the relationships between site floristic interest and urban environment, defined as the (transformed) proportion of nine classes of the Land Use Pattern in a 200m-disc around the sites (Table 2). The results of the analysis showed that the variability explained by each LUP class was low, because numerous other factors act on floristic diversity. Nevertheless, after eliminating the effects of habitat type, site area and distance to the center of Paris, all retained LUP classes had a significant impact on the site floristic interest. The presence of non-built zones (rivers and ponds notably, and, to a lesser extent, forests, open urban and rural areas, and vacant urban sites) had a positive impact on flora. In contrast, all classes of built zones, and especially collective dwellings, had a significant negative influence on floristic interest, with major consequences for management plans.

Thanks to this quantification of the effects of urban structures on floristic diversity, we were able to infer a potential floristic interest (Fig.4.II), accounting for the existing urban structures around a site. The significant correlation observed between the predicted SPV and the observed IFI suggests that SPV yields satisfying predictions regarding site interest, and that the comparison of the map of potential interest with the map of observed IFI (Fig.4.I) provides a useful tool for the definition of conservation strategies, and the identification of habitats that should be priorities for management and conservation. For example, the Seine River banks are zones of high potential floristic interest, but of generally low realized interest, due to inadequate management: when banks are concreted, the benefits of the aquatic habitat are lost. Biotechnical methods, such as live stakes, brushlayering, live cribwall, joint planting and tree revetment may be applied to stabilize river banks without destroying the vegetation (Li & Eddleman 2002). Large parks containing ponds are another example of zones with lower than expected floristic interest, (Fig.4.II, D): in these parks, intensive ornamental management may destroy indigenous biodiversity, which negatively impacts the biodiversity of surrounding green structures.

APPLICATIONS

Resources for conservation actions are always limited, especially for conservation of urban habitats and species, so that priorities have to be defined. This requires tools to quickly and efficiently evaluate the conservation interest of species, sites and habitats. Here, we proposed a new Index of Floristic Interest, combining objective quantitative and qualitative information on floristic diversity; this index can be used by managers of green areas, in combination with knowledge of the factors influencing floristic interest, to make decisions regarding the preservation of biodiversity in urban areas.

In the Hauts-de-Seine, we demonstrated that "semi-natural" habitats, such as forests and wet zones, exhibited a high floristic interest and were the main reservoir of native biodiversity of the district. As such habitats are generally restricted at the district scale, and since species richness is positively correlated with area, they should be entirely preserved. Forests, for example, host a large number of rare species. Intermediate environments exhibit the highest plant richness, which is essentially concentrated in wastelands (365 species) and urban lawns (303 species). These habitats, which are well represented in the district, should be managed in a sustainable way to prevent (1) invasion by exotic species and (2) species homogenization among sites, reducing the percentage of typical species. We finally highlighted that some sites were characterized by large differences between the realized and potential IFI. Special attention should be given to such sites, to either (1) identify the effective management choices that explain the larger than expected site interest when IFI >> SPV or (2) to improve management in sites where SPV>>IFI.

ACKNOWLEDGEMENTS

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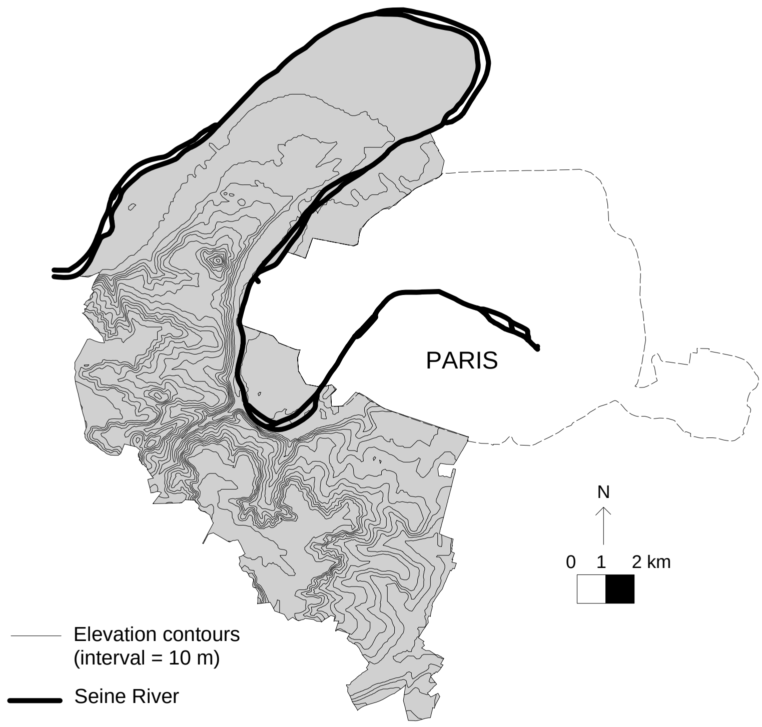

Fig.1. Location of the study area (in grey): the French district of Hauts-de-Seine.

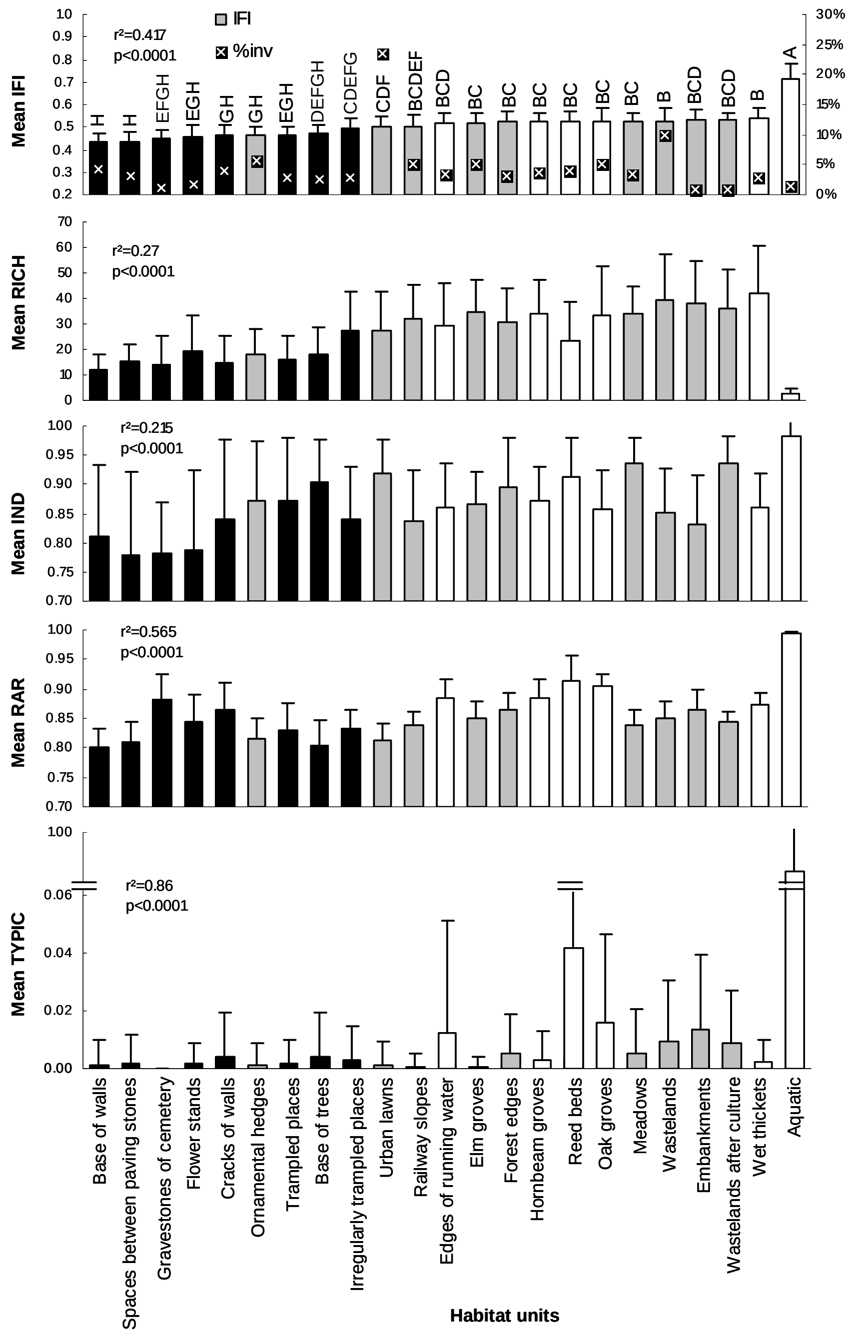

Fig.2. Mean values of floristic interest variables across habitats (Rich: species richness, Typic: proportion of typical species, Ind: proportion of indigenous species, Rar: mean rarity index and IFI: Index of Floristic Interest) and percentage of sites inventoried for each habitat (%inv, top figure). Significant differences (p=0.05) between IFI values are shown by different letters (Tukey's test). Semi-natural habitats are in white, intermediate habitats in grey, and anthropogenic habitats in black.

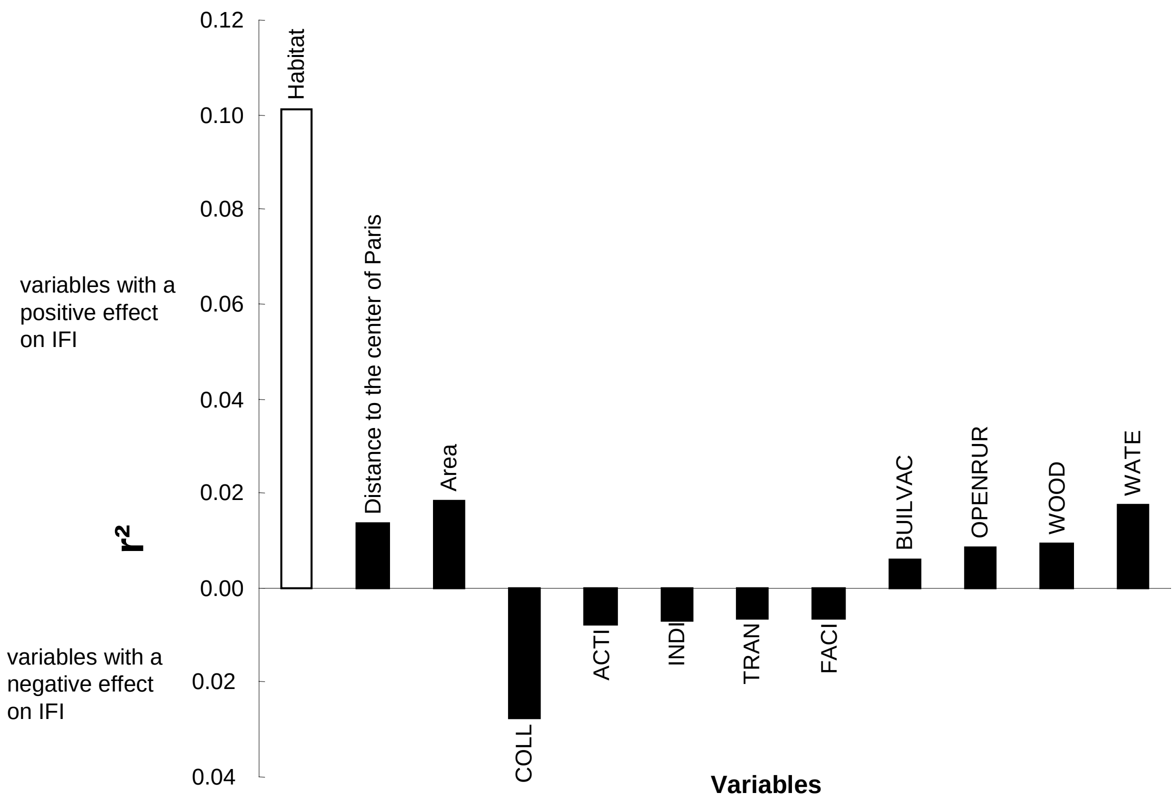

Fig.3. Distribution of r^2 of independent effects on IFI, calculated from hierarchical partitioning (500 randomizations). All contributions are significant at the upper 95% confidence limit. All variables are quantitative (in black) except habitat (in white). See table 2 for definition of LUP classes.

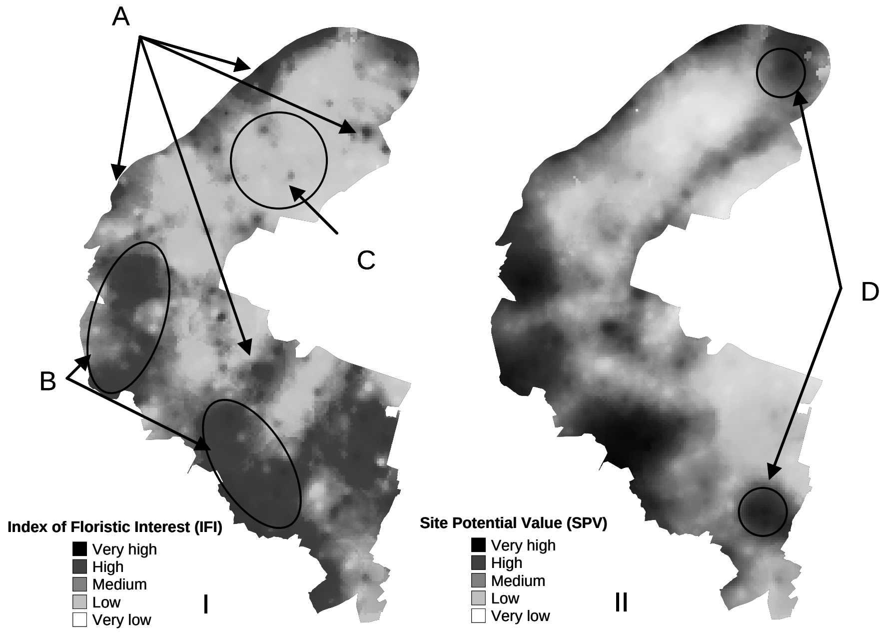

Fig.4. Distribution of interpolated and potential floristic interest in the Hauts-de-Seine. (I): Distribution of IFI inferred from the IDW interpolation (zones of higher interest are darker). (A), (B): examples of high interest zones: the Seine river banks (A) and forests (B); (C): example of a low interest zone: an industrial zone. (II): Distribution of potential floristic interest inferred from IDW interpolation. (D): Example of zones of high potential interest: two parks containing ponds.

Table 1. The 23 habitats of the Hauts-de-Seine, as defined from vegetation units of the Parisian region (Bournérias et al., 2001), together with the total number of species and the total area inventoried in each habitat.

Semi-natural environment			**Intermediate environment**			**Anthropogenic environment**		
Habitat	No. of species	Area in ha	Habitat	No. of species	Area in ha	Habitat	No. of species	Area in ha
Aquatic	19	0.002	Elm groves	279	20.13	Cracks of walls	179	5.97
Edges of running water	232	15.25	Embankments	161	0.83	Base of trees	138	3.50
Hornbeam groves	220	45.40	Forest edges	226	9.84	Base of walls	119	9.78
Oak groves	263	85.14	Meadows	231	16.91	Gravestones of cemetery	82	20.18
Reed beds	261	10.14	Ornamental hedges	197	7.79	Irregularly trampled places	208	7.25
Wet thickets	285	8.57	Railway slopes	249	14.30	Spaces between paving stones	140	4.10
			Urban lawns	303	98.35	Trampled places	158	2.82
			Wastelands	365	21.90	Flower stands	122	6.52
			Wastelands after culture	127	1.64			

Table 2. Description of the nine LUP classes (IAURIF, 2003)

Abbreviation	Land Use Patterns	Definition
ACTI	Activities	Warehouses, Offices, Companies
BUILVAC	Building sites and Vacant urban	
COLL	Collective dwellings	Tall buildings covering large areas
FACI	Facilities	Education, Health, Administration, Cemeteries, Electricity, Gas, Petroleum
INDI	Individual dwellings	Houses, including small privative gardens
OPENRUR	Open urban areas Rural areas	Parks, Gardens, Sports, Camping, Golf, Hippodrome Truck farming, horticulture, orchards, breeding grounds, pits
TRAN	Transportation	Railways, Highways, Streets, Parking lots
WATE	Water	
WOOD	Woods and forests	

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SUPPLEMENTARY MATERIAL

Appendix S1. Total independent variance (r^2) explained by a model including (1) the area of each LUP classes in the buffer, (2) the site area, (3) the site distance to the center of Paris and (4) habitat type, for each variable of floristic interest (IFI: Index of Floristic Interest, Rich: species richness, Rar: mean rarity index, Typic: proportion of typical species and Ind: proportion of indigenous species) using hierarchical partitioning

Circle radius	**IFI**	**Rich**	**Rar**	**Typic**	**Ind**
100 m	0.222	0.148	0.306	0.310	0.132
200 m	**0.230**	**0.152**	**0.330**	**0.317**	**0.147**
300 m	0.229	0.151	0.322	0.314	0.143
400 m	0.225	0.149	0.315	0.312	0.136
500 m	0.222	0.148	0.306	0.310	0.132
1 km	0.207	0.144	0.262	0.304	0.118
2 km	0.197	0.153	0.240	0.300	0.104