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Local gardening practices shape urban lawn floristic communities

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ABSTRACT

The large number of green space lawns in cities means that they shelter a high proportion of wild urban species, but the roles of landscape and management on the level of biodiversity in these spaces are little understood. We performed floristic inventories in 100 lawns in the southeast corner of Paris, France and linked their floristic diversity and composition to: (1) the characteristics of urbanization given by the Land Use Pattern and the distance from the centre of Paris, (2) local factors including luminosity and size of the lawn and (3) the type of management, including pesticide and fertilizer use, animal and public access, and mowing frequency. A total of 79 species were identified, of which 9% were naturalized. Distribution of the species was largely conditioned by the management methods applied to the green spaces: specific management strategies were associated with specific community traits and composition. As expected, the highest species richness and/or rarity were found in lawns submitted to private management, low use of pesticides and limited public access. But surprisingly high diversity was also sometimes found in small public lawns. The results establish relationships between human practices and characteristics of plant communities. We use them to make several recommendations on how best to optimize management of lawns with a view to conserving urban biodiversity.

1. Introduction

Currently more than 70% of people from developed countries live in cities (United Nations, 2008). This large-scale human colonization has created, on a local level, fierce competition for space and a growing threat to wildlife (Ding, Reardon, Wu, Zheng, & Fu, 2006; Pautasso, 2007). Although subject to the consequences of very dense human populations, urban areas are becoming an increasingly important refuge for biodiversity compared to other anthropized land types such as intensively farmed areas (Goddard, Dougill, & Benton, 2009; Von der Lippe & Kowarik, 2008). Among the habitats found in cities, a high proportion of vegetal urban space consists of lawns (Attwell, 2000; Muratet et al., 2008; Stewart et al., 2009; Zipperer & Zipperer, 1992), which therefore share a large part of the urban biodiversity.

Given their number and their cumulative surface, lawns certainly play an important role in the dynamics of urban plant populations and especially in landscape connectivity. Indeed, Dearborn and Kark (2010) demonstrated their role as corridors or stepping-stones for gene flow between nearby populations. In addition, Roberts, Ayre, and Whelan (2007) showed that lawns help to increase the distribution and size of rare plant populations, notably by re-establishing genetic connectivity with isolated populations or by maintaining genetic variation lost from natural areas. Altogether, these studies highlighted the importance of lawn habitats in reducing population extinctions due to urban fragmentation.

Even if they are small and frequently disturbed, these green spaces can provide crucially important ecosystem services in the urban context (Beard & Green, 1994; Dearborn & Kark, 2010). Lawns are useful for intercepting and infiltrating stormwater, reducing runoff and diluting numerous pollutants that run off impervious surfaces (Mueller & Thompson, 2009). Thanks to their dense biomass and root system they are efficient at controlling soil erosion (Gross, Angle, Hill, & Welterlen, 1991) and are able to absorb violent sounds much better than hard surfaces (Robinette, 1972). According to Golubiewski (2006), urban lawns are capable of storing far more C pools than native grasslands or agricultural fields, all the more when fertilization and irrigation are performed (Zirkle, Lal, & Augustin, 2011) and act as an important sink for atmospheric N deposition when management is of low to moderate intensity (Raciti, Groffman, & Fahey, 2008). Finally, lawns can provide resources for small mammals and invertebrates and contain a significant number of groups that interact with plants (*e.g.* pollinators, pest-control species, seed dispersers). This is increasingly important in cities given the growing interest in small-scale urban agriculture (Mendes, Balmer, Kaethler, & Rhoads, 2008).

Furthermore studies have shown how green spaces make an important contribution to human well-being, in terms of aesthetic beauty, physical and mental health (Irvine et al., 2010; Ulrich,

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1984), recreation and sociability (Adams, 2005). People frequenting green areas apparently not only perceive different levels of species richness but also benefit psychologically from the plant, butterfly and bird diversity (Fuller, Irvine, Devine-Wright, Warren, & Gaston, 2007).

Contrary to other habitats that are less accessible to citizens (*i.e.* industrial land, waste land, private gardens), urban green spaces – mostly lawns – represent one of the only opportunities for city dwellers to connect with nature (Miller, 2005) and for many people offer a unique introduction to environmental processes and conservation (Dearborn & Kark, 2010).

However, mainly for aesthetic reasons, these green spaces are sometimes intensively managed (frequently mowed and highly treated), leading to additional management costs (Caceres, Bigelow, & Richmond, 2010), serious threats to human health (Alumai, Salminen, Richmond, Cardina, & Grewal, 2009; Pimentel, 2005; Steingraber, 2002) and the environment (Byrne, 2005; Byrne & Bruns, 2004; Colborn & Short, 1999). Despite their potentially high ecological, educational and research benefits, urban lawns are still poorly studied ecosystems. The effects of mechanical and chemical management on their biodiversity remain thus barely studied (Robbins & Birkenholtz, 2003). Given the high number of small lawns and the wide variety of human practices applied on them, studying this habitat is an opportunity to examine how plant communities are constituted and how they are modified by anthropic disturbances from taxonomic and functional viewpoints. Furthermore, more knowledge is necessary in order to know how to increase their floristic diversity and favour the maintenance of functional lawn networks in cities.

In this study, we explore the role of lawn management on plant species diversity, composition and traits in 100 urban lawns in Paris, France. In particular, we examined our results with regard to the management initiatives that are required to promote wild species in green areas and thus improve urban biodiversity.

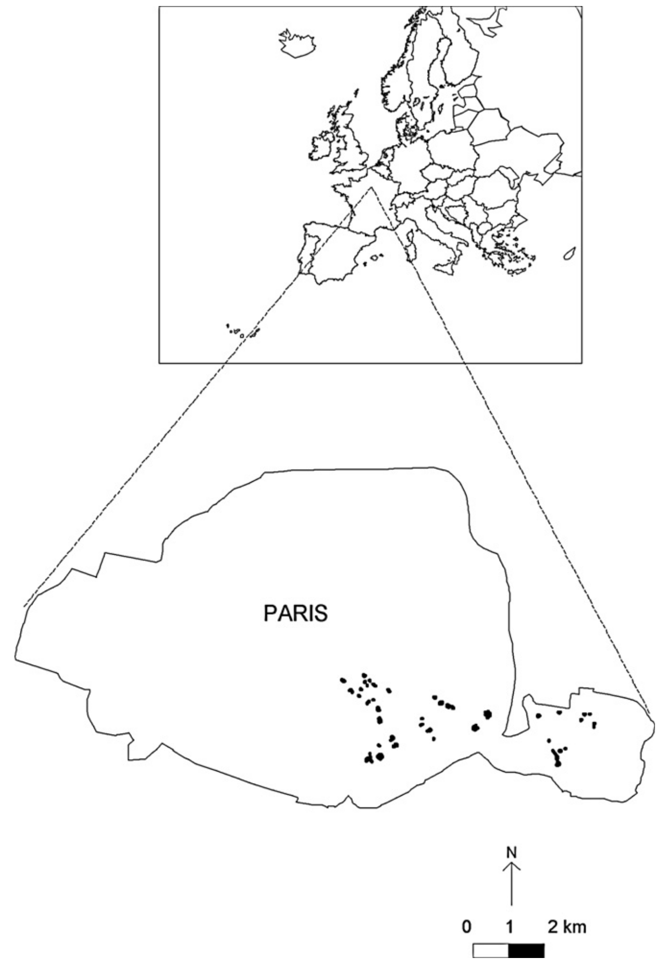

Fig. 1. Location of the study area in Paris. Each polygon corresponds to a studied lawn.

2. Methods

2.1. Study area

Lawn floristic diversity was studied in the southeast corner of Paris (48°51′23.68″N, 2°21′6.58″E) that covers 3 districts and a total area of 16.06 km^2 from the centre to the periphery of the city (Fig. 1). In this area, human density is about 24,000 inhabit./km^2 *i.e.* one of the most densely populated zones of France (INSEE, 2006). The Land Use Pattern provided by the Institute for Planning and Development of the Paris Ile-de-France Region (IAURIF, 2003) shows that open areas cover only 27% of this part of the city (breaking down as 12% parks and gardens, 6% woods, 2% sports areas, 2% water and 5% other open areas). The climate is oceanic with continental trends and the mean annual temperature is 11.7 °C with an annual rainfall of 576.4 mm.

2.2. Sampling design and inventories

A total of 100 lawns belonging to 26 greenspaces were inventoried in the study area (Appendix A). Depending on the greenspace surfaces, two to five lawns were randomly studied per greenspace. In each lawn ten 30 cm × 30 cm quadrats were systematically placed every 50 cm (leading to a total of 0.9 m^2), following a diagonal from the edge to the centre of the lawn. The list of all wild vascular plant taxa was established once in each quadrat during autumn 2007. This single-season sampling did not allow us to estimate the whole diversity present in urban lawns over a year or to evaluate the effect of season and year on floristic diversity (but see Muratet et al., 2009). Regardless, this standardized method permitted us to have comparable replicates that were sampled at the same time in similar surfaces and that differ only on the local practices applied to them and to the landscape surrounding them.

2.3. Characteristics of the lawns and their surrounding urbanization

Using a geographic information system (MapInfo Corporation, 2008), we calculated the area of each of the inventoried lawns and their distance from the centre of Paris. To characterize the urban environment around lawns we analyzed the Land Use Pattern (LUP, scale = 1:5000, IAURIF, 2003) within a 200 m buffer radius (previously identified as the best radius to detect the influence of urban activity on floristic diversity: Muratet et al., 2008). We calculated the proportion of area occupied by buildings (*vs.* unbuilt areas) in the 200 m radius around each lawn.

Some management and environmental parameters were also recorded for each studied lawn at the local scale *i.e.*: (1) owner type (public *vs.* private), (2) public access (a surrogate of soil compaction) and (3) animal access (both yes *vs.* no), use of (4) fertilizers (yes *vs.* no) and (5) pesticides (regardless of the dose and the type of products) (yes *vs.* no), (6) light (open *vs.* shaded by trees or buildings) and (7) mowing frequency (infrequent = 4–6 times a year; frequent = 12 times a year; and highly frequent = 18–24 times a year; generally, lawns are cut short with export of clippings). This information was provided by the public and private gardeners we interviewed during the inventories (see Appendix A). As this type of self-report data could be associated to several biases, we have chosen not to detail too much the management variables for the following reasons: (i) interviews had to be as short and simple as possible; (ii) gardeners were not always able to give the exact doses they used for each type of chemical treatment; including this type of information in our analyses could thus have biased our results in an unpredictable and uncontrolled way and led to strong uncertainties on our results; (iii) pesticides, *i.e.* fungicides, insecticides and herbicides are all known to negatively affect plant communities in agricultural landscapes (Geiger et al., 2010); accordingly, in order to simplify the interviews, we grouped all the types of chemical treatments in the general term of pesticides.

Management effects on urban soils are greater than environmental effects (Pouyat, Szlavecz, Yesilonis, Groffman, & Schwarz, 2010); as a result, even if environmental conditions might affect plant diversity we have focused on how gardeners manage their lawns. We have not analyzed the processes by which management decisions affect plant diversity, which might be direct (*e.g.* frequent mow, use of pesticides) or indirect (*e.g. via* modification of soil quality but see Stewart et al., 2009).

2.4. Species traits

Using the BiolFlor trait database (Klotz, Kühn, & Durka, 2002), we associated species to ecological and biological traits *i.e.* (1) life form (annual *vs*. perennial), (2) class (monocotyledonous or dicotyledonous), (3) status (native *vs*. archeophyte or neophyte; *i.e.* exotic species that arrived in the region respectively before and after 1500 AD), (4) pollination mode (insect-pollinated, wind-pollinated or selfing), (5) diaspore type (seed, fruit or fruit with appendage) (6) reproduction type (by seeds or both by seeds and vegetatively), (7) end of flowering (1 month out of 12), and tolerance to (varying between 1 and 10) (8) grazing, (9) mowing and (10) trampling.

2.5. Data analysis

Statistical analyses were performed using R 2.10.0 (R Development Core Team, 2010) and the packages ade4 (Dray & Dufour, 2007), cluster (Kaufman & Rousseeuw, 1990) and vegan (Oksanen et al., 2011).

2.5.1. Indices of floristic diversity

To assess the floristic diversity of the studied lawns, we used three classical indices: the total species richness observed in the ten quadrats of each lawn, the proportion of native species among all species (the classification of species as exotic and native was given by the Conservatoire Botanique National du Bassin Parisien, CBNBP, 2010) and the average species rarity per lawn (species rarity given in terms of regional data, referring to the proportion of sites where a given species was not observed, across all habitats of the region, Abadie, 2008). Given large differences in species richness among lawns, we log-transformed the species richness in all analysis.

2.5.2. Distance matrices

We evaluated to what extent differences in lawn floristic compositions and species abundances (based on quadrat frequency) were explained by local variations, *i.e.* management and environmental factors (see Appendix A) and by spatial factors, *i.e.* geographic distances between lawns.

The physical distance between two lawns was measured from the longitude and latitude of their centres. The floristic distance between two lawns, measuring the difference in species composition, was calculated on abundance-based matrices using semi-metric Bray–Curtis distance (Magurran, 1988). The environmental distance between two lawns was calculated using the Gower index (Gower, 1971) that includes a correction factor for missing values and accepts a mix of numeric and nominal variables. Variables used in the environmental distance calculation were the lawn area (log-transformed), and the seven management and environmental local parameters listed above.

Mantel tests based on Pearson correlations were run to evaluate the level of correlation between the floristic distances, the environmental distances, and the geographic distances. The three possible pairwise tests were run. In addition, partial Mantel tests were run to find out how much of the correlation between two distance matrices remained after taking into account the correlation with a third distance matrix.

2.5.3. Multivariate analysis

We used Hill and Smith (1976) analysis to summarize the environmental parameters of the 100 lawns. This principal component analysis allows the inclusion of a mix of numeric and nominal variables (see above). We then realized a redundancy analysis (RDA) (Rao, 1964) to evaluate the effects of environmental variables on (1) the floristic diversity indices (log-transformed site richness, proportion of native species and mean species rarity) (2) the floristic composition of lawns and (3) species traits. The number of axes kept in the analyses was determined by their significance with a nominal α level of 5% according to an ANOVA-like procedure associated with the RDA (Legendre & Legendre, 1998, see also the vegan package, Oksanen et al., 2011).

Regarding the application of the RDA approach on species traits, we clustered species into eight functional groups according to ward classification (Appendix B). We then calculated the abundance of the groups in each lawn, *i.e.* the sum of species abundances in each group. We applied the RDA approach to the abundance of functional groups explained by the environmental variables.

We used these RDA approaches rather than ones that depend on correspondence analysis (*e.g.* canonical correspondence analysis, ter Braak, 1986; and RLQ, Dolédec, Chessel, Braak, & Champely, 1996) because the latter were affected by excessive influence of rare species (Legendre & Gallagher, 2001).

We also checked that the results of RDAs were not impacted by spatial distances between lawns. Spatial autocorrelation was tested among the residuals of the models using the Mantel test, and we obtained in all cases non-significant spatial autocorrelation. We thus assumed that spatial autocorrelation was either absent or negligible.

3. Results

3.1. Lawn composition

Over the 100 studied lawns, a total of 79 species were recorded. All species were herbaceous and classified either as perennials (53%) or annuals (47%). In terms of frequency, lawns were dominated by one grass, *Lolium perenne* (present in 834 of the 1000 quadrats inventoried). In terms of species richness, lawns were dominated by forbs (87%).

The species richness of the lawns varied widely, ranging from 1 to 24 species, with a mean of 9.2 species per lawn and 3.5 species per quadrat. 19 species occurred only once whereas 4 were found in more than 50% of the lawns *i.e.*: *L. perenne* (94%), *Taraxacum* section *ruderalia* (60%), *Trifolium repens* (58%) and *Bellis perennis* (53%). *L. perenne* along with *T. repens* are normally sold in lawn seed mixtures, which might explain their abundance in gardens (Lambinon, Delvosalle, & Duvigneaud, 2004).

Lawns were mainly composed of native species (91%). Among the neophytes, two species (*Conyza sumatrensis* and *Conyza canadensis*) are considered invasive species (*sensu* Richardson et al., 2000) in the region (Müller, 2004). The most frequent neophytes were *C. sumatrensis* (25%) and *Veronica persica* (24%), followed by

Table 1
Coordinates of the management variables and the diversity indices on the first axis of the RDA applied to diversity indices. These coordinates represent the strength of the connections between environmental variables and diversity indices. For instance, the strongest connection is a negative link between rarity and public owners: public lawns contained the lowest proportion of rare species.

Variables	Coordinates
Management variables	
Built area (Arcsinus root-transformed)	0.21
Distance to Paris	0.15
Fertilizers	−0.05
Animal accessibility	−0.14
Area (log-transformed)	*−0.25*
Shaded lawns	*−0.26*
Pesticides	*−0.33*
Mowing frequency	*−0.35*
Public access	*−0.68*
Public owners	*−0.68*
Diversity indices	
Rarity	*0.69*
Richness (log-transformed)	*0.57*
Proportion of native species	−0.27

Duchesnea indica (16%), *Oxalis corniculata* (15%), *C. canadensis* (8%), *Amaranthus deflexus* (3%) and lastly *Soleirolia soleirolii* (1%), which was observed just once. *Torilis nodosa* (11%) was the only species of floristic interest that could lead to site protection (CSRPN and DIREN, 2002).

3.2. Lawn management

Lawns can be classified in two groups: those belonging to private owners and those situated in public areas. According to the interviewed gardeners, none of the private lawns we studied received fertilizer (against 55% for public lawns), none was open to the public (against 81% for public lawns) and 73% of them were rarely mowed, 4–6 times a year (against 26% for public lawns).

3.3. Factors affecting lawn communities' diversity

We used a redundancy analysis to examine the factors influencing species richness, the proportion of native species and the average rarity in a given lawn. We retained only the first axis of the RDA that explained a large part of the relation between environmental variables and diversity indices (82% of the variation, $R^2 = 0.45$, see Table 1). The location of the lawn in a public green space, as well as frequentation by the public, frequent mowing, use of pesticides (regardless of the type and the dose), and to a lesser extent, shading and lawn area were negatively associated with species richness and rarity (Table 1). The proportion of native species observed in lawns was less well explained by environmental variables than species richness and rarity. This result might be explained by the very low number of exotic species found in this study (only 7 species) and thus the low variation displayed by this variable.

3.4. Factors affecting composition within lawn communities

The first two axes of the redundancy analysis (RDA) that were applied to the lawns' plant composition and environmental variables expressed respectively 28% and 16% of the variation in species composition (Fig. 2). The environmental variables were correlated with species composition on the first axis ($R^2 = 0.73$) and on the second axis ($R^2 = 0.51$). Axis 1 was correlated with three management variables, *i.e.* owner type, public access and animal access, while axis 2 was correlated with three structuring variables *i.e.* lawn size, distance to Paris centre and the presence of buildings around the lawn, and with one management variable, *i.e.* mowing frequency.

Overlaying Fig. 2a and b, we confirmed that *L. perenne* was the most frequent species found in 98% of public lawns, 98% of lawns the public have a right to walk on and 93% of lawns that were closed to animals. This species was also present in 94% of frequently mowed lawns, *i.e.* about once a month. *V. persica* was considered to be a mowing-tolerant species, supporting 1 or 2 mows a month, except in the winter. *C. sumatrensis*, *Polygonum aviculare*, *A. deflexus* and *Stellaria media* were urbanophile species, located near Paris city centre in lawns of very built-up areas. They were also observed in small infrequently mowed lawns, *i.e.* about 6 times a year.

Species like *Prunella vulgaris*, *B. perennis* and *Festuca rubra* were mostly observed in (67–100% of) private lawns (45–69% of) lawns closed to the public and (86–100% of) lawns without pesticide use.

3.5. Factors affecting community trait composition

The first two axes of the RDA explaining the relation between species traits and environmental variables expressed respectively 42% and 27% of the variation in trait composition (Fig. 3). The environmental variables were correlated with trait variation on the first axis ($R^2 = 0.34$) and the second axis ($R^2 = 0.39$). Two major groups of species could be distinguished from the functional clustering approach: (1) a group (including functional groups G4, G5, G6, G7, G8, see Appendix B) constituted mainly by native plants that are perennial, tolerate mowing and trampling, are pollinated by insects or by wind and have a sexual or vegetative reproduction; and (2) a group (including functional groups G1, G2, G3, see Appendix B) that contained predominantly exotic plants, annuals, mowing and trampling-intolerants that are self-pollinated, and with a sexual reproduction.

Overlaying Fig. 3a and b, we derived the correlations between traits and management variables. The first axis highlighted the level of sensitivity of the functional groups to mowing frequency, shade, public ownership, public access and pesticide use. These factors tended to reduce the abundance of all functional groups (with group G5 being the most impacted and groups G7 and G3 the least). However, axis 2 showed differences between groups, *i.e.* perennial, mowing and trampling-tolerant species (G4, G5, G6, G7, G8) were mostly observed in big lawns, far from Paris centre, while annuals and intolerant species (G1, G2, G3) were mostly found close to Paris centre in small rarely mowed lawns. Insect-pollinated species (G4, G5, G6, G8) represented 40% of the species observed and were mostly found in private lawns without pesticide use and that are closed to the public. Wind-pollinated species (16%) and/or species producing fruit with an appendage (39%) – the G7 group – were principally observed in large, frequently mowed lawns located far from Paris centre, while self-pollinated species (43%) – groups G1 and G2 – were more urbanophile and found in smaller lawns near Paris centre.

3.6. Relationship between geographic, floristic and environmental distances

Mantel tests showed that geographic, floristic and environmental distances were significantly correlated. The most important correlation was obtained between floristic distances and the lawns' environmental characteristics (Mantel statistics $r = 0.31$, $P < 0.001$); this remained true when the geographic distances between sites were accounted for (partial Mantel statistics $r = 0.32$, $P < 0.001$). Environmental distances were significantly correlated with geographic distances (Mantel statistics $r = 0.20$, $P < 0.001$). However, floristic distance between sites was not correlated with geographic distance (Mantel statistics $r = 0.02$, $P = 0.29$) even when the environmental distances between sites were accounted for (partial Mantel statistics $r = -0.04$, $P = 0.82$).

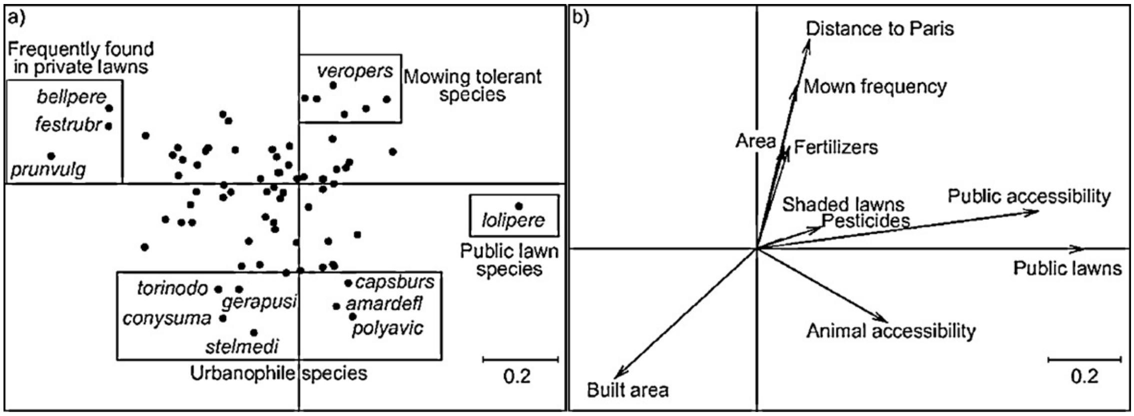

Fig. 2. RDA plot showing axis 1 (horizontal) and axis 2 (vertical) (a) species scores for the 67 most frequent species found in 100 lawns and (b) environmental variable vectors. Abbreviations for full scientific names of species mentioned in the figure include: amardefl, *Amaranthus deflexus*; bellpere, *Bellis perennis*; capsburs, *Capsella bursa-pastoris*; conysuma, *Conyza sumatrensis*; festrubr, *Festuca* Gr. *rubra*; gerapusi, *Geranium pusillum*; lolipere, *Lolium perenne*; polyavic, *Polygonum aviculare*; prunvulg, *Prunella vulgaris*; stelmedi, *Stellaria media*; torinodo, *Torilis nodosa*; veropers, *Veronica persica*.

4. Discussions

4.1. Lawn characteristics

A total of 79 herbaceous species (0.9 species/m^2) were sampled in the 100 lawns inventoried in Paris in autumn 2007. This value could not be taken as the full diversity present on Parisian lawns because species richness depend on the number of seasons and years sampled (Muratet et al., 2009) and further research is needed to evaluate temporal changes in the effects of lawn management practices. However it can be compared to studies with similar sampling effort as Thompson, Hodgson, Smith, Warren, and Gaston (2004) who, despite including bryophytes and small trees, observed 159 species (1.5 species/m^2) in 52 English lawns, while Stewart et al. (2009) found only 127 herbaceous species (0.3 species/m^2) in 327 residential lawns in New Zealand. Lawns seem to be relatively poor when compared to other urban vegetal communities, like wastelands (Muratet, Machon, Jiguet, Moret, & Porcher, 2007); but due to their large cumulated surface and their high numbers in cities (Muratet et al., 2008), they could play an important role in the dynamics of urban vegetal communities (Wania, Kuhn, & Klotz, 2006).

The lawns we studied had similar communities to temperate semi-natural grasslands. Like in other studies (Richmond, Grewal, & Cardina, 2006; Garrison and Stier, 2010), the observed patterns in plant cover and density mainly reflected establishment and growth characteristics of the grass species planted. The most abundant species we observed, *i.e.* the grasses *L. perenne*, *Festuca* gr. *rubra*, *Agrostis capillaris*, *Poa pratensis*, *Poa annua* and the forbs *T. repens*, *B. perennis*, *Taraxacum* section *ruderalia*, *Plantago major* are also dominants in most temperate lawns (Alumai et al., 2009; Byrne & Bruns, 2004; Hermy & Cornelis, 2000; Lundholm & Marlin, 2006; Müller, 1990; Stewart et al., 2009; Thompson et al., 2004). All these plants are usually contained in the seed mixtures sold to gardeners in many cities of Europe, the United States and New Zealand (Stewart et al., 2009), contributing to convergence and homogenization of lawns in plant composition between very geographically distant countries.

We noted that, like in every community, a high proportion of species occurred just once (24%) in our studied lawns. Surprisingly,

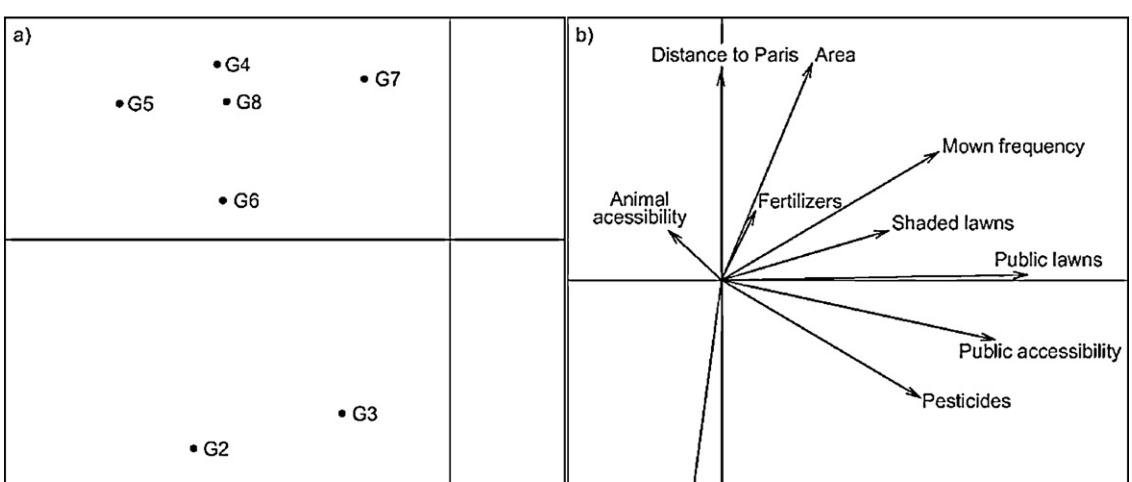

Fig. 3. RDA plot showing axis 1 (horizontal) and 2 (vertical) species communities in function of (a) trait scores (functional groups G1 to G8 see Appendix B for species details) and (b) environmental variable vectors.

less than 10% of the species recorded in the Parisian lawns were exotics, *i.e.* 7 species. This was relatively low considering the common pattern observed in cities of a higher proportion – usually around 15–20% (Trepl, 1995; Pyšek, 1998) – of exotic species in urban *vs.* natural habitats.

Trait differences between lawns seem to be driven mainly by management and area characteristics and, to lesser extent by the level of urbanization. Like in all fragmented ecosystems, such exogenous disturbances lead to strong selection between species according to their traits and thus represent the main driver for local extinction and species distribution (Williams, Morgan, Mcdonnell, & Mccarthy, 2005).

Thus, large lawns that are distant from the urban centre favoured the establishment of perennial species that are pollinated and dispersed by wind. Frequently mown lawns mostly hosted species that are tolerant to mowing and trampling and able to reproduce sexually and asexually. By contrast, small, rarely mowed lawns, situated near the urban centre primarily harboured communities of annual species that are self-pollinated and intolerant to mowing and trampling. Lawns free from pesticide use and distant from Paris centre hosted a large proportion of insect-pollinated species. This is likely due to the absence of insecticide use but also to the negative effect of urbanization on diversity and/or abundance of pollinator populations as demonstrated in several cities including Belo Horizonte, Brazil (Zanette, Martins, & Ribeiro, 2005), Stockholm, Sweden (Ahrné, Bengtsson, & Elmqvist, 2009) and Montpellier, France (Cheptou & Avendaño, 2006).

4.2. Factors influencing lawn floristic diversity and composition

We found a high correlation between floristic distances and environmental distances, highlighting the importance of local management in the structure of lawn composition. This result was reinforced by the absence of links between floristic and geographical distances even when environmental conditions seemed to be slightly spatially dependent. We showed also that local factors (use of pesticides, mowing frequency, public access and owner type) had a stronger effect on lawn floristic diversity than the quality of urbanization around the lawns.

4.2.1. Private vs. public gardens

Private lawns seemed to be a better refuge for plant diversity than public lawns. Stewart et al. (2009) had a similar result in New Zealand, where there was lower species richness in public lawns than in residential ones. This owner effect certainly reflects practices used by private gardeners that favour plant species: limited access to the public, no use of pesticides and less frequent mowing. By contrast, management of public greenspaces and lawns is often based on aesthetic, recreational and cultural values and has little to do with nature conservation. This result certainly depends on private gardener practices that may vary from one country or city to another (Gragson & Keeler, 2005)

4.2.2. Public access

Public access had a negative effect on the floristic diversity of the lawns. Even if most public lawns are closed to the public during winter (from mid-October to mid-April), the damaged caused in the summer is enough to inhibit the development of many species that are not tolerant to intensive trampling.

4.2.3. Mowing

Mowing frequency had a significant negative correlation with species richness and rarity and affected lawn species composition. Stewart et al. (2009) evidenced a floristic composition dominated by broad-leaf species in un-mowed lawns. The impact of mowing was also highlighted at the species population level in previous studies (Roxburgh, Watkins, & Wilson, 1993). When lawns are mowed frequently most plants cannot reach the reproductive phase. The consequence could be a decrease in pollen and seed exchanges and consequently a long-term risk of population extinction. This effect is magnified in the urban landscape, which can impede connectivity between plant populations living in isolated and fragmented green spaces. In this context, frequent mowing may select a small number of plants able to reproduce vegetatively that would become dominants. Annual plants are, to a large extent, eliminated.

4.2.4. Shading

This study shows that sun-exposed lawns are richer than shaded lawns. Godefroid, Monbaliu, and Koedam (2007) already found that soil elements and light intensity are the main environmental variables driving plant species composition (richness and diversity) within the inner-city in non-managed habitats, *i.e.* wastelands. Moreover, many studies have demonstrated the role of luminosity in germination and development of some species (Fenner, 1985; Ohadi, Rahimian Mashhadi, Tavakkol-Afshari, & Beheshtian Mesgaran, 2010).

4.2.5. Pesticides and fertilizers

The use of pesticides, regardless of the dose seemed to have a negative impact on lawn diversity. The few studied lawns that used pesticides showed a very low richness in common (*vs.* rare) species compared to the non-treated sites. Unlike pesticides, use of fertilizers remains widespread (47 of 100 studied lawns) and seems to have no effect on species richness and rarity. Fertilizers can affect the composition however and have been correlated with a higher incidence of mowing-tolerant species. This result could be explained by similar trends for fertilizer use and mowing frequency (see Fig. 2). Until recently, a large part of urban lawns have been subject to the use of fertilizers, herbicides, and insecticides (Robbins & Birkenholtz, 2003). The impact of pesticides and fertilizers on non-target species is one of the best-studied aspects of lawn ecology (Byrne, 2005). Most of these investigations focused on human health (Pimentel, 2005; Steingraber, 2002; Ross, Driver, Lunchick, Wible, & Selman, 2006), and on bird (Brewer, Hummell, & Kendall, 1993), soil invertebrate and micro-organism (Cheng, Grewal, Stinner, Hurto, & Hamza, 2008; Potter, 1993) or even freshwater communities (Downing, DeVanna, Rubeck-Schurtz, Tuhela, & Grunkemeyer, 2008; Overmyer, Noblet, & Armbrust, 2005). The strong impact of pesticides on soil fauna and pollinator communities could explain the loss of many associated plant species (Geiger et al., 2010). Indeed, Byrne and Bruns (2004) showed a higher number of species in lawns without chemical inputs compared to lawns managed with pesticides and fertilizers in Pennsylvania (2.5 *vs.* 10.25 species on transects of $7\,\text{m} \times 0.5\,\text{m}$). The aim of herbicides is to remove weeds, but this leads to the destruction of many other plant species, to the decrease in soil quality and, inversely, to the increase in lawn disease (rust) severity (Cheng, Richmond, Salminen, & Grewal, 2008).

5. Conclusions

This study highlighted relationships between human activities and plant community characteristics. The results obtained allow the definition of a set of practices that could enhance diversity in urban lawns and consequently favour growing biodiversity in cities.

First of all, the abandonment of pesticide and fertilizer use that has recently been proposed by many city authorities in order to improve environmental quality is an excellent prerequisite. The reduction of agrochemical inputs has become an increasingly common recommendation in lawn care programmes (Alumai et al., 2010). Morris and Bagby (2008) compared organic and conventional lawn management and found that an organic approach enables savings of $23–29 per year per single-family parcel. Low-maintenance lawns can contribute to a reduction in agrochemical inputs and care costs while favouring biodiversity and ecosystem dynamics and services.

Nevertheless, because each type of management filters species with particular traits, the maximization of the number of practices is likely to enhance the overall diversity of species and traits at the city scale and could thus also enhance human well-being in gardens (Fuller et al., 2007). This important result justifies the development of a differential management where only practices negative for the vegetation and/or humans (*i.e.* chemical inputs) are removed. Moreover this result is not specific to our region; although Stewart et al. (2009) did not focused on species traits as we did, they found that, in New Zealand, lawns with distinct maintenance intensity share less species than lawns with similar maintenance intensity, which reinforces the potential general validity of our conclusions. A growing number of studies have pointed out how aesthetic values can influence landscape management and public policies, especially in urban ecosystems (Byrne, 2005; Jackson, 2003). Lawns are probably the closer to human daily-life habitat and consequently one of the most impacted by human design. Intensive management becomes unavoidable when the objective is to obtain a homogeneous and idealized lawn. Nevertheless, given the importance of these green areas for people living in urban areas, it is necessary to find practices that can reconcile the presence of the public and biodiversity management. Planning for all public greenspace needs to allow for large areas that are rarely mowed, areas that are inaccessible to the public and tree strata adjoining open areas. The inclusion of these features in differential management programmes would be expected to have a positive impact on urban biodiversity. In this study our aim was not to detail each practice but to evaluate the respective influence of mechanical (frequency of mowing) and chemical (use or not of chemical inputs) practices on plant diversity. It is a first step and further research should be done to go deeper in the investigation of these practices by detailing the effect of each depending on precise amount (*e.g.* volume and concentration of chemical inputs) and type (*e.g.* pesticides, fungicides, insecticides and herbicides) of treatment used.

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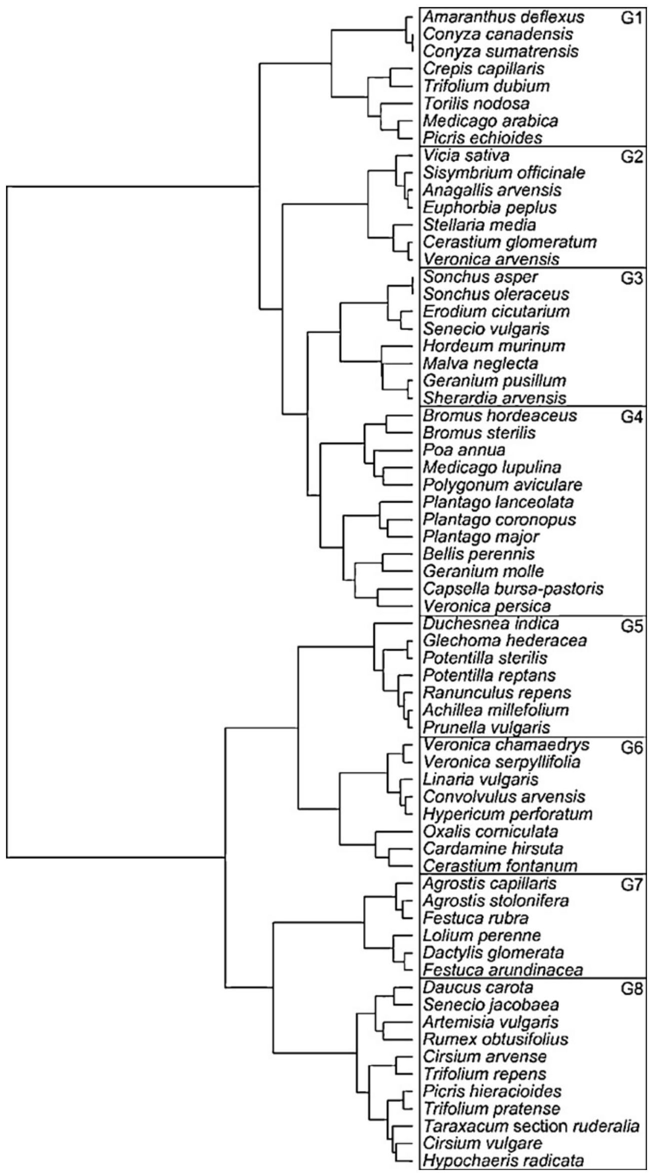
Appendix A.

Green areas studied and the management applied. Numbers in brackets correspond to the number of lawns in the green area studied with the management type mentioned.

Green area	Owner	Use of fertilizer	Use of pesticides	Mown frequency	Public access	Animal access	Luminosity	Number of lawns studied
Vega	Private	No	No	Low	No	No	Open	3
Vivaldi	Private	No	No	Low	No	No	Open	3
Rentiers	Private	No	No	Low frequency	No	No (4); yes (1)	Open (4); shaded (1)	5
FecampJ	Private	No	No	Frequent	No	No	Open	4
Paul Langevin	Public	No	No	Frequent	No	No	Shaded	3
Salpetriere	Public	No	No	Frequent	Yes	No	Open	4
Abelard	Public	No	No	Frequent	Yes	No	Open	5
Seine	Public	No	No	Frequent (4); high frequency (1)	Yes	Yes	Open	5
ChoisyP	Public	No	No	High frequency	No (1); yes (4)	No	Open	5
Curie	Public	No	No	Low	Yes	No	Open	2
Clisson	Public	No	No	Low	Yes	Yes	Open	1
Chevaleret	Public	No	No	Low	Yes	Yes	Open	4
Vincennes	Public	No	No	Low	Yes	Yes	Open	9
Rossif	Public	Yes	No	Frequent	No	No	Open (2); shaded (1)	3
ChoisyRP	Public	Yes	No	Frequent	No	Yes	Open	1
Museum	Public	Yes	No	Frequent	No (4); yes (1)	No	Open	5
Floral	Public	Yes	No	Frequent	Yes	No	Open	5
Carnot	Public	Yes	No	Frequent	Yes	No	Open	1
Fecamp S	Public	Yes	No	Frequent	Yes	No	Open	3
Tournaire	Public	Yes	No	Frequent	Yes	No	Open (1); shaded (1)	2
Nationale	Public	Yes	No	Frequent	Yes	Yes	Open	1
Jussieu	Public	Yes	No	High frequency	Yes	No (3); yes (2)	Open	5
Bercy	Public	Yes	No	Low frequency	No (1); yes (4)	No (3); yes (2)	Open (4); shaded (1)	5
Lutece	Public	Yes	No	Low frequency (1); frequent	No (1); yes (3)	No	Open	4
Peguy	Public	Yes	No (5); yes (4)	Frequent (5); high frequency (4)	No (2); yes (7)	No (6); yes (3)	Open	9
Reuilly	Public	Yes	Yes	High frequency	Yes	No	Open	3

Appendix B.

Functional groups made by the clustering.



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