Influences on the establishment and dominance of vegetation in stormwater infiltration basins

J-P. Bedell, B. Mourier, J. Provot and T. Winiarski

ABSTRACT

Infiltration basins are widely used in urban environments as a technique for managing and reducing the volume of stormwater. These basins can be spontaneously colonized by wild plants, which can be used as bioindicators of edaphic characteristics. As the basins are anthropogenic environments, the description of plant biodiversity allows the determination of which species colonize such environments and identification of the relationships between plants, basin type and operation. Nineteen infiltration basins were selected according to their catchment types (industrial, urban, agricultural). The dominant species were identified and sampled. *Rumex* sp., *Taraxacum* sp. and *Artemisia* sp. are the three types most represented (88, 61 and 55% respectively of the basins studied). Their families and their respective orders are those most commonly found (Caryophyllales, Asterales and Polygonaceae, Asteraceae). Poaceae is the family grouping with the largest number of different species (11). Although each species occupies only 1 or 2 basins, plants of this family occupy 61% of the basins. Although the catchment characteristics of the 19 basins do not play a direct role in the diversity of plant families, they can influence the presence or absence of certain species. Thus, these plants can be used as bio-indicators of basin soil and operating characteristics, such as sediment depths, inundation frequency and duration.

Key words | *Artemisia* sp., dominant species, infiltration basin, *Rumex* sp., *Taraxacum* sp., vegetation diversity

J-P. Bedell (corresponding author)
B. Mourier
J. Provot
T. Winiarski
LEHNA-IPE UMR 5023, ENTPE,
Rue Maurice Audin 69518 Vaulx-en-velin cedex, France
E-mail: *bedell@entpe.fr*

INTRODUCTION

Infiltration basins are technical structures designed to manage stormwater. The storage/infiltration in these structures leads to the settling of the suspended matter contained in stormwater, leading to deposits contaminated by heavy metals and organic pollutants (hydrocarbons, pesticides, etc.) (Deschesne *et al*. 2004; Winiarski *et al*. 2006). The aim is to gain further knowledge on this heterogeneous medium, which can be considered as a specific urban soil. The successive deposits form a surface layer that presents a risk for the degradation of the subsoil and groundwater due to the migration of contaminants. This study focuses on the characterization of urban sediments from 19 infiltration basins in different areas of land use (industrial, service industries, residential, agricultural) located in the same geological formation of the east Lyon region (fluvio-glacial deposits). These basins present diversified vegetation resulting from natural and anthropic plant colonization dynamics linked to local ecological factors. Also, the operating characteristics of the structure must be taken into account (Saulais 2011). Consequently, we focused on the vegetation that has developed on this filtering surface on which the sediments carried by stormwater runoff are deposited. The deep and open structure of the basins allows colonization by plants that benefit from light, water and nutrients. The occurrence of species can be due to the dissemination of seeds carried by different vectors such as water, wind and animals (Ramade 2003; Saulais 2011). However, other factors are also involved in the colonization of basins such as water availability, edaphic conditions and the presence or absence of pollutants (Saulais *et al*. 2011). Nineteen infiltration basins were chosen according to criteria of size, age, volume and the type of activity in the catchment concerned. A 'simplified' floristic survey of each of these basins was performed to identify the dominant species in terms of abundance and cover. A comparison of the plant diversity (family, species) present by basin was performed with the land use

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typology proposed. To achieve this, the dominant species and the main characteristics of the basins were identified. It will therefore be possible to define the conditions of occurrence and development of families and certain species of plant as well as the characteristics of the basins.

MATERIALS AND METHODS

Description of the sites

Land use typology of basin catchments was determined by using several data sources such as the European Environmental Agency (Corine Land Cover and soil sealing), Greater Lyon data and planning and water management agency data. Three types of catchment are proposed: Industrial and Commercial Zones (ZIC), Mixed Urban Areas (TUD, residential areas and city-center) and Agricultural Areas (ZA). The information collected from the basins is given in Table 1 with the information relating to the structure of the basin, the thickness of the sediment, the type of urban environment, the presence of water at surface and whether or not there is a retention basin downstream of the infiltration basin. The basins are very different in terms of structure and shape, while water may be present over the entire surface of a basin or in a more limited area (Table 1 and Additional material 1, available online at http://www.iwaponline.com/wst/068/526.pdf).

Sampling and measurements

The infiltration basins were characterized and sampled in spring 2012. For each basin, the species present, the dominant species and their areas of distribution in the basin were determined (see examples of diagrams in Additional material 1). To do this, when arriving at each site, an initial estimation was made on the upper slopes of the basin to establish a preliminary map of the vegetation present and determine whether the distribution was homogenous or dispersed, or whether certain areas were identifiable/remarkable in relation to the characteristics of the basin (water, low point, etc.). The survey was then continued in the basin by identifying, photographing and sampling the most abundant species in each area. Plant species were identified on the basis of several flora (Bonnier 1986; Bonnier & De Layens 1986; Philips 1986; Bremer *et al*. 2009. Lauber *et al*. 2012; Site Terra Botanica). Identification was performed according to foliar and size criteria, and to inflorescence characteristics. For example, the genus *Rumex sp.* was identified by its leaves and stem. *Sanguisorba sp.* was identified by its inflorescence. For Poaceae, a key was used for determination based on the shape of its ligule and the junction between the foliar sheath and the leaf blade (Leconte 2006; Kyle 2009). Some plants could not be identified at genus level due to difficulties linked to their phenological state at this period (absence of flowers). The estimation of total diversity (in terms of species) depended on the visual evaluation of the different species present over the entire area of the basin and which were identifiable at the time of establishing the botanical inventory of the site.

The Braun-Blanquet scale (Additional material 2, available online at http://www.iwaponline.com/wst/068/526.pdf), which combines both abundance and cover, can be used as an index representing the percentage of cover-abundance in comparison to the surface area of the basin (Westhoff & Van Der Maarel 1973; Saulais 2011). Cover means the surface area occupied by a species in relation to the total surface area of the zone (see examples in Figure 1). Thus, abundance is the number of individuals of this species present on the total surface area. For each dominant species, we assigned a cover/abundance index to them as a function of the Braun-Blanquet scale (Additional materials 1 and 2; Table 1).

RESULTS AND DISCUSSION

The sites and plant diversity

We noted several possible cases of plant cover for all the basins visited. Twelve of the basins studied are covered by plants covering more than 70% of the surface (Table 1 and Additional material 3, available online at http://www.iwaponline.com/wst/068/526.pdf). Certain basins had little vegetation (5% of the surface areas of the basin of Zac des Pivoles, graded Piv) or were completely covered by plants (95% on the basin Carreau, graded Car) (Table 1 and Additional material 3). In the 19 basins, 14 orders, 22 families, 44 genera and 48 dominant species were identified (Table 1; Figure 1).

The heterogeneity between basins was considerable whether viewed from the standpoint of surface plant cover, total diversity, or the abundance of identified species (Table 1; Figure 1; Additional material 3). Likewise, the simplified floristic survey, in terms of type of plant present, showed very considerable heterogeneity, ranging in estimated total diversity from two to 50 species present in the different basins (Table 1; Figure 1). Such an amount of

Table 1 | Study sites and description of some plant/vegetation characteristics

Location (Name of town)	Name of basin	Abbreviation	Type of basin	Land use	Water saturation at surface	Thickness of sediment deposit (cm)	Average of total plant cover (%)	Estimation of total diversity	*Dominant species* (Maximum abundance dominance index according to Braun-Blanquet scale)
Meyzieu	Le Carreau	Car	BI	TUD	N	20	95	30–40	*Aphanes arvensis* (4); *Rumex* sp. (4), *Festuca* sp. (5), *Taraxacum* sp. (4).
Chassieu	L'épine	Epi	BI	ZA	N	4	90	10–20	*Sanguisorba* sp. (5), *Rumex* sp. (3), *Taraxacum* sp. (2).
Chassieu	Django	Dja	BR + BI	ZIC	Y	30	90	40–50	*Rumex* sp. (4), *Eleocharis palustris* (4), *Typha latifolia* (3), *Phalaris* sp. (4), *Polygonum* sp. (2).
Décines-Charpieu	ZAC des Pivolles	Piv	BR + BI	ZIC	N	4	5	2	*Populus* sp. (+).
Chassieu	ZAC du Chêne	Che	BI	ZIC	N	15	20	10–20	*Rumex* sp. (5), *Elymus repens* (4), *Euphorbia cyparissias* (5), *Artemesia* sp. (5).
Saint-Priest	Revaison	Rev	BR + BI	TUD	Y	5	80	10–20	*Rumex* sp. (5), *Schoenoplectus tabernaemontani* (4), *Typha* sp. (3).
Bron	Centre routier	Cr	BR + BI	ZIC	N	11	90	20–30	*Festuca rubra* (5), *Rumex* sp. (5), *Thlaspi arvense* (4), *Sedum rubrotinctum* (5), *Medicago* sp. (5), *Artemisia* sp. (4), *Taraxacum* sp. (5), *Carex* sp. (4).
Bron	Triangle de Bron	TdB	BI	TUD	N	18	80	20–30	*Rumex* sp. (5), *Taraxacum* sp. (5), *Artemisia* sp. (5), *Ranunculacea* sp. (4).
Saint-Priest	Minerve	Min	BR + BI	ZIC	Y	20	85	5–10	*Rumex* sp. (4), *Typha latifolia* (5), *Phragmite australis* (5), *Iris speudacorus* (5).
Saint-Priest	ZAC Paul Claudel	PC	BR + BI	TUD	N	30	90	5–10	*Rumex* sp. (5), *Taraxacum* sp. (4), *Festuca* sp. (4).
Saint-Priest	PAE Mi-Plaine	Pith	BR + BI	ZIC	N	36	50	3	*Typha* sp. (5), *Rumex* sp. (3), *Polygonum* sp. (3).
Saint-Priest	Savoie	Sav	BR + BI	ZIC	N	0	25	10–20	*Artemisia* sp. (4), *Taraxacum* sp. (3), *Rumex* sp. (2).

(*continued*)

Table 1 | continued

Location (Name of town)	Name of basin	Abbreviation	Type of basin	Land use	Water saturation at surface	Thickness of sediment deposit (cm)	Average of total plant cover (%)	Estimation of total diversity	*Dominant species* (Maximum abundance dominance index according to Braun-Blanquet scale)
Saint-Priest	Pierre Blanche	PB	BR + BI	ZA	N	9	70	30–40	*Rumex* sp. (5), *Plantago* sp. (3), *Taraxacum* sp. (5), *Stellaria* sp. (3), *Fetusca* sp. (3), *Bromus* sp. (5), *Carex* sp. (5).
Venissieux	Charbonnier	Char	BR + BI	ZIC	Y	5	40	5–10	*Rumex* sp. (5), *Poa pratensis* (3), *Artemisia* sp. (3).
Venissieux	Boulevard Urbain Est	BuE	BR + BI	ZA	N	4	20	5	*Polygonum* sp. (4), *Taraxacum* sp. (3).
Corbas	Dauphiné	Daup	BI	ZA	N	8	80	10–20	*Alopecurus pratensis* (5), *Festuca rubra* (5), *Medicago* sp. (2), *Alopecurus pratensis* (4), *Rumex* sp. (2).
Corbas	Léopha	Leo	BR + BI	ZIC	Y	2	10	5	*Rumex* sp. (3), *Populus* sp. (+).
Mions	Chemin de Feyzin	CdF	BR + BI	TUD	Y	14	90	20–30	*Taraxacum* sp. (5), *Dactylis glomerata* (4), *Rumex* sp. (5), *Stellaria* sp. (5).
Saint-Symphorien d'Ozon	Grange Blanche	SSO	BR + BI	TUD	Y	15	80	30–40	*Fallopia* sp. (5), *Taraxacum* sp. (4), *Cardus* sp. (4), *Urtica* sp. (4), *Bromus* sp. (4), *Polygonum* sp. (4).

Br = retention basin, BI = infiltration basin, BR + BI = both types of basin present on the same site; ZA = agricultural area, TUD = mixed urban area, ZIC = industrial and commercial zone; Y = yes, N = no.

total diversity estimation is consistent with previous studies performed in 2008 in the basins Dja, Min, Pith and PB (Saulais 2011). Lastly, of the dominant species surveyed and identified, the number of orders, families and species also differed from basin to basin (Table 1 and Figure 1).

All the species observed belong to the division of Magnoliophyta (angiosperms). *Rumex* sp., *Taraxacum* sp. and *Artemisia* sp., the three most representative genera, are identified over 88%, 61% and 55% of the basins occupied, respectively (Table 1). Their respective families and orders are also those most represented (Caryophyllales, Astérales and Polygonaceae, Asteraceae). Poaceae is the family grouping with the largest number of different species (11 species). Although each species occupies only one or two basins, the Poaceae family occupied 61% of the 19 basins studied during this period. *Taraxacum* sp. and *Artemisia* sp. occupied 61% and 55% of the 19 basins. However, they were present jointly in 80% of the basins studied (Table 1).

The 19 basins can also be distinguished by the presence or absence of families, or certain species. Thus, eight basins of the 19 studied presented relatively high diversity in terms of number of species and families identified during this spring period (Figure 1). Six basins (Piv, PC, Pith, Char, BuE and Leo) presented low diversity (Figure 1). Generally, even when descending in the level of the order, plant diversity appeared 'relatively rich' in terms of number of different orders present in this type of structure in comparison to equally artificial environments (public gardens, wastelands, etc.) (Fransceschi 1996; Dana *et al*. 2001). This observation had been suspected in four basins previously

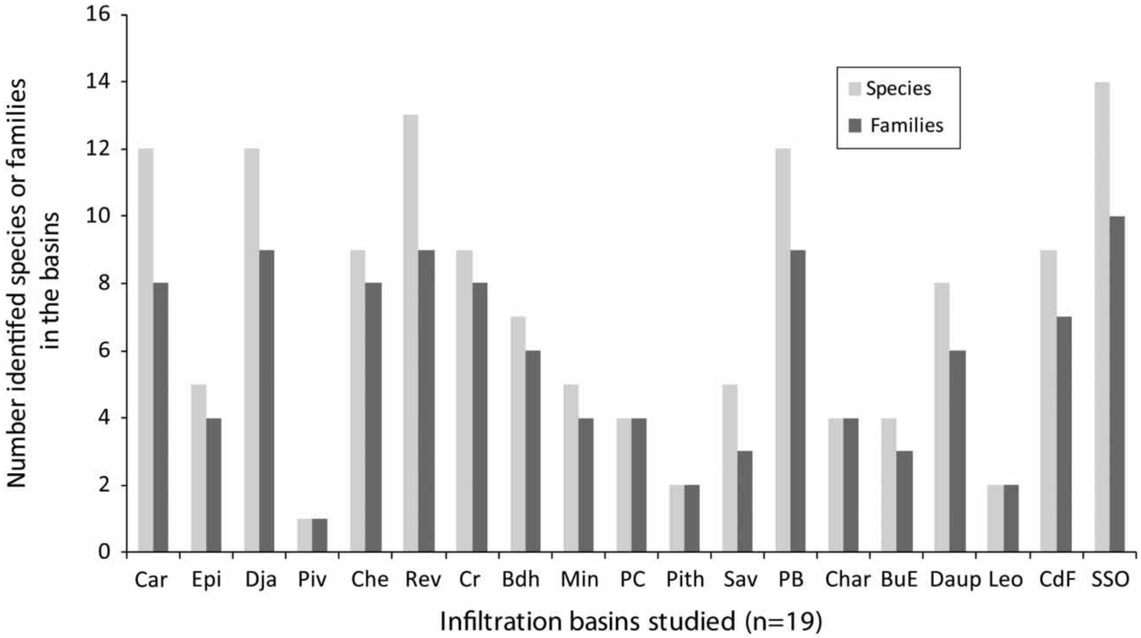

Figure 1 | Number of dominant species and families identified by basin.

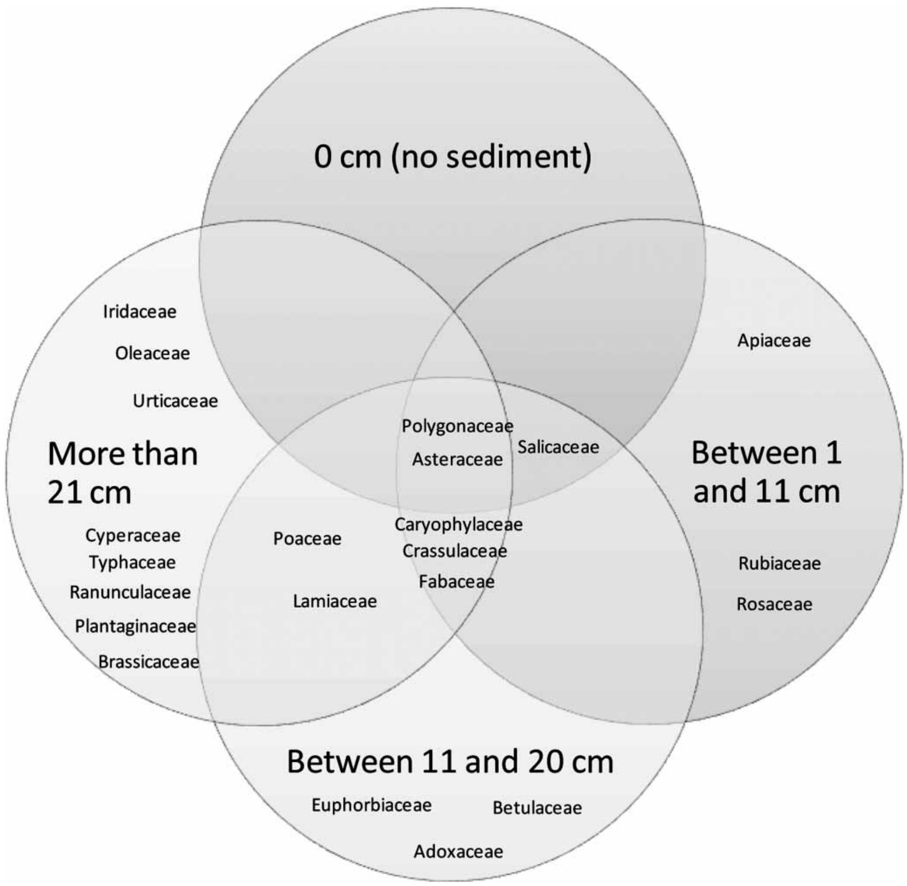

Figure 2 | Venn diagram of plant families according to depth of sediment.

studied in this region (Saulais 2011). The vegetation distribution could also be related to the presence of water, or notably water availability or the percentage of time inundated. In ephemeral wetland, vegetation zonation according to water depth, periods of inundation and time of emergence is a characteristic feature of temporary ponds and emergent shorelines (Deil 2005).

Other differentiating gradients can be soil depth and water storage capacity (on rock outcrops), duration of seepage water flow (on inselbergs), wave respectively ice scour intensity (in the shoreline habitat), frost-heaving intensity (in subarctic and oreotropical climates) and salinity (in endorheic playa lakes in arid and semi-arid climates). For Deil (2005), these environmental gradients result in repetitive patterns of contact series of plant communities (= zonation complexes). But our study was a previous step in correlation between several factors to vegetation typology in such an artificial place. Moreover, our data were acquired within a limited time (spring season) and not during a longer period of one or more years. Nevertheless, we can underline that some species liked humid soil, such as *Visnaga daucoides* (Apiaceae), or *Fallopia* sp. (Polygonaceae) up to species typical of wetland zones such as *Iris pseudacorus* (Iridaceae). A large number of basins presented also vegetation typical of eutrophic environments such as *Phalaris arundinacea*, *Rumex crispus* and *Eleocharis palustris* (Touzard *et al*. 2002). Our results led to presuming that other potential factors, such as the nature of the geological substratum and the pH of the sediments, play a role. For example, *Veronica chamaedrys* grows on calcareous soils, *Aphanes arvensis* on silica soil, while *Betula* sp. prefers acidic soils (Lauber *et al*. 2012; Site Tela Botanica).

Influence of sediment depth and maintenance operations on vegetation

As these basins are heterogeneous in term of surface, structure, functioning, age (5 up to 20 years), and undergoing maintenance operations (dredging, mowing) we presumed that sediment depth plays a key role in vegetation. These works also allowed us to highlight the relation between the presence, or absence, of certain plant families (or species) as a function of sediment depth (Figure 2). For example, *I. pseudacorus* (Iridaceae family) was found only in a single basin with 21 cm of sediment and Crassulaceae are found on shallow sediments (1 cm). But Rosaceae grow between 1 and 10 cm but not above that (Figure 2). Unlike the others, the Polygonaceae and Asteraceae families are not sensitive to the presence or depth of sediment.

Many basins are tended regularly (such as the Leopha basin) and cleaned of their sediment. Without sediment, only certain species, such as *Rumex* sp. (Polygonaceae) and *Populus* sp. (Salicaceae), are able to grow under the layer of stones forming the bottoms of the basins. Indeed, the genera *Rumex* and *Populus* are ruderal species and can withstand major disturbances like scything, flooding and sediment removal (Huber *et al*. 2012).

Previous research showed that the vegetation, particularly due to the root structure, could contribute, through the establishment of macropore, to improving the infiltration capacity of the soil (Hatt *et al*. 2009; Le Coustumer *et al*. 2009). Recent works done on the infiltration basin Django (Dja) showed an increased infiltration constant (Ks) in the presence of *Rumex crispus*, *Polygonum mite* (two Polygonaceae) and notably *P. arundinacea* (Poaceae) in comparison to the same place without vegetation (Gonzales-Merchan 2012). Here, according to this possible role of such a plant in infiltration facilities, we note that two of them, the Polygonaceae and *Phalaris* sp., are not influenced by sediment depth and the Poaceae was detected only in basins with more than 10 cm of sediment.

Other basins, like Le Carreau and Dauphiné, are mown and cut, strongly reducing their diversity and making identification impossible. Consequently, knowledge of diversity can be strongly biased by the time when identification is performed, whether in relation to the physiology of the species (in this study only spring plants were observed) or by the management/operation of the basin (mowing, trampling, permanent presence of water, clogging, etc.).

Influence of land use type on vegetation

One hypothesis is that the nature of the urban fabric from which the runoff flows governs the diversity of the species present. Thus, we use the average number of species and families identified in the ZIC, TUD and ZAC (Figure 3 and Additional material 4, available online at http://www.iwaponline.com/wst/068/526.pdf).

However, if we examine on the basis of plant families (Figure 3), it can be seen that certain families only develop in a specific urban environment. For example, Urticaceae only grow close to TUD while Rubiaceae and Apiaceae only grow in agricultural environments. In this study, Iridaceae and Oleaceae were found only in basins typical of ZIC areas. Other plant families were less influenced by the catchment such as Polygonaceae and Poaceae (Figure 3).

Greater numbers of species and families were determinated in basins identified as TUD than in ZIC basins

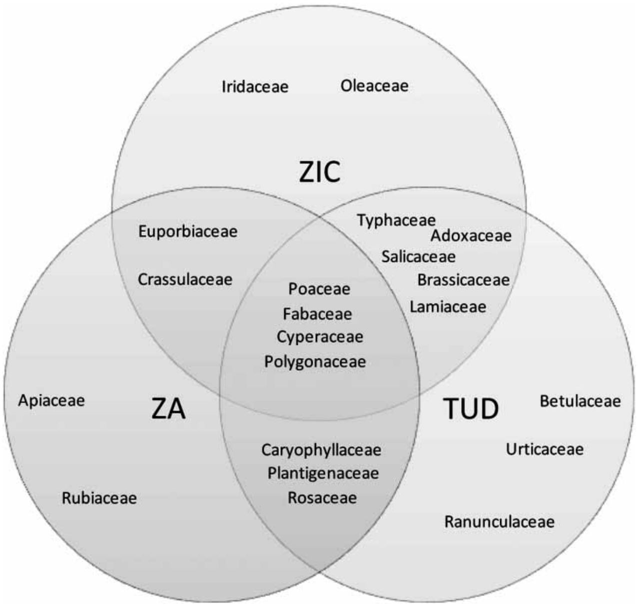

Figure 3 | Venn diagram of plant families according to land use type. (ZA = agricultural area; TUD = mixed urban area; ZIC = industrial and commercial area.)

(Additional material 4). The presence of certain species permits the distinguishing of certain basins from the others, rather than taking a global view of all the species by family. Thus, the presence of a species also makes it possible to qualify the state of a basin in light of the plants present. For example, it can be seen that the presence of nitrogen, confirmed by the presence of nitrophilic species (like *Galium mollugo*, Rubiaceae, in the Dauphiné basin), is correlated with an agricultural environment (ZA). Thus, agriculture and the contribution of nitrate fertilizers influence the selection of nitrophilic species in certain basins. The species *Trifolium* sp. (Fabaceae family) is characteristic of an alkaline soil and the *Sedum* sp. (of the Crassulaceae family) of a lack of water, as in the basin of the East Urban Boulevard where there were only five different species. But this could also be due to the effect of active drainage in this basin. Some species, including *I. pseudacorus* and *Medicago* sp., require a high water content and are insensitive to pollutants, hence their probable presence in the ZIC basins. The urban environment may not therefore have an effect on the diversity of dominant species in the basins studied, rather it has an effect on the presence or absence of a specific species. We observed that 8 basins had species that were 'specific' to them (i.e. 44% of the basins studied), tending to give an indication of the type of soil and its humidity. We compared this with results from temporal wetland where the first tendencies of globalization of the ephemeral wetland flora can be observed due to the sensitivity of such habitats to human impact. However, they also shelter extremely rare and isolated taxa (Deil 2005) as with some species in our studied basins. Several factors are involved in the colonization of basins by plants. For example, previous works on several basins highlighted the importance of water availability. In addition, the presence of sediment was also suspected as being an influential factor (Saulais 2011). Although the urban environment does not play a direct role in diversity as such, it influences the presence or absence of species through a catchment effect. In addition, by comparing data between the families present in certain urban environments and the presence of species as a function of sediment layer, it is possible to distinguish families whose presence is favoured (such as Rubiaceae at the Dauphiné basin) or limited by them. Thus, the Rosaceae do not grow in basins in ZIC catchments, perhaps due to the effect of pollution. Consequently, the type of urban environment, in the same way as sediment depth, acts as a filter for species capable or not of growing in a basin, by providing the chemical elements likely to favour or prevent their development.

CONCLUSIONS

A large number of factors such as sediment depth, urban and agricultural environment and the physicochemical characteristics of soil associated with the characteristics of the geological substratum can influence the establishment of certain types of plant. The anthropic factor also plays a role as the maintenance of these basins affects the diversity of the plants present and the dominant species that colonize them. However, the main factor favouring the development of plants in these artificial systems remains water and its availability. Consequently, common and widespread plants owe their presence to the large amounts of water in the infiltration basins, whereas rare plants are influenced by the external inputs of the urban environment and parameters such as sediment depth and the physical parameters of the soil. Finally, the pollutants present in the sediment may exert selective pressure on the presence or absence of certain species and families. The doses of pollutants in the plants identified will be analyzed to obtain information on these plants' capacities and potential for phytoremediation, and, more generally, on their adaptation to an anthropized environment.

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REFERENCES

Bonnier, G. 1986 Les noms des fleurs. Editions Belin.

Bonnier, G. & De Layens, D. 1986 Flore Portative et complète de la France, de la Suisse et de la Belgique. Editions Belin, Paris, France.

Bremer, B., Bremer, K., Chase, M. W., Fay, M. M., Reveal, J. L., Soltis, D. E. & Stevens, P. F. 2009 An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. *Botanical Journal of the Linnean Society* **161**, 105–121.

Dana, E. D., Vivas, S. & Mota, J. F. 2001 Urban vegetation of Almería City – a contribution to urban ecology in Spain. *Landscape and Urban Planning* **59** (4), 203–216.

Deil, U. 2005 A review on habitats, plant traits and vegetation of ephemeral wetlands – a global perspective. *Phytocoenologia* **35** (2–3), 533–705.

Deschesne, M., Barraud, S. & Bardin, J. P. 2004 Spatial distribution of pollution in an urban stormwater infiltration basin. *Journal of Contaminant Hydrology* **72**, 189–205.

Fransceschi, E. A. 1996 The ruderal vegetation of Rosario City, Argentina. *Landscape and Urban Planning* **34** (1), 11–18.

Gonzales-Merchan, C. 2012 Amélioration des connaissances sur le colmatage des systèmes d'infiltration d'eaux pluviales. PhD Thesis, Institut National des Sciences Appliquées de Lyon, Lyon, France, 300 pp.

Hatt, B. E., Fletcher, T. & Deletic, A. 2009 Hydrologic and pollutant removal performance of stormwater biofiltration systems at the field scale. *Journal of Hydrology* **365**, 310–321.

Huber, H., Chen, X., Hendriks, M., Keijsers, D., Voesenek, L. A. C., Pierik, R., Poorter, H., De Kroom, H. & Visser, E. J. W. 2012 Plasticity as a plastic response: how submergence-induced leaf elongation in *Rumex palustris* depends on light and nutrient availability in its early life stage. *New Phytologist* **194**, 572–582.

Kyle, J. 2009 Identification des graminées de pâturage. http://www.omafra.gov.on.ca/french/livestock/beef/facts/06-096.htm.

Lauber, K., Wagner, G. & Gygax, A. 2012 Flora Helvetica (Édition Française).

Leconte, D. 2006 Clé de détermination des principales graminées prairiales. Groupement Nationale Interprofessionnel des semences et plants. N162: 157–167, France.

Le Coustumer, S., Fletcher, T., Deletic, A., Barraud, S. & Lewis, J. F. 2009 Hydraulic performance of biofilter systems for stormwater management: Influences of design and operation. *Journal of Hydrology* **376**, 16–23.

Philips, R. 1986 Les fleurs des chemins et campagnes. Editions Bordas.

Ramade, F. 2003 *Eléments d'écologie-Ecologie fondamentale*. 3ème edn. Dunod, Paris, France, 690 pp.

Saulais, M. 2011 Colonisation végétale des bassins d'infiltration et de rétention. PhD thesis, Institut National des Sciences Appliquées de Lyon, Lyon, France, 245 pp.

Saulais, M., Bedell, J. P. & Delolme, C. 2011 Cd, Cu and Zn mobility in contaminated sediments from an infiltration basin colonized by wild plants: The case of *Phalaris arundinacea* and *Typha latifolia*. *Water Sciences and Technology* **64** (1), 255–262.

Site Tela Botanica. http://www.tela-botanica.org/site:botanique.

Touzard, B., Amiaud, B., Langlois, E., Lemauviel, S. & Clément, B. 2002 The relationships between soil seed bank, aboveground vegetation and disturbances in an eutrophic alluvial wetland of Western France. *Flora* **197**, 175–185.

Westhoff, V. & Van Der Maarel, E. 1973 The Braun-Blanquet Approach. *Junk* **5** (20), 617–726.

Winiarski, T., Bedell, J.-P., Delolme, C. & Perrodin, Y. 2006 The impact of stormwater on a soil profile in an infiltration basin. *Hydrogeology Journal* **14** (7), 1244–125.

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