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1 **Are acts of selective planting and maintenance drivers for vegetation change in**  
2 **stormwater systems? A case study of two infiltration basins**

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11 **Highlights**

- 12 • Vegetation changes were observed over a decade in two urban stormwater basins  
13 • Maintenance seems to be a driver of short-term vegetation change  
14 • Water drives vegetation occurrence and short- and long-term ecological changes  
15 • Combining water level and vegetation maintenance may help prevent invasive species  
16 • Select vegetation and water level management should be considered for optimum operation  
17

18 **Summary**

19 Infiltration basins have been designed to receive and infiltrate stormwater. Upstream, the  
20 stormwater runs off urban surfaces, is collected by the sewer system, and then routed to  
21 infiltration basins. Then, the suspended solids carried by stormwater accumulate at the surface  
22 and form a sedimentary layer. Plants then colonize the soil surface and shape a new ecological  
23 system, ruling at the same time water quality and quantity. In this study, we monitored the  
24 dynamics of vegetation over two decades in two infiltration basins. One of these basins was  
25 subjected to vegetation maintenance (planting and mowing once every year), whereas the  
26 other basin was left to be colonized by spontaneous vegetation. Basic maintenance (1/year)  
27 may change the species at the beginning of the operation of the basins, but the impact is short  
28 term. However, this may be sufficient to prevent the growth of some invasive species. In the  
29 long term, spontaneous vegetation and water regimes turn the original ecosystem into a new  
30 one, combining initial planted species with new species. Our results show that the water  
31 regime seems to be the main factor controlling vegetation and that dry conditions allow the  
32 establishment of grasslands with typical plant species. Vegetation maintenance and the

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33 management of water levels may help prevent the establishment of invasive species and  
34 maintain species for the optimal functioning of infiltration basins.

35  
36 Key words: gardening; grassland vegetation; plant species development; stormwater basin;  
37 *Typha* sp.; wetland vegetation

## 38 Introduction

39 Within the context of urbanization and the sealing of peri-urban areas, stormwater  
40 management techniques have been developed for stormwater infiltration instead of routing it  
41 towards sewer systems (de Winton et al., 2013; Le Coustumer et al., 2007; Le Coustumer,  
42 2008; Tedoldi et al., 2016). The determination of how plants evolve in infiltration basins, is  
43 crucial for understanding and managing the functioning of these basins. These plants actively  
44 participate in the proper functioning of infiltration basins, for instance, by compensating for  
45 clogging at the surface and promoting infiltration (Gonzalez-Merchan et al., 2014).

46 The dynamics of vegetation are notably conditioned by local hydric conditions (e.g., wetting  
47 and drying cycles, water pathways at the surface), temperature, and edaphic conditions  
48 (Greenway et al., 2007; Robertson et al., 2018). Hydric conditions determine the access plants  
49 have to water. Meanwhile, edaphic conditions determine the access plants have to nutrients  
50 and determine the conditions for root system development (Marschner, 2011). Both, edaphic  
51 and hydric conditions in such artificial systems are massively impacted by the functioning of  
52 the infiltration basins and, in particular, clogging resulting from suspended matter and  
53 pollutant loads (e.g., El-Mufleh et al., 2014; Lassabatere et al., 2010). The co-evolution of  
54 hydric conditions, edaphic conditions, and vegetation determines the ecological succession of  
55 these infiltration basins.

56 Vegetation succession in infiltration basins has often been an area of interest (Bishop et al.,  
57 2000; Holtmann et al., 2019; Mitsch et al., 2014). A study conducted in 19 stormwater  
58 wetlands showed a strong relationship between water level and vegetation with vegetation  
59 cover generally high (>80%) at a median depth of water <0.35 m (Robertson et al., 2018).  
60 Therefore, ruderal vegetation appears to be distributed in a spatial pattern corresponding to  
61 variations in the specific attributes of the site (including water conditions, pH, soil structure,  
62 and associated biotic and abiotic stresses) (Osmond et al., 1987). However, the question of  
63 maintenance practices that combine initial planting with frequent mowing has never been  
64 clearly addressed for these types of infiltration systems, especially in terms of vegetation  
65 change, and impacts on water infiltration, pollutant removal, and sorption. As a result, this

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66 study investigated the effect of maintenance (planting and mowing) on vegetation changes in  
67 two infiltration basins (Minerve and Django Reinhardt basins located in the region of Lyon,  
68 France). We compared the vegetation succession in these two infiltration basins; one planted  
69 before operation with mowing (one year), against a basin left to vegetate spontaneously from  
70 a bare state at the beginning of the operation. Temporal and spatial variations in vegetation  
71 development were monitored in these two basins over the recent decade.

## 72 **Materials and methods**

### 73 1. Site locations

74 The studied infiltration basins "Minerve" (69800 Saint Priest, France; N045°42.906'  
75 E004°54.995') and "Django Reinhardt" (69680 Chassieu, France; N045°44.163'  
76 E004°57.478') are located in the East Lyon suburbs with an average rainfall amount of 800  
77 mm/year and an average temperature of 12 °C (Figure 1, Supplementary materials Table 1).  
78 The two basins overlay a glacio-fluvial deposit originating from the Quaternary period  
79 (Winiarski et al., 2006). They have settled over a deep non-saturated zone, with a water table  
80 at a depth of 13 m for the Django basin and around 3 m for the Minerve basin (Voisin et al.,  
81 2018). The Minerve basin, 4,333 m<sup>2</sup> in area, has been collecting water from a tertiary activity  
82 watershed since 1999, with a storage volume of around 6,500 m<sup>3</sup>. The related watershed has  
83 an area of 146 ha and an average runoff coefficient of 0.8. The Django Reinhardt basin  
84 collects stormwater from an industrial watershed, 185 ha in area, and has an average runoff  
85 coefficient of 0.7. The basin has an area of 9,112 m<sup>2</sup> and began operations in 2002 with a  
86 storage volume of around 27,000 m<sup>3</sup>. Regarding vegetation, the two basins were subjected to  
87 opposite strategies. For the Minerve basin, the vegetation was planted before operation began  
88 and the basin was frequently mowed (once each year) to maintain the targeted vegetation. In  
89 contrast, no plants were planted in the Django Reinhardt basin, which was left with the initial  
90 bare soil. The spontaneous and natural vegetation was free to colonize the basin. After a  
91 decade of operation, vegetation settled and shaped the water pathways in the two basins, as  
92 illustrated in Figure 1.

### 93 2. Sampling and identification of flora

94 All annual floristic surveys were conducted from March to May. The vegetation was  
95 monitored in 1999, 2008, and 2015 for the Minerve basin and in 2002, 2008, and 2015 for the  
96 Django Reinhardt basin. Spring proved to be the best period for the determination of flora  
97 (Bedell et al., 2013; Saulais, 2011; Saulais et al., 2011). The species were identified using the  
98 floristic inventories available in botanical books and websites (Rameau et al., 2018, 2008,

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99 1999; [www.tela-botanica.org](http://www.tela-botanica.org)). In the field, 12 quadrats (Django Reinhardt) and 10 quadrats  
100 (Minerve), each 1 m<sup>2</sup> in area, were positioned in homogenous areas to represent the main  
101 vegetation patches. Aerial photographs were used to optimize the locations of the quadrats  
102 (Figure 1). In each quadrat, the species and their related frequencies were identified. The  
103 vegetation cover was quantified as the surface area occupied by the species, divided by the  
104 total area of the quadrat. The abundance was determined as the number of individuals per  
105 quadrat, as suggested by Saulais (2011). An abundance index was then calculated using the  
106 Braun-Blanquet method (Wikum and Shanholtzer, 1978).

## 107 Results and discussion

108 In the Minerve basin, 30 different species were planted before the start of operations (Table 1;  
109 Sup materials 1). Wetland species, *Acorus calamus* (6%), *Iris pseudacorus* (12%), and  
110 *Phalaris arundinacea* (22%), were among the most frequent species planted (Figure 2, year  
111 1999). From 1999 to 2008, the species richness decreased, with only eight species surviving  
112 after nine years of operation (Table 1). All survived species belonged to the group of wetland  
113 species in 1999 and 2008. Between 1999 and 2008, only three of the 30 planted species  
114 survived. And five new species appeared as *Typha angustifolia* and *T. latifolia* (Figure 2). ~~and~~  
115 ~~the loss of 27 planted species~~ The three wetland species planted before operations began on  
116 basin (i.e., *A. calamus*, *I. pseudacorus*, and *P. arundinacea*), survived in the basin. In 2015,  
117 18 species were counted, with the appearance of 10 additional species. The wetland plants  
118 covered approximately 61% of the basin's surface (in area), compared to 100% in 1999 and  
119 94% in 2008. These species included mainly *A. calamus*, *Typha latifolia*, *I. pseudacorus*, and  
120 *Phragmites australis*, as well as a few helophyte species (e.g., *Schoenoplectus*  
121 *tabernaemontani*, *Solanum dulcamara*, and *P. arundinacea*) (Figure 2). The rest of the basin,  
122 located at the western end of the basin (farthest from the water entry), turned into a dry  
123 grassland zone (Figure 2). This zone was densely covered with 10 additional ruderal pioneer  
124 species from the Asteraceae group, including mostly *Solidago canadensis*, *Geranium*  
125 *dissectum*, *Cardamine hirsuta*, *Rumex obtusifolius*, and *Poa* sp. (Figure 2; Table 1). It seems  
126 that the co-evolution of hydric conditions, edaphic conditions, and vegetation turned a part of  
127 the original wetland into a new grassland area, with the main changes occurring between 2009  
128 and 2015. This co-evolution seems to result from meteorological conditions (chronic drought)  
129 and is assumed to be the main driver for vegetation communities, with macrophytes and  
130 helophytes in the zones that had turned into ponds, and the regression of helophyte  
131 communities, in lieu of ruderal pioneer species, in the grassland zone.

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132 In the Django basin, no vegetation was sown or planted in 2002 and its initial state comprised  
133 only bare soil (Figure 3). In 2008, 58 species appeared and formed distinct vegetation groups  
134 corresponding to three contrasting ecological environments: the dry and stony zones (*Senecio*  
135 *inaequidens*, *Capsella bursa pastoris*, *Cardamine hirsuta*), wetlands with variation in water  
136 ponding (*P. arundinacea*, *Polygonum mite*, *Galium aparine*), and the transition zones, which  
137 were temporarily submerged in water (*T. latifolia*, *S. tabernaemontani*, *Eleocharis palustris*)  
138 (Figure 3, Table 1). In 2015, relative stability in species richness was recorded with 57  
139 species, most of which remained unchanged (Figure 3) because of the unchanged ecological  
140 environments (Table 1). The wetland zone, occupying around 43% of the basin, was  
141 dominated by *P. arundinacea* and *T. latifolia*, in association with Cyperaceae and *S.*  
142 *dulcamara*. The transition zones were mostly colonized by *Rumex* sp., while the dry zones  
143 covered 51% of the basin and hosted mainly Asteraceae, Brassicaceae, Poaceae, and  
144 Lamiaceae (Figure 3, Table 1). These results show the rapid dynamics of vegetation  
145 colonization, with a steady state being attained in less than six years (that is, in 2008).  
146 However, the decrease in area occupied by macrophytes after 2008 (these were reduced to *P.*  
147 *arundinacea*, *T. latifolia*, and *S. tabernamontani*) and the increase in the grassland area,  
148 revealed a recent change in water pathways with more water retained at the entry of the basin  
149 due to sediment dynamics (preferential deposition in the first part of the basin) and/or changes  
150 in the incoming water fluxes in relation with interannual climate variations. We then expect  
151 changes in the basin functioning to change water pathways and thus, determine the vegetation  
152 cover. Away from these water pathways, the bare areas were colonized by pioneer vegetation,  
153 typical of dry and rocky environments, such as Asteraceae or Brassicaceae.

154 Our observations indicate that firstly, the dynamics of vegetation colonization are  
155 characterized by a rapid stabilization of communities only after a decade. These results are in  
156 line with those reported by Mitsch et al. (2014). This study investigated the colonization of  
157 unplanted systems and observed a large increase in the species number during the first five  
158 years, followed by a gradual increase during the following decade, and stabilization only after  
159 approximately 17 years. Secondly, the main factors for vegetation succession seem to be  
160 related to the changes in soil quality and characteristics (edaphic conditions such as nutrient  
161 levels and pH) and hydric conditions (changes in the water regime in the infiltration basin as a  
162 consequence of changes in incoming water fluxes). The chronic drought, along with the  
163 changes in the water pathways, promoted changes in wetlands in drier zones with the  
164 replacement of macrophyte and helophyte species with grassland species, including  
165 Asteraceae (at the expense of Iridaceae). For example, the amplitude of water level

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166 fluctuations was the driving factor in *Phragmite* development, while substrate characteristics  
167 were less important (Hanslin et al., 2017). Thirdly, species persistence requires a broad  
168 ecological valence that allows the species to adapt to environmental conditions (nutrient  
169 contents and hydric conditions) and helps the species to compete with other plant species.  
170 Thus, the two most macrophytic species, *P. arundinacea* and *T. latifolia*, managed to remain  
171 on the site, seeking shelter in flooded zones (wetlands) during unfavorable conditions, and  
172 expanding again during more favorable periods. In addition to its broad ecological valence, *P.*  
173 *arundinacea* is known as a pioneer plant capable of colonizing environments easily,  
174 especially after restoration work (Staentzel et al., 2018a, 2018b). These observations apply to  
175 both the infiltration basins, whether unplanted or planted.

176 As a matter of fact, vegetation monitoring can be employed to follow/maintain and/or  
177 optimize the functioning of infiltration basins and their hydraulic performance. Previous  
178 studies have shown that hydraulic conductivity is two to four times higher in vegetated areas  
179 than in bare ones (Gonzalez-Merchan et al., 2014), particularly in the case of sediment  
180 deposition. Shrub root systems open the soil structure and enhance water infiltration.  
181 Additionally, some species found in our basins, such as *P. arundinacea*, are well suited to  
182 limit sediment deposition and subsequent clogging, promoting the proper hydraulic  
183 performance of the basin (Gonzalez-Merchan et al., 2014). Moreover, Holtman et al. (2019)  
184 showed that a greater plant species richness in 35 artificial urban stormwater ponds was  
185 driven by a greater habitat heterogeneity, which was explained by (i) the “genuine” effect, (ii)  
186 the existence of three large habitat zones (terrestrial, semi-aquatic, and aquatic), and (iii) the  
187 regular management of the ponds.

188 The comparison between the two infiltration basins facilitated the characterization of the  
189 effects of planting. Despite maintenance vegetation practices, the dynamics of vegetation lead  
190 to utterly different vegetation cover over time. Among the 30 planted species, only three  
191 survived in the Minerve basin. In addition, the same types of species (typical of the wetlands  
192 in the region) managed to colonize the basins, regardless of the presence of maintenance.  
193 Consequently, the effect of basic vegetation maintenance (planting and mowing; one time per  
194 year) on vegetation cover is questionable. Vegetation maintenance alone did not seem  
195 efficient for maintaining species in the long-term. Conversely, in the short-term, the effect of  
196 maintenance operations proved enough to limit the growth of certain invasive species. For  
197 example, the mowing at the beginning of October was used to remove the aerial parts of  
198 *Ambrosia artemisiifolia* L. and *Buddleia* spp., which are invasive species. The changes in

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199 hydric conditions in autumn (water ponding due to less evapotranspiration and more water  
200 loads in winter) prevented these invasive species from recolonizing the basin. The  
201 combination of mowing and water ponding proved very efficient in limiting these invasive  
202 species in our study. Conversely, in the Django, the same species were observed and survived  
203 longer before being replaced by other species. Furthermore, the period with the presence of  
204 invasive species was longer. In previous studies, Ho and Richardson (2013) suggested that  
205 frequent flooding should be favored to avoid exotic invasive species such as *Microstegium*  
206 *vimineum* (Japanese stilt grass). In this study, we suggest combining the management of  
207 vegetation with that of hydric conditions (water levels in the basins) to limit the more  
208 efficiently invasive species. Indeed, neither one nor the other is sufficient alone. Apart from  
209 invasive species, for which the influence of basic maintenance may be sufficient, vegetation  
210 management does not seem efficient for shaping vegetation communities in the long-term.  
211 Local environmental conditions, including changes in edaphic or hydric conditions, resulting  
212 from basin operation evolution and colonization by indigenous species, may be much more  
213 influential in shaping plant communities in the long-term.

## 214 Conclusions

215 In artificial infiltration basins, the evolution of vegetation communities is driven by the  
216 combination of their eco-physiological properties and changes to the operation of the  
217 stormwater basin. This includes the management of the inlet (water and related suspended  
218 solids and pollutant loads) and vegetation maintenance. The management of the basins  
219 strongly determines the hydric and edaphic conditions. In addition, vegetation maintenance  
220 may help to cement certain species and reduce/eradicate other species (such as invasive  
221 species). However, our study showed that vegetation maintenance alone was insufficient in  
222 eradicating invasive species and maintaining the planted species. Indeed, additional ecological  
223 processes (colonization by other species) predominated and prevented the planted species  
224 from surviving. In other words, vegetation maintenance combined with management of the  
225 water levels seems to be efficient for controlling invasive species - but the long-term control  
226 of vegetation remains uncertain. Based on our results, our recommendations include  
227 employing hydric conditions (i.e., managing the water levels by facilitating the creation of  
228 water ponds) to limit the recolonization of invasive species after mowing. We also  
229 recommend keeping certain zones ponded to serve as shelters for interesting macrophyte  
230 species. However, the odds of shaping plant communities in the long-term seem to be quite  
231 low. The control and optimization of plants is a requisite for the optimal management of  
232 infiltration basins and their hydraulic functions. In addition to massive human interventions,



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233 the combination of a few optimized interventions with “ecological” processes (as link  
234 between biotic and abiotic factors, for example edaphic conditions), along with an adapted  
235 design of the infiltration basin (a topography with thalwegs), may optimize the plant  
236 communities and, in turn, the operation of infiltration basins.

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331 Table 1: Evolution over time of the number of species including planted species (in  
 332 parentheses) and related vegetation coverage (in %, in italics) in Minerve (planted) and  
 333 Django Reinhardt (unplanted) basins.

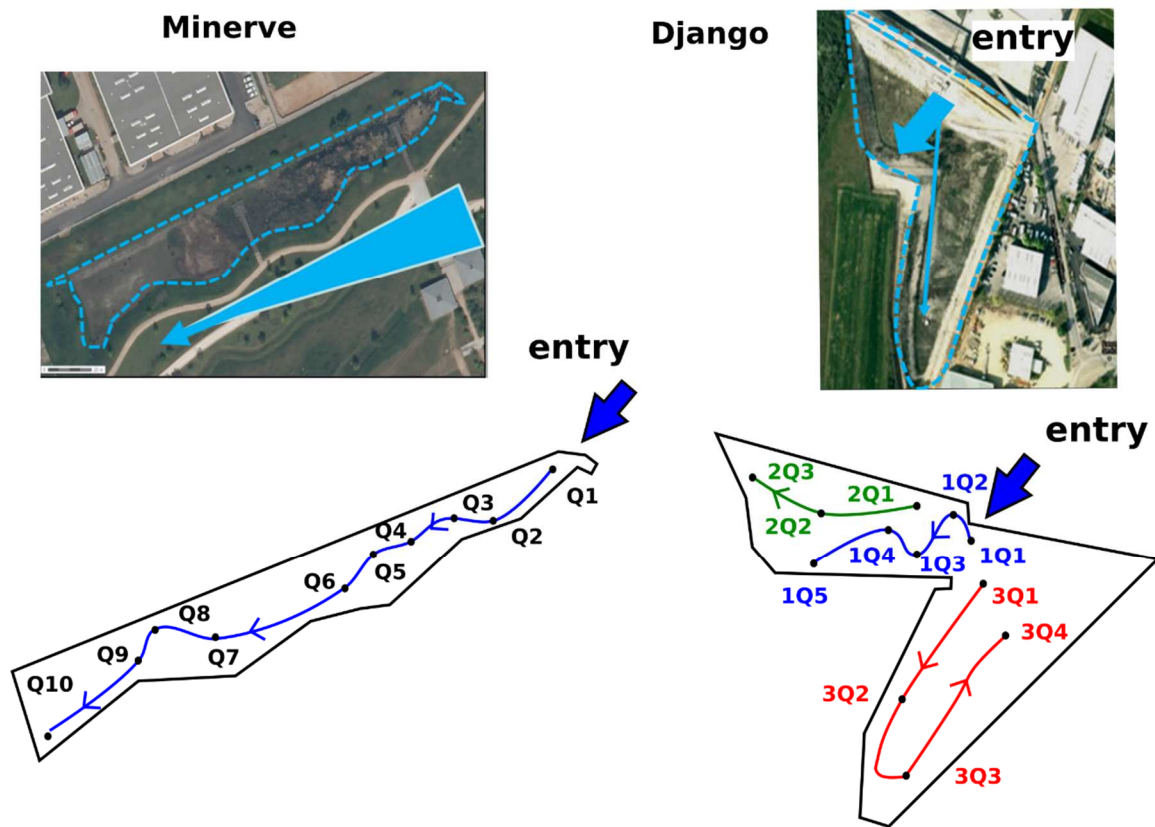
	<b>Minerve</b>				<b>Django Reinhardt</b>			
	Bare soil	Wetland	Grassland	Total	Bare soil	Wetland	Grassland	Total
<b>1999/2002</b> <b>**</b>	0 <i>0%</i>	30 (30)* <i>100%</i>	0 <i>0%</i>	30 -	0 <i>100%</i>	0 <i>0%</i>	0 <i>0%</i>	0 -
<b>2008</b>	0 <i>6%</i>	8 (3)* <i>94%</i>	0 <i>0%</i>	8 -	0 <i>20%</i>	6 <i>44.3%</i>	52 <i>35.7%</i>	58 -
<b>2015</b>	0 <i>6%</i>	8 (3)* <i>61.3%</i>	10 <i>32.7 %</i>	18 -	0 <i>6.05%</i>	6 <i>42.85%</i>	51 <i>51.1%</i>	57 -

334 (value)\* = number of planted species in 1999 for Minerve; \*\* 2002 for Django Reinhardt, 1999 for Minerve

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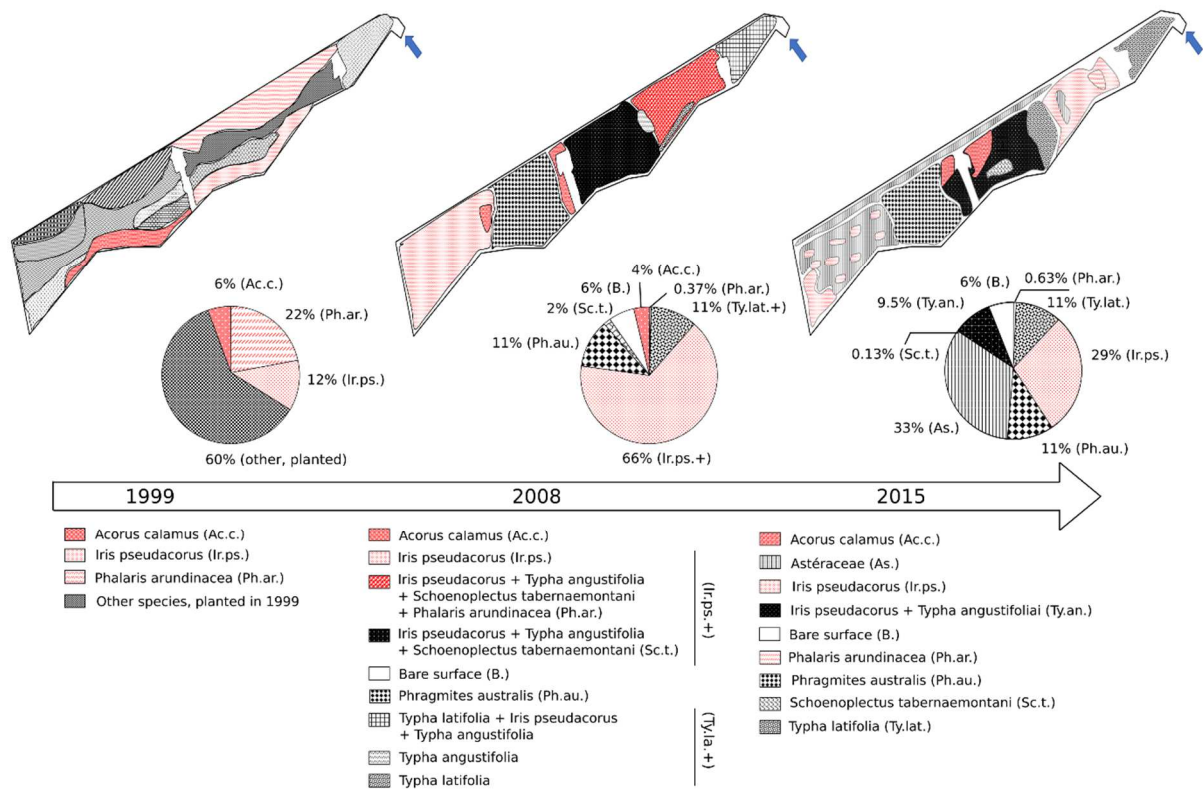


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339 Figure 1: Aerial view of the two basins (Google Maps. Accessed Apr. 2014). Left: Minerve  
 340 Basin (Bron, 69, France); Right: Django Reinhardt Basin (Chassieu, 69, France), and  
 341 localization of the sampled sediment and quadrats in Minerve basin (n=10; left down) and  
 342 Django Reinhardt basin (n=12; right down). Dotted blue lines delineate the boundaries of the  
 343 basin; the arrows indicate the path of the water. Three distinct paths were identified for the  
 344 Django Reinhardt basin versus one sole water pathway for the Minerve basin.

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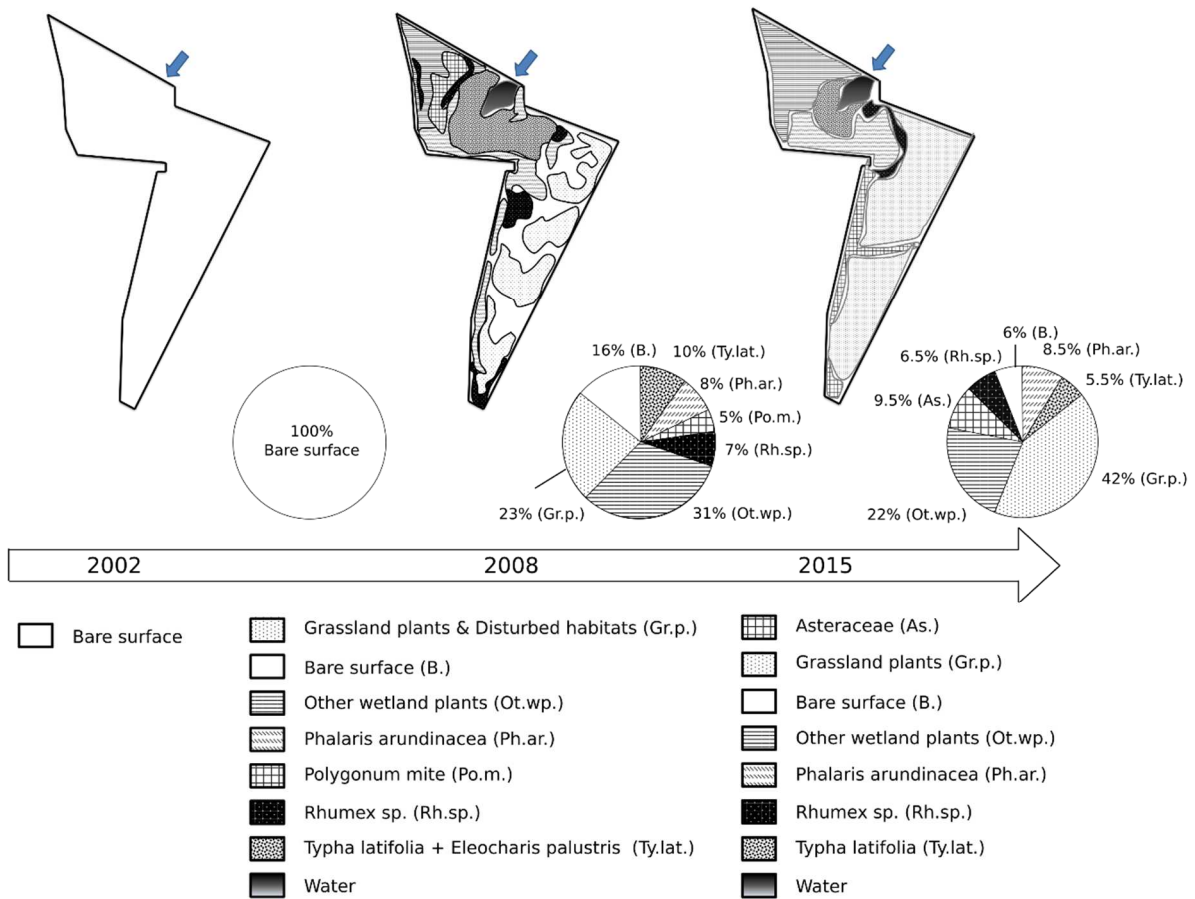
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348 Figure 2: Evolution over time of the vegetation in the Minerve basin and the spatial  
 349 distribution of species for the three dates: 1999 planting and beginning operation of the basin,  
 350 2008 (9 years of operation), and 2015 (16 years of operation). Species are sorted by  
 351 alphabetic order in the legend. Red color corresponds to planted species before the operation  
 352 of the basin.

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355 Figure 3: Time development of the vegetation in the Django Reinhardt basin and the spatial  
 356 distributions of species for the three dates: 2002 beginning of operation of the basin, 2008 (6  
 357 years of operation), and 2015 (13 years of operation). Species are sorted by alphabetic order  
 358 in the legend.

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