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Research Article

Trees and Shrubs Monitoring Using an Ecological Approach: The Conclusion of the Restoration Project of Borgotrebbia Landfill (Northern Italy)

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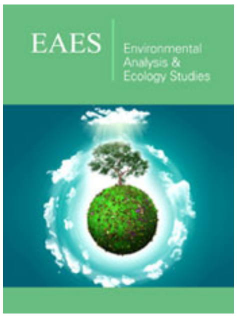

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Abstract

Plants growth monitoring in restored landfills are poorly available in literature. These data might be of critical importance for the evaluation and improvement of current and future restoration projects. Our study was focused on the plant's growth monitoring during a Life project (LIFE10 ENV/IT/000400 NEW LIFE), designed to restore a closed landfill (located in Northern Italy) using reconstituted soils. The growth monitoring was conducted on mortality rate, stress symptoms and phenological cycle completion of 10 plant species (trees and shrubs). Data were acquired during the 12 months following the end of the restoration with an ecological approach, using Landolt's indices and CSR functional strategy. It was observed that the stress-tolerant and the heliphilous ruderal species were the ones that best adapt to the restored environment (dead plants:0-39%; unhealthy plants: 24-42%), whereas the most competitive species were the ones with highest mortality (17-43%) and stress symptoms (43-51%).

Keywords: Restoration; Landfill; Plant monitoring; Ecological indices; Functional strategy

Introduction

Environmental restoration of degraded lands is one of the most urgent thematic to solve [1] due to world population growth and urban centres expansions, two phenomena causing land degradation and water and land ecosystem imbalances [2]. On a global level, soil consumption and land degradation [3] caused by urbanization proceed at a rate of 30ha day^{-1} (ISPRA 2017). In order to fight degradation, during the last decades many environmental restorations took place in the world [4-10].

In urbanized areas, one of the most emblematic examples of degradation are the landfills, where solid wastes are compressed and isolated in order to avoid leachate losses; when the landfills are closed, they are covered with soil and planted, but none monitoring and maintaining are done, so often the closed landfills became a degraded land. Led by this chance, in the last years many closed landfill restoration projects took place [11-25] along with the development of more sustainable methods and technologies for municipal solid wastes management [26]: recycling process, new generation incinerators and bio-digester [27].

Altogether, these topics are increasingly attracting the attention of our society, with a growing number of initiatives for their support and promotion. The EU Biodiversity Strategy aims to ensure by 2020, ecosystems and their services are maintained and enhanced by establishing green infrastructure (strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services (EU Commission 2016) and restoring at least 15% of degraded ecosystems (EU Commission 2010). Despite all the efforts by different researchers (engineers, biologists, pedologists, chemists, architects) to improve the environmental restoration projects in highly degraded contexts, like landfills, there's still a lot of work to do. Firstly, the restored areas are to be surveyed by acquiring data through a long-term monitoring; this is the only way to gain knowledge of possible errors occurred during the realization.

Despite the importance of this kind of survey, in many cases it's not possible to do it, mainly because of founds. Due to this, the data concerning the main environmental components (soil, vegetation, water) of restored areas are low [28-39], especially those regarding restored landfills [17,15,21,22,40]. The main aim of this work was to present an ecological survey of trees and shrubs planted during a Life project (LIFE10 ENV/IT/000400 NEW LIFE; web site: http://www.lifeplusecosistemi.eu), co-founded by European Union, aimed at restoring a closed landfill located in Piacenza (Emilia Romagna, Italy) using reconstituted soils [28]. The ecological survey, to understand the species' responses in the new environment, was carried out using the Landolt's ecological indices [41] functional strategy in accordance with the bioindication principles [42]. This research wants to prove how such simple and cheap methods may grant useful information about the restoration and the plants' adaptation to restored areas.

Study area

The closed landfill is located in Borgotrebbia, municipal territory of Piacenza (Emilia-Romagna, Italy) near Trebbia River (coordinates: 45°04'13'' N, 9°39'33'' E; altitude: 60m) (Figure 1). The area, 20ha wide, is in Trebbia Fluvial Park and, partially, inside a Site of Community Importance (SCI 4010016 Basso Trebbia). The solid urban wastes' landfill was active between 1972 and 1985. Wastes were buried in a 4-5m layer and then covered with a 20-30cm cap of degraded soils. In 2012, with the New Life project, the spontaneous vegetation and the soil of the closed landfill were studied [28,43-46] (Figure 2). Several ruderal species of *Sellarietea mediae* and *Artemisietea vulgaris* phytosociological classes, typical of degraded environments, were observed. The cap soil had poor water holding capacity, low organic carbon content, it was compacted and with stoniness, its values of clay, total $CaCO_3$, CEC, P_2O_5, K_2O, pH and salinity were used to calculate, in 5 sampling points, LCC [47] & FCC [48] (Figure 1 & Table 1). In this way, the study area soils were described having sever limitation for agricultural use, limiting their use to grazing or wildlife and with low fertility [28,46].

This was in accordance with the lack of more exigent species, like trees and shrubs. The restoration of the closed landfill was made by means of soil restoration by reconstitution. Reconstituted soils were produced by a technology (mcm Ecosistemi Patent), designed to act on two types of soils: on Technosol and degraded soils. By the means of this pedotechnique chemical and mechanical actions were applied to a mixture of degraded soil and environmental and pedological suitable materials such as waste of productive activities (sludge from paper industry and cellulose transformation processes, washing sludge of inert materials and water treatment sediments for drinking water supplies): the mixture was crushed, so the added organic fraction was incorporated into the mineral particles of the soil, then a mechanical compression realized the new reconstituted soil aggregates [46-48].

From October 2014 to August 2017, 10ha of the study area were covered with reconstituted soils 1m deep. Physicochemical properties of the reconstituted soil were performed and so LCC and FCC were calculated in the same previous sample points (Figure 1 & Table 1). The new soils were described having moderate limitations that restrict the choice of plants or that require moderate conservation practices and characterized by a high fertility [46-70], thus confirming other studies on reconstituted soils [28, 45,46,49,50]. From October 2016 to December 2017, over 3,000 trees and shrubs of 16 autochthonous species (Table 2), were planted in the area (Figure 3). All these plants were no more than 2 years old. The 16 species had to improve the ecological conditions and the landscape of the area, they had to produce edible fruits for birds, being the area a resting spot for migratory birds. In order to promote the plants to take roots, cuts of the herbaceous vegetation and a watering program during the drought season were made and still continue.

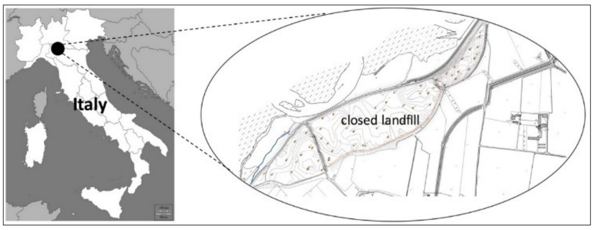

Figure 1: Geographical localization of the study area.

Figure 2: Closed landfill before environmental restoration.

Figure 3: Tree planting intervention and monitoring area definition.

Table 1: Physical-chemical parameters of landfill soil before (2011) and after (2016) environmental restoration in the 5 sample points (data from Manfredi et al., 2019).

	SP 1		SP 2		SP 3		SP 4		SP 5	
	2011	2016	2011	2016	2011	2016	2011	2016	2011	2016
Root restricting layer cm	35	>150	26	>150	24	>150	35	>150	22	>150
Clay* %	15	11	12	10	12	11	12	13	10	10
Parent material %	12	<5	18	<5	37	<5	12	<5	25	<5
Gravel %	6.5	<0.3	5	<0.3	28	<0.3	6.2	<0.3	6.8	<0.3
Organic C* %	1.7	4.7	2.7	6.6	1.9	5.1	2.3	7.5	2.7	4.9
pH*	7.9	7.8	7.5	7.7	7.9	7.7	8.1	7.6	8	7.5
Salinity* dS $^{m-}$1	0.2	0.8	0.3	2.8	2	2.4	0.2	1.4	0.1	2.7
$CaCO_3$ tot* g kg^{-1}	38	124	55	243	130	173	138	199	60	189
P_2O_5* mg kg^{-1}	99	104	48	95	18	85	139	121	80	133
K_2O* mg kg^{-1}	82	199	95	211	98	284	99	183	82	206
C.E.C.* meq $100g^{-1}$	19.7	31.2	12.1	34.5	8.5	33	32.2	41	15.9	37

SP sample point; *Data are the average of 3 sub-samples.

Table 2: Floristic list of trees and shrubs planted.

Species
Acer campestre L.
Ulmus minor Mill.
Quercus robur L.
Carpinus betulus L.
Salix alba L.
Rosa canina L.
Prunus spinosa L.
Cornus mas L.
Cornus sanguinea L.
Ligustrum vulgare L.
Corylus avellana L.
Euonymus europaeus L.
Rhamnus cathartica L.
Frangula alnus L.
Sambucus nigra L.
Spartium junceum L.

Materials and Methods

Trees and shrubs' monitoring were conducted on a monthly basis across 2017 considering 8-400m² (20x20m)-plots (A, B, C, D, E, F, G and H) homogeneously distributed on the area. In every plot all the species were identified using Pignatti [68] and numbered. For every species, a radar chart with Landolt's ecological indices (2010) (T, temperature; L, light intensity; F, soil moisture; R, substrate reaction; N, nutrients; H, humus; D, aeration) and a triangular plot with CSR strategy of each species were made to compare the plants ecological needs with the related functional strategy. The functional strategy of each plant was retrieved from recent literature [51].

Monthly the following data were collected in every plot:

A. Number of dead plants (without considering dead plants within 14 days after planting);

B. Number of plants showing stress-related symptoms (leaf yellowing and/or plant pathologies);

C. Number of flowered plants;

D. Number of plants producing fruits.

The % mortality rate was evaluated for every species as follows:

$$M = \frac{d}{p} * 100$$

Where *M* was mortality rate, *d* was the number of dead plants during 2017 and *p* was the size of the population in which the dead plants occurred. The % of unhealthy, flowered and fruit-producing plants were calculated in the same way. Data were then organized in a matrix and statistically analyzed with Principal Component Analysis (PCA). PCA was performed using the "vegan" package [52] of R 3.5.1 software (R Development Core Team 2018). Species with less than 8 individuals were excluded from calculations because not significant.

Result

215 plants from 16 different species were planted inside the 8 plots (Table 3). 6 species (*Ulmus Minor, Quercus robur, Carpinus betulus, Salix alba, Corylus avellana, Spartium junceum*) were represented by less than 8 individuals and so were excluded from the statistical analysis and results.The requirement of the species, based on the ecological indices of [41] were evaluated from the radar charts analysis (Figure 4). The species had similar requirements of temperature (T), light intensity (L) and soil

water content (F) being moderately heliophilous, typical of mild weather and tolerating a moderate soil water content. *Euonymus europaeus*, *Rhamnus cathartica*, *Frangula alnus* and *Sambucus nigra* had a peculiar tolerance for poorly aerated soils (D) (compact soils), *Sambucus nigra* required a lot of soil nutrients (N) whereas *Rhamnus cathartica* and *Frangula alnus* tolerated poorly fertile soils. *Frangula alnus* was the only species that required elevated amounts of humus (H).

Table 3: Number of monitored plants in the 8 plots.
A, B, C, D, E, F, G & H: Plots *Species with less than 8 individuals.

Species	Number of Individuals in Plots							
	A	B	C	D	E	F	G	H
Acer campestre	1	1	1	2	2	1	0	1
*Ulmus minor**	1	3	0	0	0	0	0	0
*Quercus robur**	2	0	0	1	0	0	0	0
*Carpinus betulus**	0	0	0	0	0	0	0	1
*Salix alba**	0	0	0	1	1	0	1	0
Rosa canina	0	0	1	0	0	7	3	5
Prunus spinosa	0	2	6	0	2	8	11	3
Cornus mas	4	1	0	0	1	2	0	0
Cornus sanguinea	8	1	8	3	1	3	8	1
Ligustrum vulgare	7	2	0	13	4	3	6	4
*Corylus avellana**	0	3	0	0	0	0	0	0
Euonymus europaeus	0	2	1	1	1	3	1	2
Rhamnus cathartica	0	0	0	1	2	1	2	2
Frangula alnus	0	6	3	3	5	6	2	3
Sambucus nigra	0	3	0	0	3	1	2	4
*Spartium junceum**	2	1	0	1	0	0	0	0

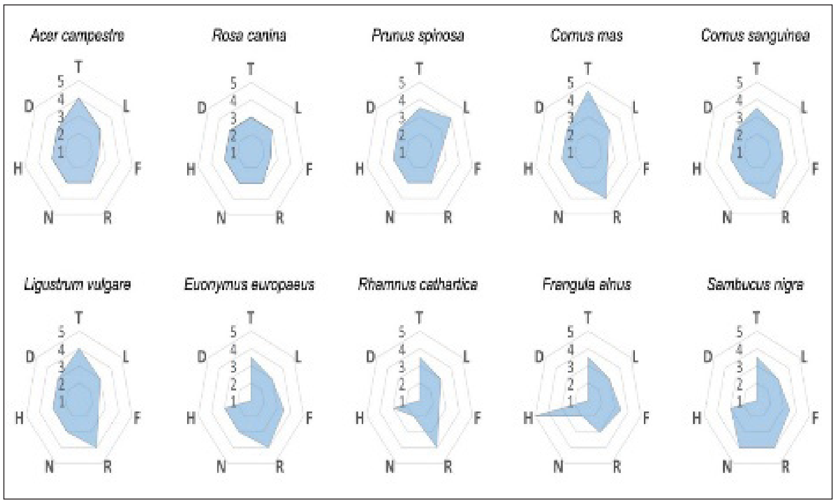

Figure 4: Radar charts of ecological indices of Landolt et al. (2010) for every monitored species.

Key: T-Temperature; L-Light intensity; F-Soil moisture; R-Substrate reaction; N-Nutrients; H-Humus; D-Aeration.

From CSR triangular graph (Figure 5) it was possible to observe the functional strategies of the species. The CSR strategies were: *Cornus mas*, *Euonymus europaeus* and *Rhamnus cathartica* S/CSR, *Rosa canina* SR/CSR, *Cornus sanguinea* CS/CSR and *Acer campestre* CSR. *Frangula alnus* (S/SR) and *Ligustrum vulgare* (S/CS) were the most stress-tolerant species, whereas *Sambucus nigra* was the most competitive (C/CSR) and *Prunus spinosa* was the most ruderal (SR/CSR) [51].

All the 10 species showed stress-related symptoms (Figure 6) while mortality didn't occur in 3 of the 10 species (*Acer campestre*, *Rosa canina*, and *Ligustrum vulgare*) during 2017. Only *Cornus sanguinea*, *Ligustrum vulgare*, *Frangula alnus* were able to produce flowers but only *Ligustrum vulgare* e *Frangula alnus* completed their biological cycle by producing mature fruits (Figure 7), this could be due to the unlike time required by the species to reach sexual maturity. From PCA biplot (Figure 8) emerged that the species showing higher mortality and stress rates were the most competitive that required soil nutrients, available water content and a neutral-to-basic pH. The ruderal heliophilous species, requiring well aerated soils, were the ones showing less suffering from the new environment.

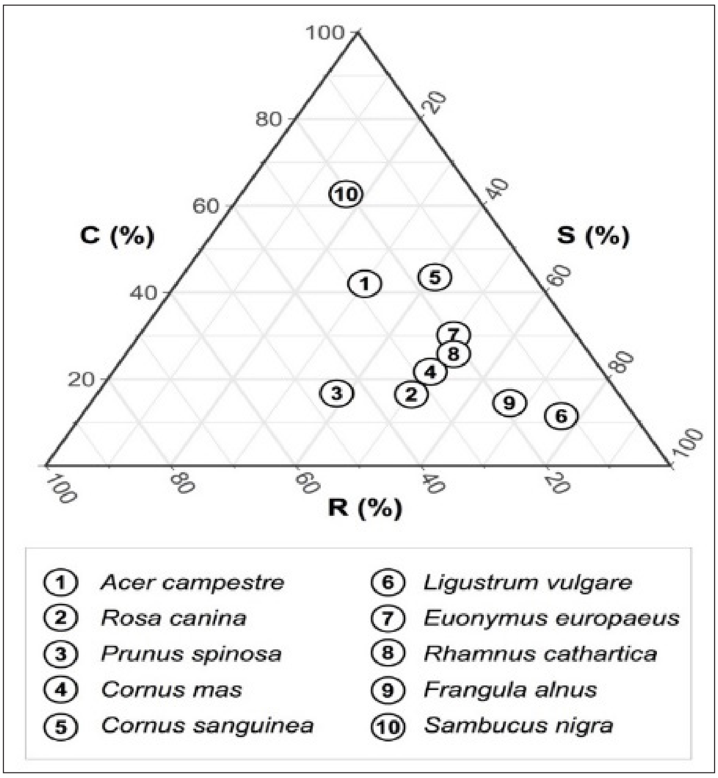

Figure 5: CSR strategies of the ten species considered.

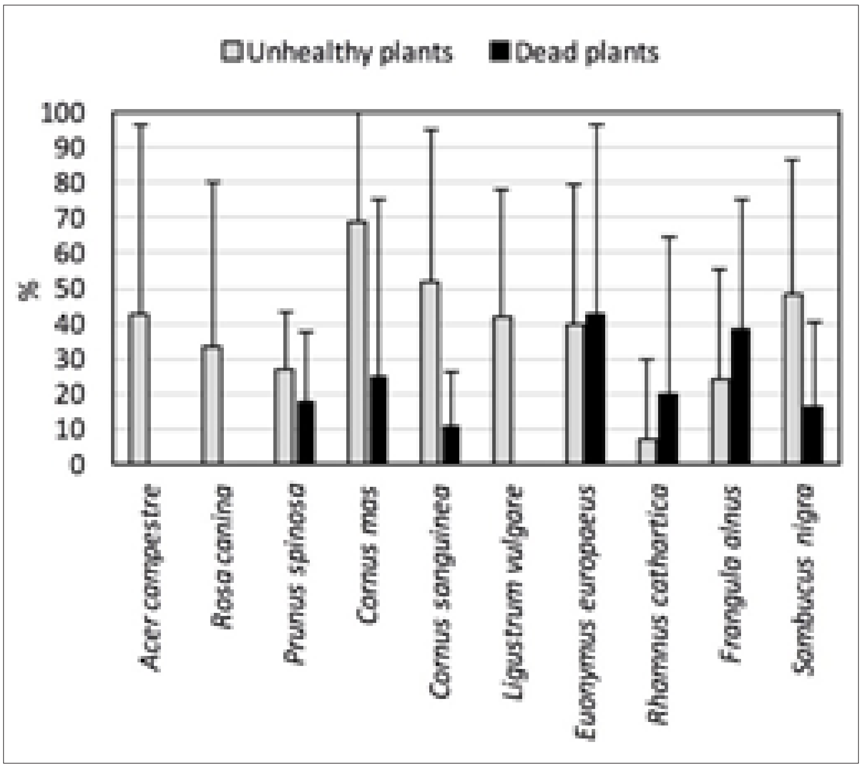

Figure 6: Percentage of dead and unhealthy plants.

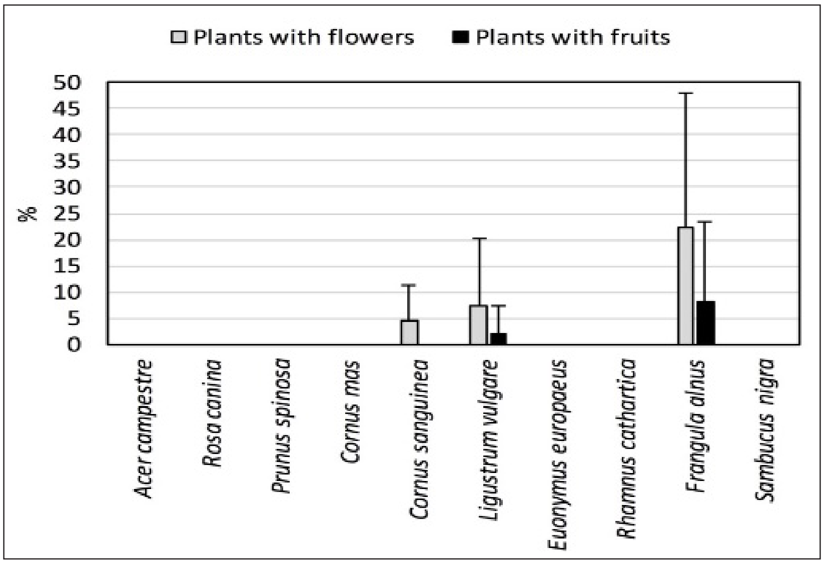

Figure 7: Percentage of flowered plants and fruit-producing plants.

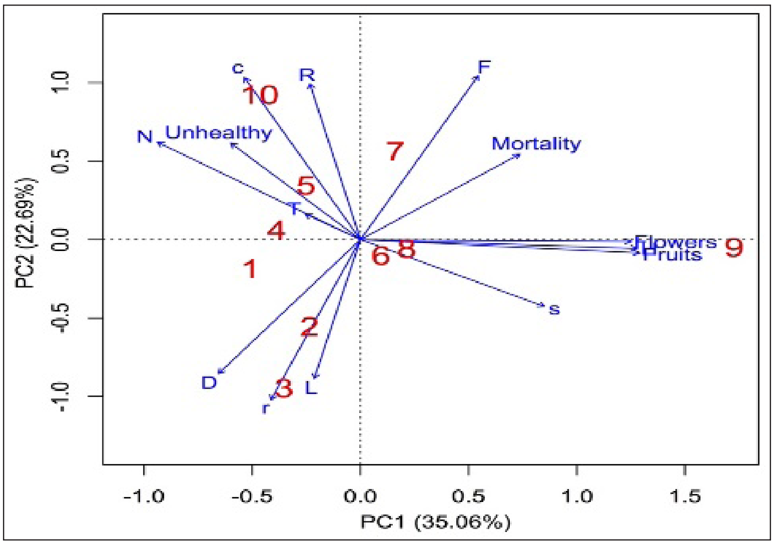

Figure 8: PCA ordination biplot of species (1. Acer campestre; 2. Rosa canina; 3. Prunus spinosa; 4. Cornus mas; 5. Cornus sanguinea; 6. Ligustrum vulgare; 7. Euonymus europaeus; 8. Rhamnus cathartica; 9. Frangula alnus; 10. Sambucus nigra).

Key: T-Temperature; L-Light Intensity; F-Soil Moisture; R-Substrate Reaction; N-Nutrients; H-Humus; D-Aeration; C-Competitor Strategy; S-Stress-Tolerant Strategy; R-Ruderal Strategy; Mortality, Percentage Of Dead Plants; Unhealthy, Percentage of Unhealthy Plants; Flowers, Percentage Of Flowered Plants; Fruits, Percentage Of Plants With Fruits.

Discussion

This study is an example of a simple and effective ecological approach to post-restoration vegetation survey. These data are useful not only to biologists and botanists, but also to all the people involved in planning and evaluation restoration projects. The combined use of traditional (ecological indices) and innovative (CSR functional strategy) methods is successful. Landolt's indices application allowed to understand that the most fitting species for the reconstituted soil were the ones best tolerating elevated luminous radiation levels (heliophilous) requiring well-aerated and humus-rich soils, like *Acer campestre*, *Rosa canina*, *Prunus spinosa*, *Ligustrum vulgare*, *Rhamnus cathartica* and *Frangula alnus*. Ecological indices confirmed that, being the reconstituted soils well-aerated, non-compacted, rich in organic matter and high fertile.

CSR strategy represents a univocal system applicable to every tracheophyte [51] and as reported for the first time in this study, applicable also to restored areas survey. It can be observed that the most competitive species had more adaptation problems (mortality rate and stress-related symptoms) whereas ruderal and stress-tolerant plants best adapted to the restored environment. This result was confident with the fact that competitive species could live in an environment without stresses (defined as external constraints which limit the rate of dry matter production [53] or disturbances (factors causing plant biomass destruction [53]. Indeed, transferring highly competitive plants from a protected artificial environment, like a nursery, to a non-protected one, like a restored landfill, may have represented the main stress able to affect their survival, health and ability to complete the phenological cycle. So, to improve the overall restoration efficiency, it can be said that stress-tolerant and ruderal species, based on their CSR strategy, had to be chosen rather than competitive ones. Even though nowadays CSR strategy of over 3,000 species is known [51,54-56] there's still a lot of work to do to define the functional strategy for as many as possible species included herbaceous species, given their importance in anthropic-perturbed ecosystems. Indeed, in synphytosociology (or dynamic phytosociology) [57], is known that the initial stages in a forest formation process are herbaceous species [58,59] and that the same are in environmental restored areas [60,31,55,56]. Further surveys should be carried out on the study area on the whole vegetation system (including herbaceous species). These kinds of surveys, being the key to understand the highly complex dynamics in the restored areas, should be made till the current potential vegetation [61-70] will be reached. Unfortunately, it's not so, because these monitoring are costly, and they need technicians with specific skills.

Conclusion

This study highlighted how monitoring trees and shrubs growth, using both classic (ecological indices) and modern (CSR functional strategy) methods, may give useful information to improve the interventions efficiency in a restored landfill. Based on the results, it would recommend those involved in environmental restoration projects to select the plants accordingly to their specific CSR functional strategy. In order to obtain better environmental results, autochthonous ruderal and stress-tolerant plants should be used. Moreover, it would like to urge to monitor the post-intervention for at least 20 years [31]. Even though the long-term surveys are time consuming and expensive, are also fundamental to understand the highly complex dynamics underlying the restored areas. Lastly, the use of new technologies and materials, like reconstituted soils, are hoped to be applied to closed landfills restoration, in a world-wide optic, to fight environmental degradation.

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