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MONITORING OF PHRAGMITES AUSTRALIS IN A CONSTRUCTED WETLAND. A METHOD FOR DATA AGGREGATION

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Abstract. A constructed wetland was built on Italian Alps in 2007; this plant was monitored for three years through surveys every two weeks, checking and examining all its components, including vegetation, composed by *Phragmites australis* (PA). For reed monitoring, a representative PA sample was identified, and measurements were made considering plants belonging to this sample. Many parameters were considered, depending on the season and on plants development: stems number and height during spring and summer, presence and number of inflorescences in summer. During the second and the third growing season (spring and summer 2009 and 2010) also the percentage of substratum covered by plants. Two different aggregation parameters were created both to aggregate collected data and to define a methodology for the monitoring of plants health and functionality in constructed wetlands: Development Parameter (DP) and Population Parameter (PP). Aggregation parameters were structured to contain all the collected data referred to a single phytoremediation bed, considering different weights for parameters with different importance in PA functionality into the constructed wetland. DP was calculated for 2008 growing season, when PA density was still low. It determines plants average development degree in phytoremediation beds. PP was calculated for both 2009 and 2010 growing season, when plants spread over gravel beds substratum was high. It determines plants population development, considering the vegetal component of the phytoremediation system as a whole, and each pool as an ecosystem. From DP and PP implementation, reeds into the constructed wetlands had a limited development during the first growing season, and a very good development during second and third growing season, forming a functional population in each gravel bed.

Keywords: data aggregation, bio-monitoring, vegetation, *Phragmites australis*, constructed wetland, phytoremediation.

1. Introduction

Constructed wetlands are a reliable wastewater treatment technology, and they represent a suitable solution for the treatment of various kinds of wastewater (Vymazal 2011). Plants development is essential for treatment wetland effectiveness in improving water quality: they play a direct role up-taking nutrients from the wastewater; besides plants presence involves many different synergic mechanisms fundamental for the wetland's reclamation efficiency. Vegetation has physical effects such as filtering effects, flow speed reduction improving sedimentation, substratum surface stabilisation, medium clogging prevention, light and wind speed attenuation. Also plant metabolism contributes to wastewater phytoremediation: roots exudates can enhance remediation processes, besides macrophytes are able to transfer oxygen to the rhizosphere allowing the formation of a micro-ecosystem near their roots, populated by microorganisms that are responsible for many remediation processes (Brix 1996; Brix 1997).

A large number of indices exist to describe natural ecosystems (e.g. Shannon's index, Simpson's index) and, generally, parameters attesting a good quality are species richness and diversity (Nagendra 2002). In fact, in natural environment, a large number of different species indicates a good environmental quality. But considering a constructed wetland bed, the formation of a monospecific stand is the optimum for vegetation role in remediation processes. Thus, in this case, vegetal biodiversity is undesirable. For this reason existing indices are not applicable to define health and development of vegetal compound in a phytoremediation plant.

2. Background and aims

In 2007 a pilot constructed wetland was built in Morgex, on Italian Alps, 920 m above sea level, to treat wastewaters coming from a mountain dairy. Average monthly temperature ranges from –1 °C in January to 18.9 °C in July (Fig 1). Average yearly rainfall is 694 mm.

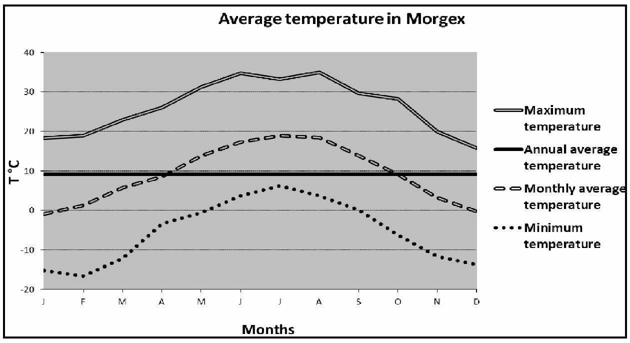

Fig 1. Average temperature in Morgex

Treatment system was designed to test constructed wetland functioning in cold climate, as primary treatment for dairy wastewaters. It is composed by a fat-removal unit followed by a storage and accumulation tank containing two submersible pumps for wastewater lifting. Pumps lift wastewater alternatively to two sub-surface vertical flow (SSF-Vs) beds; after crossing these pools, wastewater flows to a sub-surface horizontal flow (SSF-H) bed and finally it is conveyed to a storage tank (Fig 2). All three vegetated beds are planted with *Phragmites australis*. Reclamation efficiencies, plants development and structures were monitored since October 2007.

A large data of PA growth and development was collected, thus data management was onerous. A method to concentrate data and to give an immediate information about PA development was necessary.

In order to both synthesize collected data and try to define a methodology to describe vegetation development using a single value, two different parameters were created: Development Parameter (DP) and Population Parameter (PP).

3. Sampling Methods

PA was monitored from October 2007 to October 2010, in the three beds that constitute the operational core of the considered constructed wetland, through periodical inspections every two weeks. At first a plant sample was identified to ensure a representative monitoring. Considering that in SSF-Vs beds and in SSF-H bed the number of PA planted was respectively about 600 and 450, with a density of 4 plants/square meter, samples was composed by respectively 64 and 48 plants, that is 10.66 % for the three beds. Selected plants distribution on pools surface was uniform and formed a sort of grid: in SSF-Vs gravel beds 16 areas with a surface of 1 square meter was considered, while in SSF-H the number of areas was 12; these zones had constant distances one from the other, so that samples were composed by plants coming from both parietal and internal zones. Each identified area contained 4 plants, and was identified with a letter; in each areas plants were numbered, in this way each plant forming the sample was identified with an alphanumeric code, formed by the letter that represents the area and the number proper of each single *Phragmites A.* Plants forming the sample were marked with a yellow band reporting the identification code, to be easily identified during each monitoring (Fig 3).

4. Parameters

During the monitoring period (three years), a large number of data was collected to determine plants growth and spread over phytoremediation pools; the considered parameters changed according to plant growth, therefore according to the season.

- Winter season (November–March): no parameters measured because no plants growth occurs in this period;
- Growing season (April–October): stems number and height, presence and number of inflorescences (only in summer), percentage of populated substratum (only during second and third growing seasons).

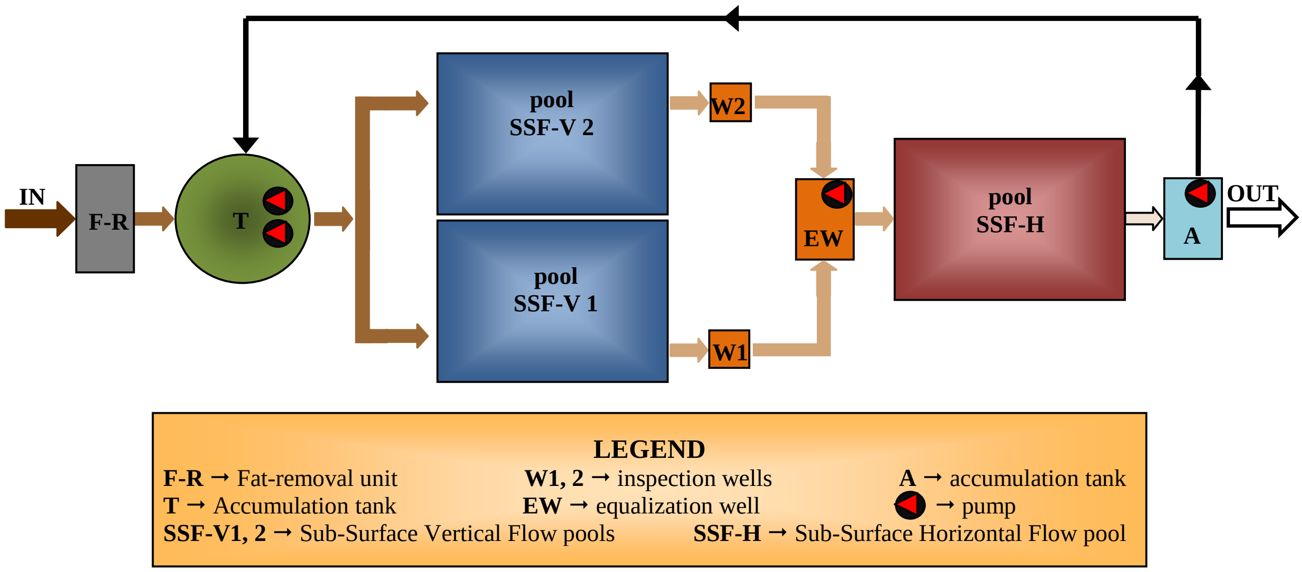

Fig 2. Morgex constructed wetland layout

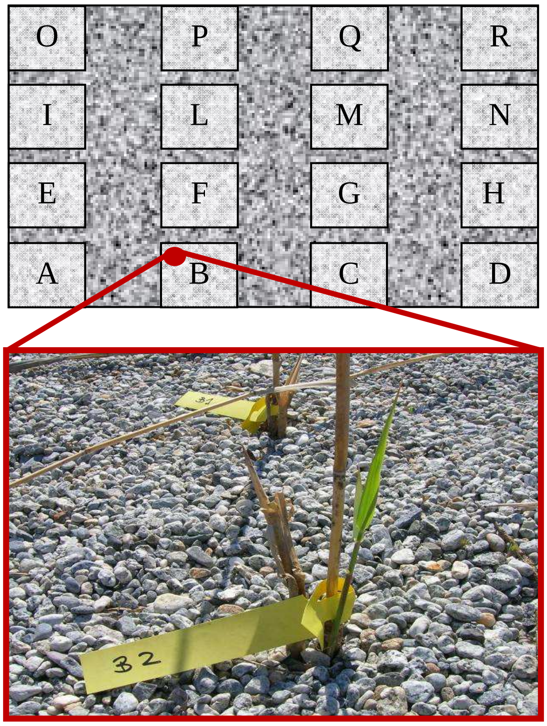

Fig 3. Example of areas location (the image represents areas closer each other than in reality, for this example) and plant labeling. Areas were identified with a capital letter into the first sub-superficial vertical flow bed. Plant B2, located in B area, was marked with a yellow band reporting its ID alpha-numeric code (picture taken on April 26, 2008)

PA was planted from October 16th to 20th, 2007. Until March 22nd, 2008, the wetland was covered by the snow, so the first information about plants situation, acquired in spring, was a balance about the number of plants survived in beds. This balance occurred because a relatively big number of PA was eradicated by both wind and snow, and because of the limited plants root apparatus.

The first growing season started in April 2008, when the first shoots were seen, and the last measurements were made on October 11th, 2008; during this period the monitored parameters were: stems health, number of shoots (or of stems, in summer), height of the tallest shoot (or stem), presence and number of inflorescences (in late summer). From the survey on May 10th, 2008, for each gravel bed three plants were chosen for a systematic photographic acquisition that lasted until the end of 2010 growing season. In this way, both numerical and visual data are available to describe plants development in the phytoremediation beds.

During the second (2008–2009) winter season, that is since plants came into the dormant season to the development of new shoots in spring, no measurements were made because of snow and because no variation of plant growth occurred.

In 2009 growing season, plants development made impossible both to reach the PA for the measurements and to distinguish to which plant the stems belonged. In fact, in each pool, plants formed an homogeneous stand, thus the vegetable constituent of the constructed wetland could be considered as a “whole”, a uniform population for each gravel bed. This is why the monitored parameters, in the second growing season, were referred to the *Phragmites A.* population of each pool, instead of being referred to each single plant. The parameters were: stems number and height, number of inflorescences and percentage of populated substratum in each gravel bed. The number of stems was determined evaluating their density in a square decimeter, in different areas of phytoremediation pools, located on beds borders. The choice of each area was made to assure result representativeness. Measurements in different areas of the same bed were mediated to obtain an average value representative of the whole PA stand. Average stems height determination was made through a wide number of measurements, without considering younger shoots. The number of inflorescences was considered relatively to the percentage of stems ending with an inflorescence. The percentage of covered substratum is the only parameter introduced ex-novo for plants monitoring during the second growing season. This parameter evaluation was made through on site observations and photographs analysis, using the grid initially built to identify plant sample. In the second SSF-V pool, to consider the presence of an area totally PA free (because of a systematic wastewater spill), also on site measurements were performed.

In the third winter season (2009–2010), no measurements were made for the same reasons explained for the second cold season; in 2010 growing season, evaluated parameters were the same considered to describe plants development during the previous growing period.

5. Aggregation methods

Data collected during the three growing seasons were wide and heterogeneous. Evaluated parameters are significant also separately, but our objective was to obtain a synthetic description of PA development in the constructed wetland, therefore an aggregation of available data was essential. Because of differences in data collected in different growing seasons, two aggregation parameters were studied to synthetized available data about PA population into the wetland’s pools: the Development Parameter, related with data acquired during 2008 growing season, and the Population Parameter, related with data acquired in 2009 and 2010 growing seasons.

Development Parameter (DP): this parameter gives the average development degree of the typical plant. A data analysis was made to define maximum and minimum values for each parameter and to determine their weight, and a table for score attribution was filled in. The maximum value adopted is considered as the optimum value for the parameter, because it represents the development objective. Both minimum value and classes division (between maximum and minimum) was chosen through collected data analysis; classes had to grant a good sample distribution within themselves and, at the same time, they had to range over the maximum identified value, even if, in the sample, no plants reached that standard. More precisely, for the parameter *stems height*, the maximum value was identified as that reached by PA in the SSF-H pool at the end of the second growing season, when plants development was satisfying; minimum and class division were chosen studying reeds height distribution during the first growing season. For the parameter *stems number*, the maximum value comes from some considerations: from observation of SSF-H pool when plants development was satisfying, it was possible to find as a good value for stems density 4 stems/(square decimeter), that is 400 stems/(square meter). Literature data used to design this constructed wetland reported 4 PA/(square meter) (Sigmund 2005) as the number on plants to put into the beds. Thus an adequate stem number is reached when each plant has about 100 stems, so this value was chosen as the maximum for this parameter. For minimum and class distribution choice, collected data were analyzed. For the parameter *inflorescences number*, values were not represented by numbers but by percentages, because otherwise this parameter would be too linked to stems number. As for the previous parameters, the maximum value was identified through observation of plants when a suitable development was reached, while minimum and class division were deducted from data analysis.

A different maximum achievable score was determined to give a different weight to parameters. The difference in maximum score corresponds to a difference in classes number. In fact, each entire number, from 1 to parameter maximum value, corresponds to a class; therefore, for each parameter, classes number is equal to maximum achievable value. Stems height and stems number have the same maximum value (thus number of classes), therefore their weight is proportional, otherwise inflorescences number have an half maximum value, thus its weight is half. These weights were stated considering that inflorescences presence gives a minor contribution in PA role in the constructed wetland remediation efficiency in comparison to the other parameters.

PA developed faster and bigger in SSF-H bed than in vertical pools, and measurements were prevented after the monitoring on June 21, 2008, because of stems density. Therefore two tables for score attribution were created, because inflorescences were not yet present at the beginning of summer. Tables for score attribution are

Table 1 and Table 2.

To calculate DP value, to every PA forming the sample (and still alive after 2007–2008 cold season) a score for each evaluated parameter was attributed, building a single table for each gravel bed, separately. The average score was calculated for every parameter.

Table 3 reports, as an example, the table created to calculate DP value at the end of the growing season for the first SSF-V.

To determine DP, the three average scores of the parameters were added and after they were normalized to one, dividing their sum by the maximum total score achievable: 25 (

Table 1). When this parameter is calculated for a period when no data about inflorescences are available, normalization is made dividing the sum of the average score by 20, that is the maximum score achievable without considering inflorescences (Table 2). The DP varies from 0 to 1, where these numbers represent, respectively, the worst and the optimum development for a PA in a constructed wetland. DP referred to the end of 2008 growing season was determined only for SSF-Vs, adding the three parameters average scores, deducted from data collected on October 11, 2008; DP value in early summer was determined for all the three gravel beds adding the two parameters average scores resulting from data acquired on June 21, 2008.

Population Parameter (PP): this second parameter describes the development of the entire PA population into the three phytoremediation beds, considering reeds in each pool as a population in an ecosystem. The steps that led to the construction of this parameter are very similar to those crossed creating DP: at first the table for score attribution was created, then a table was filled in and, finally, PP was calculated. The table for score attribution (Table 4) is equivalent to that created for DP considering stems height, stems number and inflorescences number. The new parameter considered is *percentage of populated substratum*.

Table 1. Score attribution table to calculate DP when data about inflorescences are available, used for SSF-Vs at the end of the first growing season

Development Parameter – end of first growing season										
Parameter 1: stems height										
Value [cm]	up to 30 cm	≥30	≥40	≥50	≥60	≥80	≥100	≥120	≥180	≥240
Score	1	2	3	4	5	6	7	8	9	10
Parameter 2: stems number										
Value [n°]	up to 9	≥10	≥15	≥20	≥25	≥30	≥40	≥50	≥75	≥100
Score	1	2	3	4	5	6	7	8	9	10
Parameter 3: inflorescences number										
Value [n°]	0	1	n° inflor.<10%*		10%*<n°inflor.<20%*		20%*<n°inflor.<30%*		n°inflor.>30%*	
Score	0	1	2		3		4		5	

* of stems number

Table 2. Score attribution table for DP determination when data about inflorescences are unavailable, used for SSF-H and SSF-Vs during the early summer period

Development Parameter – early summer of first growing season										
Parameter 1: stems height										
Value [cm]	up to 30 cm	≥30	≥40	≥50	≥60	≥80	≥100	≥120	≥180	≥240
Score	1	2	3	4	5	6	7	8	9	10
Parameter 2: stems number										
Value [n°]	up to 9	≥10	≥15	≥20	≥25	≥30	≥40	≥50	≥75	≥100
Score	1	2	3	4	5	6	7	8	9	10

* of stems number

Table 3. Scores attribution and average for the three parameters considered to calculate DP for the first SSF-V gravel bed at the end of the first growing season (example table)

First SSF-V pool – Data collected on October 11, 2008						
Plant	Highest stem height [cm]	Stems n°	Inflor. n°	Score		
				Stems height	Stems number	Inflor. num.
A3	47,5	22	0	3	4	0
A4-A5	68	33	0	5	6	0
B2	72	29	0	5	5	0
B4	105	21	0	7	4	0
C2	89	18	0	6	3	0
C4-C5	106	52	0	7	8	0
E3	66	24	0	5	4	0
H1	78	25	0	5	5	0
H3	110	20	0	7	4	0
I2	45	24	0	3	4	0
L3	106	25	1	7	5	1
Q2	112	29	1	7	5	1
R1	89	19	0	6	3	0
Σ	1093,5	341	2	73	60	2
					Scores average	
Average	84,12	26,23	0,15	5,62	4,62	0,15

Table 4. Table for score attribution for Population Parameter determination

Population Parameter – end of both second and third growing season										
Parameter 1: stems height										
Value [cm]	up to 30	≥30	≥40	≥50	≥60	≥80	≥100	≥120	≥180	≥240
Score	1	2	3	4	5	6	7	8	9	10
Parameter 2: stems number										
Value [n°]	up to 9	≥10	≥15	≥20	≥25	≥30	≥40	≥50	≥75	≥100
Score	1	2	3	4	5	6	7	8	9	10
Parameter 3: inflorescences number										
Value [n°]	0	1	inflor.n°<10%*	10%*<inflor.n°<20% *	20%*<inflor.n°<30%*	inflor.n >30%*				
Score	0	1	2	3	4	5				

Parameter 4: percentage of populated substratum																					
Value [%]	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	100
Score	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

* of stems number

Table 5. Values of Development Parameter in early summer and at the end of the first growing season

DP values for the three phytoremediation beds						
Date	Pool	Average scores				DP
		Stems height	Stems number	Inflorescences number	Pool	
June 21, 2008	1st SSF-V	2.526	1.05	nd	3.579	0.179
	2nd SSF-V	2.667	1	nd	3.667	0.183
	SSF-H	5.225	1	nd	6.225	0.311
October 11, 2008	1st SSF-V	5.615	4.615	0.154	10.384	0.415
	2nd SSF-V	5.667	3.083	0.167	8.917	0.357

Table 6. Values of Population Parameter at the end of second and third growing season

PP values for the three phytoremediation beds							
Date	Pool	Scores					PP
		Stems heigth	Stems number	Infloresc. number	% populated substratum	Pool	
October 10, 2009	1st SSF-V	8	10	5	17	40	0.889
	2nd SSF-V	8	10	5	14	37	0.822
	SSF-H	10	10	5	20	45	1
October 9, 2010	1st SSF-V	8	10	5	18	41	0.911
	2nd SSF-V	8	10	5	17	40	0.889
	SSF-H	10	10	5	20	45	1

It is a percentage value, so it was not necessary to decide maximum and minimum values. Considering PA functionality into the phytoremediation beds, this new parameter was thought to be the most important one in attesting PA population quality. For this reason its weight is twice that given for stems height and stems number, thus classes number is double. The table created for score attribution is reported (Table 4).

To calculate PP values, for each gravel bed the scores corresponding to the four parameters are summed, and this sum is normalized to one, dividing it by 45, that is the maximum total score achievable.

6. Results verification

After every survey on field, observations and remarks, as well as photographic documentation, were recorded and stored, to provide a database used as a benchmark, to check compliance between the development directly observed and the result of the chosen aggregation method.

7. Key results and discussion

Development Parameter (DP): results are reported in Table 5. This parameter describes globally vegetation development in a constructed wetland in the first period after planting, in particular after the first growing season. DP was calculated twice, to allow at least a comparison between all the three pools. In fact, in SSF-H pool a large number of undesired plants was born, preventing access to the bed and therefore parameters measurement at the end of the growing season. This is the reason why data are from two different dates, at the beginning of the first growing season, on June 21, 2008, and in the end, on October 11, 2008.

June 21, 2008, is the last date for which a comparison between all pools is possible. Data reported in Table 5 show that PA development in SSF-V beds is still low on June 21, 2008, and DP values for the two vertical beds are very similar. On the contrary, plants development in horizontal pool is higher, about +70 % (0.13 points). This difference may be due to both presence of peat layer in SSF-H and to pool location that grants a bigger protection from weather. In effects the percentage of eradicated or broken plants during the cold season 2007–2008 for 1st and 2nd SSF-V was respectively 56.5 % and 42.6 % and for SSF-H pool 14 %. DP values calculated with data acquired on July 21, 2008, reflects winter damages suffered by PA.

October 11, 2008, at the end of the first growing season, is the second data when DP was calculated. Results are different from the first DP values, also because the development is bigger. Besides the difference in plants development in the two SSF-Vs was +16.25 % (0.058 points) for the 1st one, while on June the difference was +2.2 % (+0.004 points) for the 2nd one. This result was affected by the presence of a small but continuous wastewater spill in the second vertical bed that was seen to inhibit plants growth even during the second growing season.

Even if DP was not applied for SSF-H at the end of the first growing season, collected data are sufficient to determine that PA in SSF-H bed were very much developed than in vertical pools. Probably this difference is caused by the presence of the peat layer on the gravel bed of the horizontal pool.

Population Parameter (PP): results are reported in Table 6. Parameters *Stems number* and *Inflorescences number* have the maximum value in all the three pools at the end of both second and third growing season. This means that two growing seasons occurred because PA population in the constructed wetland reached a suitable development level under the point of view of these two parameters. *Stems height* is smaller in SSF-Vs than in SSF-H in both growing seasons. For PA in vertical pools, at the end of the third growing season this parameter was bigger than in the same period of the previous year, but the difference is not big enough to overcome the class with score 8. On October 10, 2009, the medium stems height was 140 cm in SSF-Vs, and, on October 9, 2010, it was 160 cm, that is not enough to enter the class with score 9, that need an height equal or bigger than 180 cm. Values of parameter *Percentage of populated substratum* are most variable. In SSF-H pool, as for all the parameters, scores are maximum. In the first vertical pool, at the end of the third growing season, this parameter gained a point, that is a class, reaching score 18. PA population into the second SSF-V gained 3 points that correspond to an equivalent number of classes, during the third growing season. Plants development was higher in first SSF-V than in second one, but development gap decreased from +0.067 points in October 2009, to +0.022 points at the end of the third growing season. This strong improvement was helped avoiding wastewater spill repairing a broken tube in late November 2009. Thanks to this maintenance plants presence in the affected area increased exponentially. Since the end of the second growing season, population development in SSF-H reached the optimum value; the difference with SSF-Vs was about 0.1 point.

Both parameters show a clear difference between vertical and horizontal pools plant development. The reasons why this difference occurred may be in the presence of a peat layer on the gravel bed in SSF-H, in the more protected location of the horizontal pool, and in the fact that wastewater arriving in the last pool was less polluted, because it had previously crossed vertical beds. In fact, considering the second vertical pool and plants distribution on its substratum before and after wastewater spill, wastewater was proved to have a strong inhibition effect on plants development.

Results obtained applying both DP and PP, reflect the observations carried out during the periodical monitoring, that were registered and collected, together with a photographic database (not shown). Correspondence between data aggregation output and field-observed data shows the validity of the proposed method for data aggregation, applied to the studied constructed wetland.

8. Conclusions and prospects for future

In this study, the method implemented for the aggregation of a large amount data (from a three years monitoring) was easily applicable and representative of the real development of the constructed wetland vegetal component. In the examined constructed wetland, PA reached a development level functional to their role at the end of the second growing season. Time needed by plants is probably due to a sum of several different factors: (1) PA were planted in autumn and they could not develop a suitable root apparatus before winter; (2) a large number of plants was eradicated or damaged during the first winter season, and plants density was about half of planned one; (3) short warm season duration, because of wetland site altitude; (4) wastewater pollutant load, high because wetland is used as primary treatment.

Standards to attest an ecosystem health are very different from those needed to attest the correct vegetation functionality in a constructed wetland. This study proposes a first application of the proposed methodology. Further applications and studies will be implemented to attest the validity and adaptability to other constructed wetlands. If this method will be proved to have general applicability, a standardized way to define plant development in wetlands will be available.

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