

Root system assessment of helophytes

Resistance and root growth capacity in vegetated fiber rolls

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1 Abstract

Helophytes are widely used in river and wetland restoration, and this usage shows how important is to study their behaviour to optimise their implantation and resistance.

Growth capacity of six native species (*Carex vulpina*, *Carex pendula*, *Iris pseudocorus*, *Phragmites australis*, *Scirpus holoschoenus* and *Juncus inflexus*) was analyzed in different environments: controlled, fiber rolls and wild. Conservation status of vegetated fiber roll installed in different restored areas was also evaluated.

Analysis in different environments was conducted based on helophytes' biophysical characteristics of which were obtained stability rates. Otherwise, analysis in restored areas was carried out considering conservation status of the vegetated fiber rolls and the hydraulics of the area in order to determine their resistance.

From these results it can be affirmed that the development of the species highly depends on the environment where they are, but the development of the root system has no dependency on the environment. The controlled environment is the most ideal (as it had good conditions of sand, soil and water), but vegetated fiber roll is closer to the controlled than the wild environment. Therefore, vegetated fiber rolls are a good system to implant helophytes in wild areas, as it has a good development of the root system. Moreover a good resistance of vegetated fiber rolls was observed in restored areas, where 3.75 m/s velocity was achieved successfully, although they were not installed in dynamical areas.

2 Methodology

2.1 Study areas

In order to know the resistance of vegetated fiber rolls an analysis of the conservation conditions of vegetated fiber rolls installed in rivers was done. Rainfall, peak flow, drought and mean shear stress of the bottom section were defined for each place, from the implantation until now, to know the circumstances that may had affected the area and to evaluate the response of the vegetated fiber rolls.

The evaluation was made in different locations throughout Catalonia: Fluvià river, Besalú (2008); Congost river, Granollers (2008); Besòs river, Montcada (2000); Sant Esteve de Ses Rovires, Anoia (2007) ; Vallcorba mountain stream, Sant Quirze del Vallès (2009); Fluvià river, Olot (2007); Santa Coloma river, Santa Coloma de Farners (2008); Mogent river, Llinars del Vallès (2003); Seca river, Mollet del Vallès (2007); Colobriers mountain stream, Sabadell (2008); Cànoves river, Cardedeu (2004), Vallmanya and Reixac rivers, in Palafolls and Tordera (2009).

Roots' growth development analysis was made in controlled environment, vegetated fiber rolls and wild areas.

- **Controlled environment.** The growth of six helophyte species (*Carex vulpina*, *Carex pendula*, *Iris pseudocorus*, *Phragmites australis*, *Scirpus holoschoenus* and *Juncus inflexus*.) was studied in a homogenous environment, collecting data from 6 specimens each month. In order to carry out this part a special area was built in Aquanea's plant nursery, in Terrassa (Barcelona).
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Image 1. General view of the controlled environment

- **Vegetated fiber rolls.** FR-N1 vegetated fiber roll model was selected as in contains four of the six species (*Carex vulpina*, *Iris pseudocorus*, *Scirpus holoschoenus* and *Juncus inflexus*). This part of the study was also executed in Aquanea's plant nursery, in Terrassa (Barcelona).



Image 2. Vegetated FR-N1 fiber roll model before extraction.

- **Wild environment.** The same six species of the controlled environment were extracted from wild areas. Only one sampling was made and was located in two places: *Carex vulpina*, *Iris pseudocorus* and *Juncus inflexus* were extracted in Castelló d'Empúries, in Alt Empordà Natural Parc -PNAE- (Girona), while *Scirpus holoschoenus*, *Carex pendula* and *Phragmites australis* were extracted in Colobriers river, Sabadell (Barcelona).



Image 3. Colobriers mountain stream



Image 4. Alt Empordà Natural Park

2.1.1 Root growth capacity

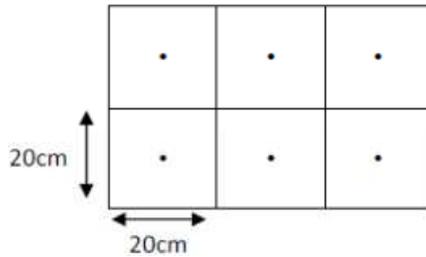
To analyse the root growth capacity several measures were taken: stem diameter, aerial height, aerial width, root system's depth, root system width and root system's volume. From these data four indexes were calculated, which indicate helophytes' stability and solidity: relative stability index, relative solidity index, root system stability and global stability.

Averages of the indexes and the hydraulics of the area were analysed to be able to compare the data of the helophytes from the three environments. Further, these results were compared with results obtained from shrubs (Cornelini et. al., 2008 ¹).

¹ Cornelini P., Federico C., Pirrera G. – ARBUSTI AUTOCTONI MEDITERRANEI PER L'INGEGNERIA NATURALISTICA. Primo contributo alla morfometria degli apparati radicali – Azienda Regionale Foreste Demaniali Regione Siciliana – Collana Sicilia Foreste, n° 40. 2008

2.1.1.1 Controlled environment

Growth was evaluated monthly sampling 6 specimens of each species. The controlled environment was built sized 12 m. x 0,8 m. x 1 m. (length x width x height). The distance between specimens was 20 cm. and 240 specimens were planted, distributed as shown in the next figure.



Sampling was carried out monthly over six months, with daily watering. Before the extraction of the 6 specimens of each species aerial measures and pictures were taken (stem diameter, aerial height, aerial width). The selection of the specimens was carried out at random. After the extraction root system's depth, root system width and root system's volume were measured.



Image 5. Extraction process.



Image 6. Measuring root system.



Image 7. Measuring roots volume.



Image 8. Six specimens of *Phragmites australis* after the extraction.



Image 9. Stem diameter.

2.1.2 Vegetated fiber rolls

Due to the characteristics of the fiber rolls 3 specimens of the *Carex vulpina*, *Iris pseudocorus*, *Scirpus holoschoenus* and *Juncus inflexus* were measured and extracted every two months. When the plants are rooted to the fibers of the fiber roll it is difficult to extract the specimens from it. The roots entangle with the fibers and it is necessary to disassemble most of the fiber roll, as it was also difficult to distinguish them by eye. As some species have more than three specimens of specie in the FR-N1 fiber roll, the selection of the specimens was achieved at random. The same measurements as in the controlled environment were made.



Image 10. Detail of the root system in a piece of a fiber roll.



Image 11. Carex extraction from a fiber roll.

2.1.3 Wild environment

In wild areas 3 specimens of *Carex vulpina*, *Carex pendula*, *Iris pseudocorus*, *Phragmites australis*, *Scirpus holoschoenus* and *Juncus inflexus* were extracted in one single sampling. The same measurements and methodology as in controlled environment was carried out, to enable comparisons between environments.



Image 12. Image of the extraction of a *Scirpus holoschoenus* in Colobriers mountain stream.



Image 13. Image of the *Iris pseudocorus* extracted in Alt Empordà Natural Park.

2.2 Vegetated fiber roll resistance

The assessment was made in those areas defined in section 1.2.1. In each study areas maximum flow, meteorological data and the conservation conditions (including appearance of the material, quality/state of the installation and conservation of the plantation) was analysed.

Hydraulics of the study area was studied, considering shear stress, flow and peak velocity from the implementation until now. The hydraulic study was carried out with the Manning formula and Master Flow software.

3 Results

3.1 Biophysical analysis of the helophytes

3.1.1 Physical characteristics of the helophytes

The results demonstrate higher values in wild areas of stem diameter, aerial height, aerial width, root system width and root system's volume, meanwhile root system's depth and Index A are higher in vegetated fiber rolls.

SPECIE		<i>Juncus inflexus</i>	<i>Iris pseudacorus</i>	<i>Carex vulpina</i>	<i>Scirpus holochoenus</i>	<i>Phragmites australis</i>	<i>Carex pendula</i>	AVERAGE
WILD ENVIRONMENT	Stem diameter (mm)	0,8	18,0	7,7	4	9,2	13,5	8,9
	Aerial height (cm)	53,3	104,2	136,7	123,75	75,0	103	99,3
	Aerial width (cm)	20,7	29,0	60,0	118,25	32,7	131,75	65,4
	Root system's depth (cm)	26,8	43,3	36,0	46,75	48,3	43,25	40,8
	Root system's width (cm)	16,0	25,0	41,7	32,75	29,7	29,5	29,1
	Root system's volume(ml)	236,7	833,3	416,7	3875	516,7	925	1133,9
	Index A	0,8	0,9	0,4	0,7	0,8	0,7	0,7
CONTROLLED ENVIRONMENT	Stem diameter (mm)	0,2	1,1	0,3	0,2	0,2	0,9	0,5
	Aerial height (cm)	41,7	33,0	29,6	58,3	40,8	33,8	39,5
	Aerial width (cm)	22,1	20,2	33,3	30,9	13,9	36,5	26,1
	Root system's depth (cm)	32,4	33,0	36,4	40,7	31,8	31,2	34,3

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	<i>Root system's width (cm)</i>	14,5	13,1	12,2	18,4	21,7	14,4	15,7
	<i>Root system's volume(ml)</i>	107,0	128,3	120,3	135,0	73,7	126,7	115,2
	<i>Index A</i>	1,1	1,3	1,5	1,1	0,7	1,1	1,1
VEGETATED FIBER ROLL	<i>Stem diameter (mm)</i>	0,2	1,1	0,4	0,2	-	-	0,5
	<i>Aerial height (cm)</i>	56,1	55,0	67,1	54,1	-	-	58,1
	<i>Aerial width (cm)</i>	30,5	38,1	54,9	26,9	-	-	37,6
	<i>Root system's depth (cm)</i>	48,2	52,6	39,1	55,8	-	-	48,9
	<i>Root system's width (cm)</i>	14,4	21,3	20,2	20,8	-	-	19,2
	<i>Root system's volume(ml)</i>	213,3	224,4	205,0	222,2	-	-	216,3
	<i>Index A</i>	1,7	1,2	1,0	1,3	-	-	1,3

Table 1: Average of the helophytes physical's values.

Note: Index A (Root system structure index). (0,5-1) Medium/basic root system; (1-1,5) Tend to a root subject with taproot; (>1,5) Tend to have a good developed root system.

3.1.2 Comparison of the physical characteristics between helophytes and shrubs

The biophysical characteristics and stability rates of shrubs have a higher rate than helophytes. Index A is the only one which is higher in helophytes.

	Root system's depth (cm)	Root system's width	Index A
Helophytes	40,35	21,61	1,02
Shrubs	56,39	53,13	0,53

Taula 2: Comparison of the physical characteristics and indexes between helophytes and shrubs

Nota: Shrubs data was obtained from Cornolini, et al. 2008.

3.1.3 Comparison of the indexes averages in different environments

The higher values of the indexes are found in the controlled environment, followed by the vegetated fiber roll, while the lower values are in the wild environment.

INDEX*	WILD ENVIRONMENT	CONTROLLED ENVIRONMENT	VEGETATED FIBER ROLL
<i>Relative strength</i>	0.46	0.94	0.88
<i>Potential stability</i>	0.68	0.82	0.57
<i>Root system stability</i>	0.34	0.76	0.53
<i>Global stability</i>	0.33	1.05	0.39

Taula 3: Averages of the indexes from the species values, for each environment.

*DEFINITIONS:

INDEX	
Root system's structure :	$A = 1/2 \text{ root system's depth / root system's width}$
Relative stability:	$S = \text{root system's depth / aerial height}$
Relative solidity:	$s = \text{root system's width / aerial width}$
Root system's stability:	$R = \text{Relative stability} * \text{relative solidity}$
Global stability:	$P = \text{Relative stability} * \text{relative solidity}^2$

3.2 Avaluació de la dinàmica i l'evolució de l'estat de conservació dels rolls vegetalitzats instal·lats en àrees naturals

EVALUATION OF THE STATE OF FIBER ROLLS IN PONT DE LES MORES (OLOT)
1. LOCATION River Fluvià Municipality Olot
2. SAMPLE DATA Date of Installation of fiber roll May 2007 Sampling date 11/04/2011 Project reference: Proposal for the landscape improvement in Fluvià river in Olot.
3. DESCRIPTION OF THE CONSTRUCTION Linear meters of fibers 70 m.l. Executive details: <div style="text-align: center;"> </div>
4. EVALUATION <p>Evaluation of the material: The material doesn't show breaks or degradation. The structure is physically in good conditions.</p> <p>Implementation evaluation: The fiber roll is there but it has moved. The bound does not work because the pegs are all loose and this causes that the fiber roll is not correctly compacted to the soil and the water passes over and behind the fiber.</p> <p>Evaluation of the plantation: Current species are difference from the ones which were planted, some are missing but no other plants have colonized the fiber.</p> <p>Comments: Basic presence of <i>Carex pendula</i>, absence of <i>Iris pseudacorus</i> and <i>Scirpus holochoenus</i>. It seems that the work has been incorrectly planned. Some places have no pegs or rope, although it probably has a high slope which does not help helophytes to be well stacked.</p>

EVALUATION OF THE STATE OF FIBER ROLLS IN VALLMANYA AND REIXAC RIVERS

1. LOCATION

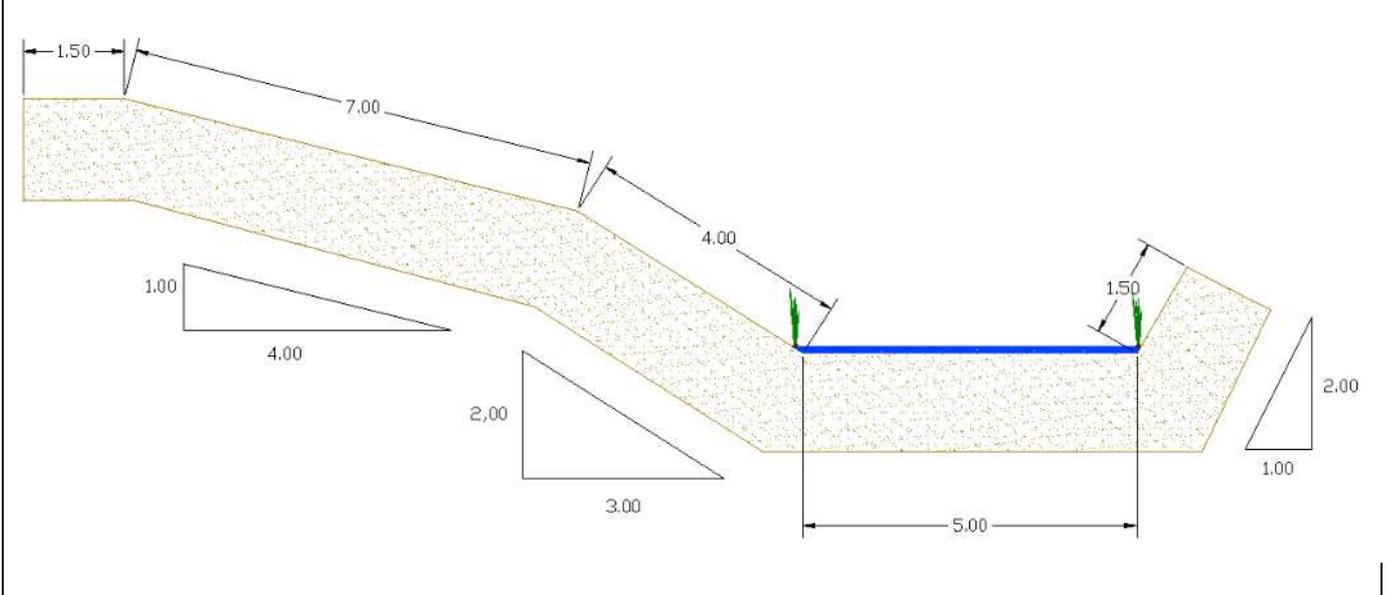
River Vallmanya and Reixac
 Municipality Palafolls and Tordera

2. SAMPLE DATA

Date of Installation of fiber roll 2009
 Sampling date 12/04/2011
 Projecte de referència: Restauration project of the river area of Valmanya and Reixac rivers.

3. DESCRIPTION OF THE CONSTRUCTION

Linear meters of fibers 150 m.
 Executives details:



4. EVALUATION

Evaluation of the material: No breaks or degradation are observed in the material, the structure and conditions are maintained.
Implementation evaluation: The fiber roll has not moved, is well attached to the soil with all the pegs and the bound working correctly.
Evaluation of the plantation: Current species are the same that were planted.
Comments: The initial percentage of species was the following: *Iris pseudacorus* 20%, *Carex pendula* 20%, *Scirpus holochoenus* 15%, *Carex vulpina* 15%, altres espècies 30%.
 At the moment this percentage has changed, with a predominance of *Iris pseudacorus* (70%), *Carex pendula* (12%) and *Carex vulpina* (13%) with the same abundance and *Scirpus holochoenus* in less abundance (5%).

EVALUATION OF THE STATE OF FIBER ROLLS IN SANT ESTEVE SES ROVIRES RIVER

1. LOCATION

River Anoia

Municipality Sant Esteve de Ses Rovires

2. SAMPLE DATA

Date of Installation of fiber roll 2007

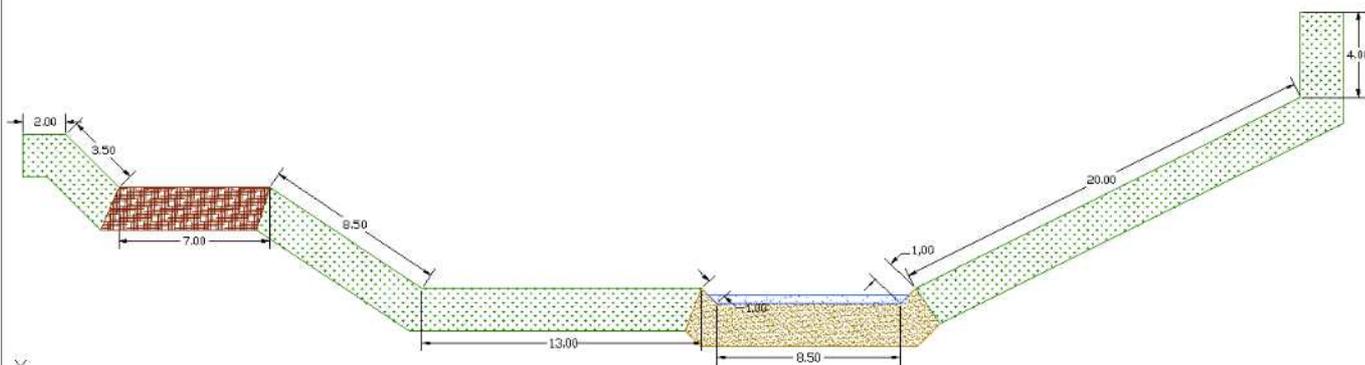
Sampling date 14/04/2011

Project reference

3. DESCRIPTION OF THE CONSTRUCTION

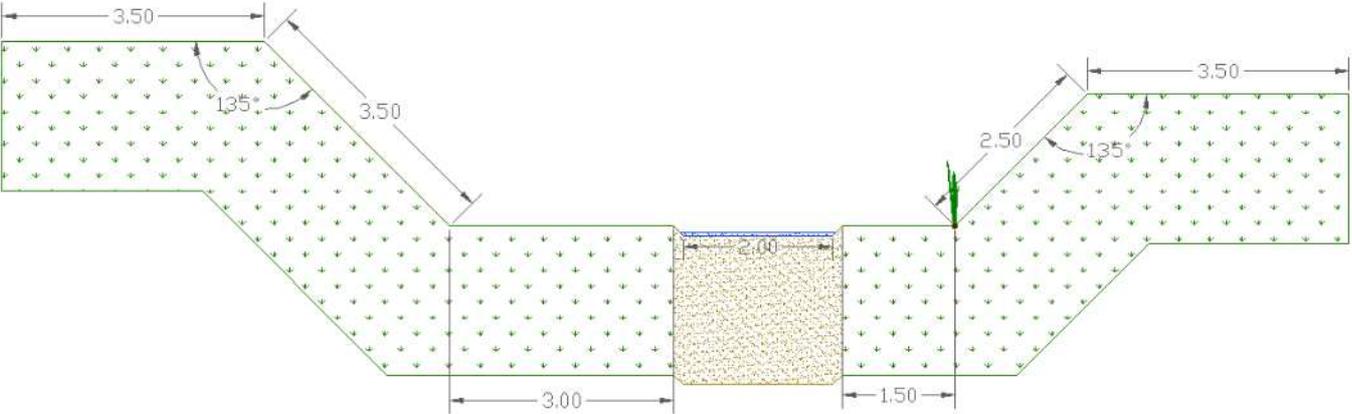
Linear meters of fibers 50 m.

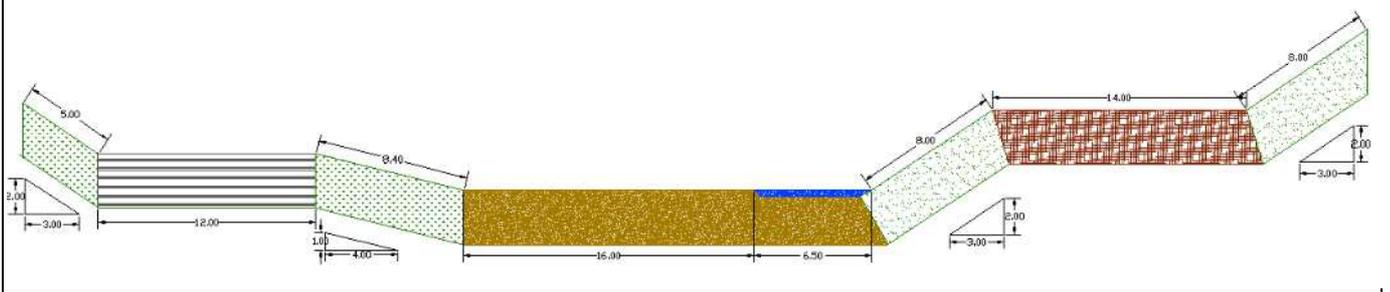
Executive details

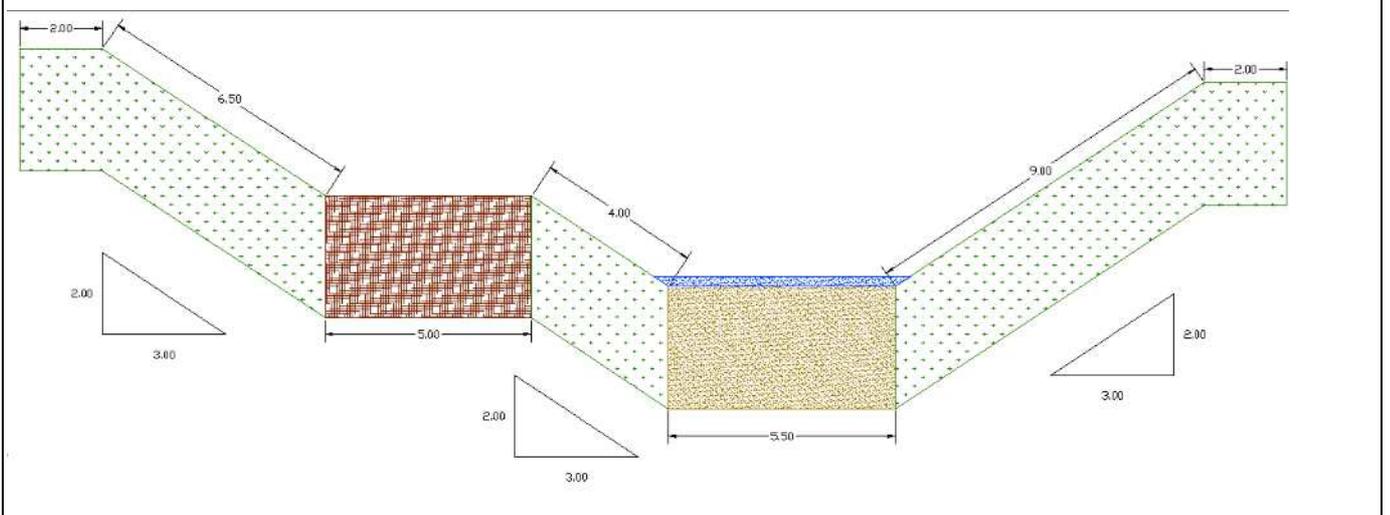


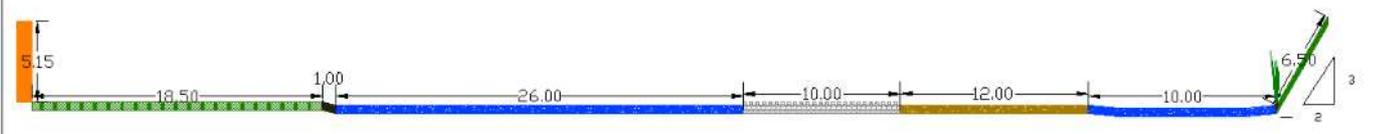
4. EVALUATION

Comments: It was not possible to find the fiber roll. It was possibly located under the sand.

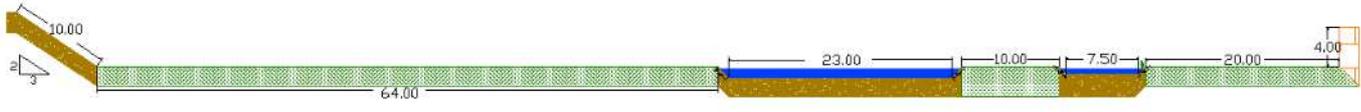
EVALUATION OF THE STATE OF FIBER ROLLS IN SECA RIVER
<p>1. LOCATION</p>
<p>Riera Seca Municipality Mollet</p>
<p>2. SAMPLE DATA</p>
<p>Date of Installation of fiber roll 2007 Sampling date 14/04/2011 Project reference: Proposal for revegetation and protection of the slope base of the urban stretch of Seca river in Mollet del Vallès.</p>
<p>3. DESCRIPTION OF THE CONSTRUCTION</p>
<p>Linear meters of fibers 40m Executives details</p> 
<p>4. EVALUATION</p>
<p>Evaluation of the material: No breaks or degradation are observed in the material, the structure and conditions are maintained. Still intact. Implementation evaluation: The fiber roll has not moved, is well attached to the soil with all the pegs and the bound working correctly, preventing the flow to pass through the front and the back of the fiber roll. Evaluation of the plantation: Current species are the same that were planted. Comments: Main presence of <i>Carex pendula</i>, <i>Scirpus holochoenus</i> and <i>Iris pseudacorus</i>.</p>

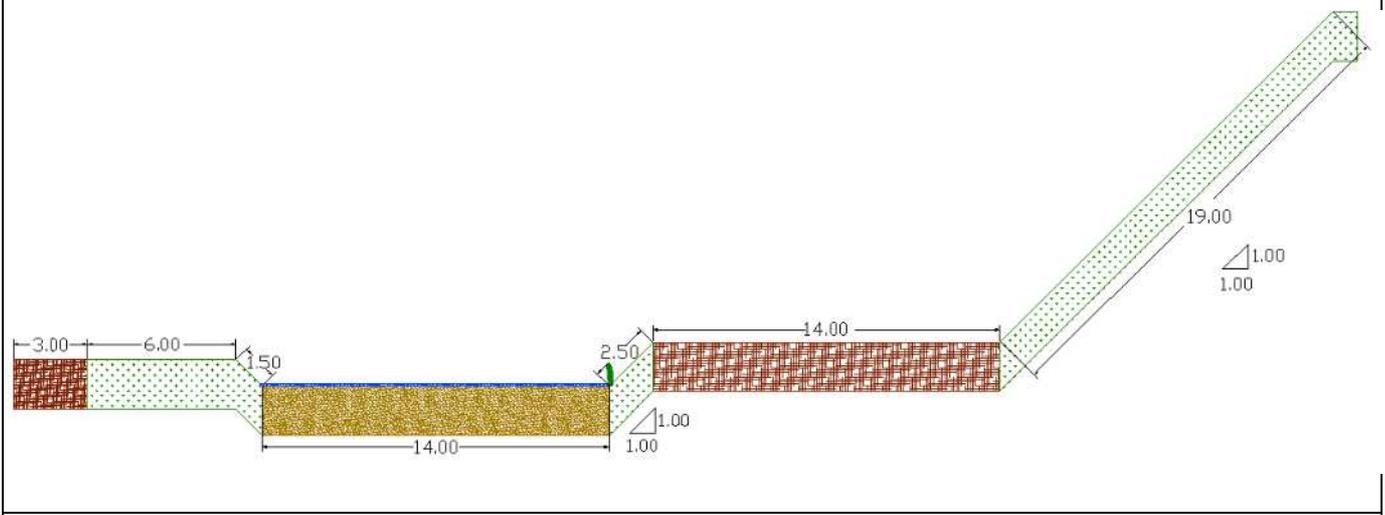
EVALUATION OF THE STATE OF FIBER ROLLS IN MOGENT RIVER
<p>1. LOCATION</p>
<p>River Mogent Municipality Llinars del Vallès</p>
<p>2. SAMPLE DATA</p>
<p>Date of Installation of fiber roll 2003 Sampling date 12/4/2011 Project reference</p>
<p>3. DESCRIPTION OF THE CONSTRUCTION</p>
<p>Linear meters of fibers 40m Executive details</p> 
<p>4. EVALUATION</p>
<p>Evaluation of the material: No breaks or degradation are observed in the material, the structure and conditions are maintained.</p> <p>Implementation evaluation: The fiber roll has not moved, is well attached to the soil with all the pegs and the bound working correctly, preventing the flow to pass through the front and the back of the fiber roll.</p> <p>Evaluation of the plantation: Current species are the same that were planted, but there are no <i>Scirpus holochoenus</i> or <i>Carex vulpina</i> in the fiber roll, although no other species have colonized it.</p> <p>Comments: <i>Iris pseudacorus</i> occupies the entire fiber roll, there are no other species.</p>

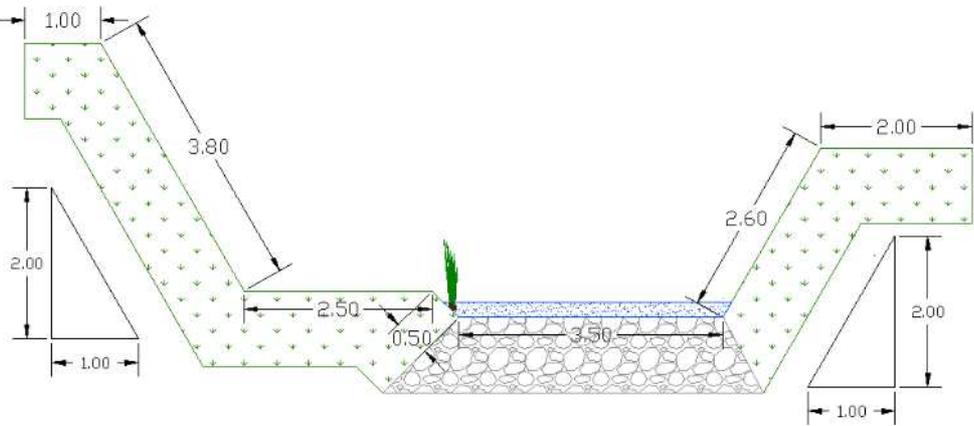
EVALUATION OF THE STATE OF FIBER ROLLS IN CÀNOVES RIVER
<p>1. LOCATION</p>
<p>Riera Cànoves Municipality Cardedeu</p>
<p>2. SAMPLE DATA</p>
<p>Date of Installation of fiber roll 2004 Sampling date 12/4/2011 Project reference: Proposal for environmental improvement in cànoves river and Llibera mountain stream, in Cardedeu.</p>
<p>3. DESCRIPTION OF THE CONSTRUCTION</p>
<p>Linear meters of fibers 10m Executives details</p>
 <p>The diagram illustrates the construction of a fiber roll in a riverbed. It features two central rectangular sections: a brown one on the left and a yellow one on the right, both 5.00m wide. These are connected by a 4.00m wide section. The structure is flanked by two sloped sections with a 2:3 slope (vertical:horizontal). Dimensions include a 2.00m top width on the left, a 6.50m length for the left slope, a 9.00m length for the right slope, and a 2.00m top width on the right. Triangular slope indicators show a 2.00m vertical rise for every 3.00m horizontal run.</p>
<p>4. EVALUATION</p>
<p>Evaluation of the material: No breaks or degradation are observed in the material, the structure and conditions are maintained.</p> <p>Implementation evaluation: The fiber roll has not moved, is well attached to the soil, the bound is in good conditions, preventing the flow to pass through the front and the back of the fiber roll. It is not possible to see the pegs because they are sunk.</p> <p>Evaluation of the plantation: Current species are not the same that were planted. <i>Iris pseudacorus</i> is absent in the fiber roll, although no other species have colonized it.</p> <p>Comments: The fiber roll is totally colonized by <i>Carex pendula</i>.</p>

EVALUATION OF THE STATE OF FIBER ROLLS IN FLUVIÀ RIVER
1. LOCATION River Fluvià Municipality Besalú
2. SAMPLE DATA Date of Installation of fiber roll 2008 Sampling date 11/4/2011 Project reference: Restauration project of the Molí spring surroundings' degraded area and improvement of the river area.
3. DESCRIPTION OF THE CONSTRUCTION Linear meters of fibers 40m Executive details 
4. EVALUATION <p>Evaluation of the material: No breaks are observed in the material, although the structure and conditions are not maintained since fibers are degraded.</p> <p>Implementation evaluation: The fiber roll is present but it has moved. The bound works but the pegs are all loose and there are fewer pegs than at the moment of the installation. Some fiber rolls are well attached to the soil and work correctly but some others are not well attached, which allow water pass over and behind the fiber roll.</p> <p>Evaluation of the plantation: Current species are not the same that were planted. There is new specie in the fiber roll: <i>Typha sp.</i></p> <p>Comments: The fiber roll is now composed by 50% <i>Iris pseudacorus</i>, 40% <i>Carex pendula</i>, 5% <i>Scirpus holochoenus</i> and 5% <i>Carex vulpina</i>. Nowadays 20 m. of vegetated fiber roll are remaining but 20 m. of fiber roll are floating, just tied to one end.</p>

EVALUATION OF THE STATE OF FIBER ROLLS IN CONGOST RIVER
1. LOCATION
River Congost Municipality Granollers
2. SAMPLE DATA
Date of Installation of fiber roll 2008 Sampling date 12/04/2011 Project reference
3. DESCRIPTION OF THE CONSTRUCTION
Linear meters of fibers 50m
Executive details
4. EVALUATION
<p>Evaluation of the material: No breaks or degradation are observed in the material, the structure and conditions are maintained. Still intact.</p> <p>Implementation evaluation: The fiber roll has not moved, is well attached to the soil with all the pegs and the bound working correctly, preventing the flow to pass through the front and the back of the fiber roll.</p> <p>Evaluation of the plantation: Current species are not the same that were planted. There are not <i>Carex vulpina</i> and <i>Scirpus holochoenus</i> is scarce. There is new specie in the fiber roll: <i>Lythrum sp.</i></p> <p>Comments: Main abundance of <i>Iris pseudacorus</i> (95%), with presence of <i>Scirpus holochoenus</i>(2,5%) and <i>Lythrum</i> (2,5%).</p>

EVALUATION OF THE STATE OF FIBER ROLLS IN BESÓS RIVER
1. LOCATION
River Besós Municipality Montcada
2. SAMPLE DATA
Date of Installation of fiber roll Sampling date 14/04/2011 Project reference: Proposal for the construction of structural stabilization in a section of the ordinary river bed in Besòs river in Santa Coloma de Gramanet.
3. DESCRIPTION OF THE CONSTRUCTION
Linear meters of fibers 20m Executive details 
4. EVALUATION Evaluation of the material: No breaks or degradation are observed in the material, the structure and conditions are maintained. Still intact. Implementation evaluation: The fiber roll has not moved, is well attached to the soil, preventing the flow to pass through the front and the back of the fiber roll. It is not possible to check id with all the pegs and the bound are working correctly because of poor visibility. Evaluation of the plantation: Current species are not the same that were planted. There is <i>Typha sp.</i> and <i>Urtica sp.</i> In the fiber roll. Comments: Main abundance of <i>Iris pseudacorus</i> (90%), with less abundance of <i>Scripus holochoenus</i> (5%) and <i>Carex pendula</i> (2,5%).

EVALUATION OF THE STATE OF FIBER ROLLS IN SANTA COLOMA RIVER
<p>1. LOCATION</p>
<p>River Santa Coloma Municipality Santa Coloma</p>
<p>2. SAMPLE DATA</p>
<p>Date of Installation of fiber roll November 2007 Sampling date 11/04/2011 Project reference Technical documentation for the tender of the Conservation and improvement of the surroundings of Santa Coloma river and Castanyet river project (stretches 2,3,4 and 5).</p>
<p>3. DESCRIPTION OF THE CONSTRUCTION</p>
<p>Linear meters of fibers 110 m.l Executive details</p>  <p>The diagram illustrates the layout of fiber rolls. It starts with a 3.00m segment, followed by a 6.00m segment, a 1.50m transition, a 14.00m segment, a 2.50m transition, another 14.00m segment, and finally a 19.00m segment on a slope. Slopes are indicated as 1.00/1.00.</p>
<p>4. EVALUATION</p>
<p>Evaluation of the material: No breaks or degradation are observed in the material, the structure and conditions are maintained. Still intact. Implementation evaluation: The fiber roll has not moved, is well attached to the soil with all the pegs and the bound working correctly, preventing the flow to pass through the front and the back of the fiber roll. Evaluation of the plantation: Current species are the same that were planted (<i>Carex pendula</i>, <i>Iris pseudacorus</i>, <i>Carex vulpina</i>). There are no new species colonizing the fiber rolls. Comments: Main abundance of <i>Carex pendula</i> (50%) and <i>Iris pseudacorus</i> (40%) and less abundance of <i>Carex vulpina</i> (10%).</p>

EVALUATION OF THE STATE OF FIBER ROLLS IN COLOBRERS MOUNTAIN STREAM
<p>1. LOCATION</p>
<p>Riera Colobrers Municipality Sabadell</p>
<p>2. SAMPLE DATA</p>
<p>Date of Installation of fiber roll 2008 Sampling date 14/4/2011 Project reference River bank restoration of Colobrers mountain stream to the confluence of the Ripoll river.</p>
<p>3. DESCRIPTION OF THE CONSTRUCTION</p>
<p>Linear meters of fibers 100m Executive details</p> 
<p>4. EVALUATION</p>
<p>Evaluation of the material: No breaks or degradation are observed in the material, the structure and conditions are maintained.</p> <p>Implementation evaluation: The fiber roll has not moved, is well attached to the soil with all the pegs and the bound working correctly, preventing the flow to pass through the front and the back of the fiber roll.</p> <p>Evaluation of the plantation: Current species are the same that were planted, although there are some new species, which are not helophytes, in the fiber roll.</p> <p>Comments: The abundance of species in the fiber roll is: <i>Iris pseudacorus</i> 50%, <i>Scirpus holochoenus</i> 25%, <i>Carex pendula</i> 20% and <i>Carex vulpina</i> 5%.</p>

3.2.1 Resistance estimation of fiber roll from the hydraulic parameters

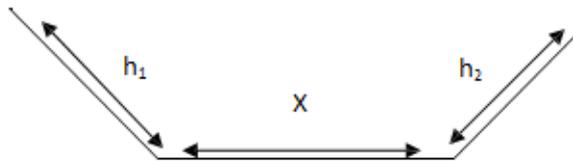
FLUVIÀ RIVER, PONT DE LES MORES (OLOT)

Flooding episodes from the installation

Data	28/12/2008	14/4/2007	1/2/2009
Peak flow	30.72 m ³ /s	13.27 m ³ /s	11.39 m ³ /s
Velocity	3.74m/s	1.61 m/s	1.38 m/s

Source: Fluvià river's gauging station in Olot.

Cross section



X (m)	h ₁ (m)	h ₂ (m)
15	3	6

Shear stress associated to a maximum flow²

R	γ	i	τ	Lithology of the river banks where the fiber rolls are installed (i)
0.507m	10000N/M ³	0.004 m/m	20.28 N/m ²	Gravel

Meteorological data Average rainfall : 68.99mm

Average temperature: 13.17 °C

Humidity: 72.25%

Source: Olot's weather station.

² The calculation of the shear stress associated to a maximum flow is $\tau = R \gamma i$ (Newton/m), where γ is water weight, R is the hydraulic radius and i is the slope of the river.

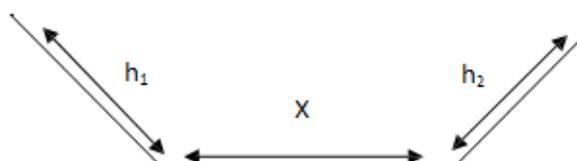
ANOIA RIVER, SANT ESTEVE SES ROVIRES

Flooding episodes from the installation

Date	10/10/2010	10/6/2010	16/3/2011
Peak flow	13.72 m ³ /s	2.84 m ³ /s	1.80 m ³ /s
Velocity	2.88m/s	0.59 m/s	0.38m/s

Source : Jorba's gauging station, in Anoia river.

Hydraulic section



X (m)	h1 (m)	h2 (m)
8,5	32	24

Shear stress associated to a maximum flow

R	γ	i	τ	Lithology of the river banks where the fiber rolls are installed (i)
0.477m	10000N/M ³	0.002 m/m	9.54N/m ²	Gravel

Meteorological data Average rainfall : 603.3mm/any

Average temperature: 16.1 °C

Humidity: 68.2%

Source: Castellbisbal's weather station.

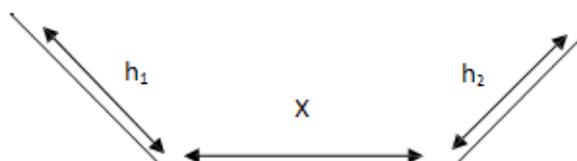
MOGENT RIVER, LLINARS DEL VALLÈS

Flooding episodes from the installation

Date	15/3/2011	13/9/2006	27/2/2003
Peak flow	63.684m ³ /s	15.61 m ³ /s	11.83 m ³ /s
Velocity	2.69m/s	0.65 m/s	0.50 m/s

Source : Montornès del Vallès' Gauging station in Mogent river.

Hydraulic section



X (m)	h ₁ (m)	h ₂ (m)
13.4	22.5	16

Shear stress associated to a maximum flow:

R	γ	i	τ	Lithology of the river banks where the fiber rolls are installed (i)
23.69m	10000N/M ³	0.009 m/m	79.08N/m ²	Gravel

Meteorological data

Average rainfall : 729.95 mm/any

Average temperature: 13.47 °C

Humidity: 73%

Source: Dosrius's weather station.

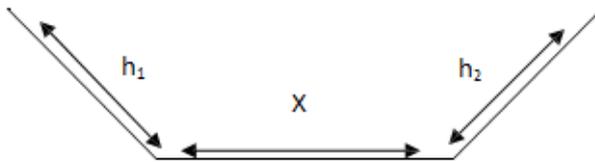
FLUVIÀ RIVER, BESALÚ

Flooding episodes from the installation

Date	28/12/2008	14/4/2007	1/2/2009
Peak flow	30.72m ³ /s	13.27 m ³ /s	11.39 m ³ /s
Velocity	1.29 m/s	0.55 m/s	0.48m/s

Source : Olot's Gauging station, in Fluvià river.

Hydraulic section



X (m)	h ₁ (m)	h ₂ (m)
77.5	5.15	6.5

Shear stress associated to a maximum flow

R	γ	i	τ	Lithology of the river banks where the fiber rolls are installed (i)
0.304m	10000N/M ³	0.01 m/m	30.43N/m ²	Gravel

Meteorological data

Average rainfall : 887,67 mm/any

Average temperature: 13,37 °C

Humidity: 72%

Source : Olot's weather station.

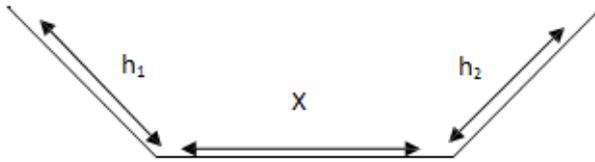
CONGOST RIVER, GRANOLLERS

Flooding episodes from the installation

Date	15/3/2011	2/11/2008	13/2/2011
Peak flow	57.38 m ³ /s	9.62 m ³ /s	5.93 m ³ /s
Velocity	1.93m/s	0.62m/s	0.19m/s

Source: Garriga's gauging station, in Congost river.

Hydraulic section



X (m)	h ₁ (m)	h ₂ (m)
7.5	33.5	4

Shear stress associated to a maximum flow

R	γ	i	τ	Lithology of the river banks where the fiber rolls are installed (i)
0.64m	10000N/M ³	0.0072 m/m	45.08N/m ²	Gravel

Meteorological data

Average rainfall : 698.37 mm/any

Average temperature: 14.17 °C

Humidity: 76%

Source : Vilanova del Vallès' weather station.

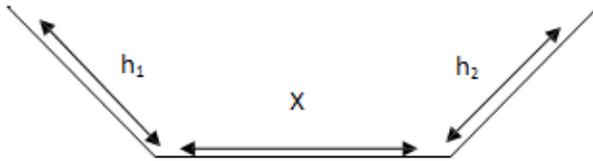
BESÓS RIVER, MONTCADA

Flooding episodes from the installation

Date	27/2/2003	13/9/2006	4/12/2003
Peak flow	86.5 m ³ /s	82.53 m ³ /s	54.98 m ³ /s
Velocity	1.35 m/s	1.29 m/s	0.86 m/s

Source : Santa Coloma de Gramanet's gauging station, in Besòs river.

Hydraulic section



X (m)	h₁ (m)	h₂ (m)
124.5	10	4

Shear stress associated to a maximum flow

R	γ	i	τ	Lithology of the river banks where the fiber rolls are installed (i)
0.50 m	10000N/M ³	0.0053 m/m	26.47N/m ²	Gravel

Meteorological data Average rainfall : 572.5 mm/any

Average temperature: 15.24 °C

Humidity: 67%

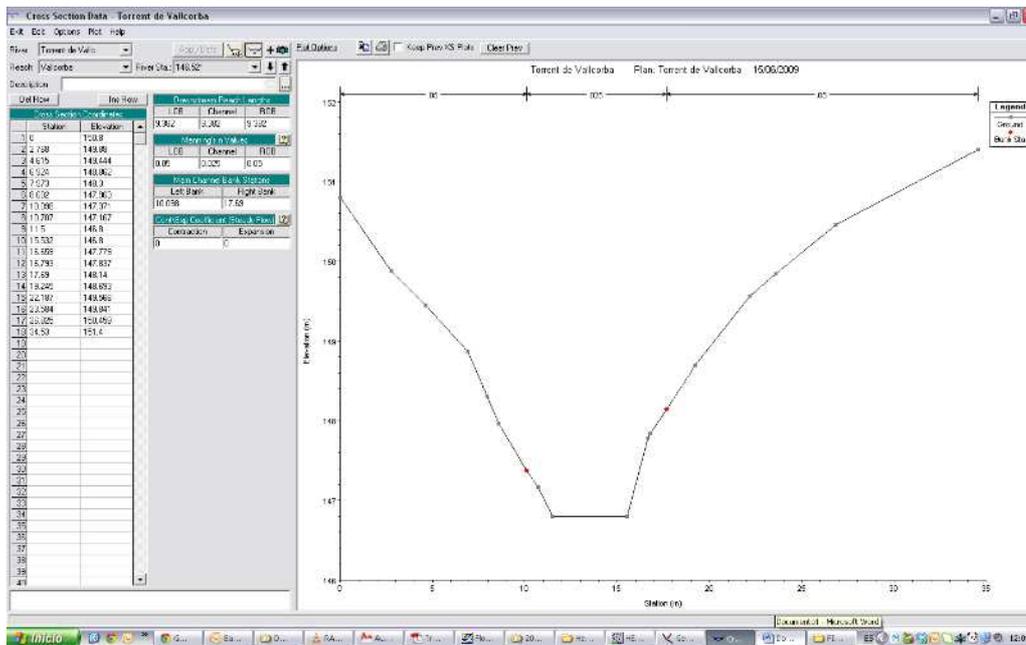
Source : Cerdanyola del Vallès' weather station

VALLCORBA MOUNTAIN STREAM, SANT QUIRZE DEL VALLÈS

Flooding episodes from the installation

Date	17/09/2010
Average rainfall	68.8 mm
Peak flow	42.43 m ³ /s
Velocity	4.18 m/s

Hydraulic section



Shear stress associated to a maximum flow

R	γ	i	τ	Litologia dels bancs on estan fixats els Fiber rolls (i)
0.92 m	10000N/M ³	0.0213 m/m	195.96 N/m ²	Gravel

3.2.2 Discussion

Assessment point	Stress (N/m ²)
Fluvià river, Olot	20.28
Fluvià river, Besalú	30.43
Mogent river, Llinars del Vallès	79.20
Congost river, Granollers	45.99
Besós river, Montcada i Reixac	26.37
Anoia river, Sant Esteve de Ses Rovires	9.54

4 Conclusions

The results demonstrate there is a great variation between species and within species although there is a clear trend. Their development highly depends on the environment, and it should be considered that the controlled environment was quite good for the helophytes.

It is important to highlight the root system's structure index for helophytes is among good and very good, which confirms this species have a good root system development. In this respect emphasize that, on the contrary that containers or pots, vegetated fiber rolls allow implementing well developed plants in natural areas.

On the contrary, the indexes of relative stability are approximately 1, which are not very high, but considering that the aerial part is flexible and it doesn't offer the same resistance, we may consider it is a good result. The same conclusions apply for potential stability index.

The root system's depth of the helophytes has a remarkable average of 40.8 cm in wild environments, 34.3 cm in controlled environments and 48.9 cm in fiber rolls.

Specifically, it is found that *Phragmites australis*'s root system depth is around 30 cm although necessity may encourage deeper roots. That result coincides with the criteria used in water treatment systems.

Other cases as *Iris pseudacorus* and *Scirpus holoschoenus* may be considered as the most interesting species, even though *Juncus acutus* potential was observed. This latter in a fiber roll has an excellent root system structural index of 1.7, with an average of the root system's depth of 48.02 cm. The species with the larger root is *Scirpus holoschoenus*, with an average of the root system's depth of 55.8 cm.

On the other hand, vegetated fiber rolls are closer to an ideal environment than a wild environment, achieving a good root system development of the plants, which confirms it is a good system for introducing helophytes in natural areas.

Finally, a good resistance of vegetated fiber rolls was observed in restored areas, where 4,18 m/s velocity was achieved successfully, although they were not installed in dynamical areas. The resistance of fiber rolls in the studied works depends more on the quality of the implantation than natural impacts.

Castellar del Vallès (Barcelona), January 2012