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Macrophytes communities associated to soil bioengineering techniques for erosion control in riverbanks[1]

Maria Hosana Santos[2], Francisco Sandro Rodrigues Holanda[2*], Janisson Bispo Lino[2], Tássio Lucas Souza Santos[2], Cátia Santos Fontes[2], Marks Melo Moura[3], Renisson Neponuceno Araújo Filho[4]

[1]Parte da dissertação do primeiro autor, Programa de Pós-graduação em Agricultura e Biodiversidade, Universidade Federal de Sergipe, Brasil.
[2]Universidade Federal de Sergipe, Departamento de Engenharia Agronômica, campus São Cristovão. Av. Marechal Rondon, s/n, CEP 49100-000, São Cristóvão, SE, Brasil.
*Autor para correspondência: fholanda@infonet.com.br
[3]Universidade Federal do Paraná, Departamento Ciências Florestais, Av. prof. Lothario Meissner, 900, CEP 80210-170, Curitiba, PR, Brasil.
[4]Universidade Federal do Tocantins, Curso de Engenharia Florestal, campus Gurupi. Rua Badejos, s/n, CEP 77404-970, Gurupi, TO, Brasil.

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ABSTRACT – The objective of this study was to evaluate the temporal and spatial richness of aquatic macrophyte settlement in a right bank of the São Francisco river, northeastern Brazil. The botanical material was collected and assembled exsiccate from April 2014 to September 2015, totaling four samplings at the points identified as: Vegetated Slope (A); Vegetated Riprap (B); Eroded Slope (C), Cribwall (D); Vetiver Grass Contour Line (E). It was identified 66 species distributed in 23 families. The Vegetated Slope in the rainfall period presented higher species richness and diversity. The soil bioengineering techniques at points B, D and E presented a stable river bank, thus creating a favorable environment for a larger settlement of macrophytes.

Keywords: biodiversity, cribwall, Lower São Francisco, riprap

RESUMO – **Comunidades de macrófitas associadas a técnicas de bioengenharia do solo para controle de erosão em margens de rios.** O objetivo do trabalho foi avaliar a riqueza temporal e espacial do povoamento de macrófitas aquáticas em um talude da margem direita do rio São Francisco, no nordeste brasileiro. O material botânico foi coletado para montagem de exsicata, no período de abril de 2014 a setembro de 2015, totalizando quatro amostragens, nos pontos identificados como: (A) Talude Vegetado, (B) Enrocamento Vegetado, (C) Talude Erodido, (D) Parede Krainer e (E) Cordão de Vetiver. Foram identificadas 66 espécies distribuídas em 23 famílias. Talude Vegetado no período de chuvas apresentou maior riqueza e diversidade de espécies. As técnicas de bioengenharia de solos nos pontos B, D e E possibilitaram a estabilização dos taludes na margem do rio, e assim, criando um ambiente favorável para um maior povoamento de macrófitas.

Palavras-Chave: Baixo São Francisco, biodiversidade, enrocamento, Parede Krainer

INTRODUCTION

Macrophytes compose a taxonomic diversity of organisms with different life forms, which extend from floodplain areas to fully aquatic environments, populated by organisms from algae to angiosperms (García-Girón *et al.* 2019). Macrophytes are classified as emerged, rooted plants, and their leaves remain out of the water; floating plants, free floating, rooted to the sediment, and their leaves remain floating on the water surface; submerged plants, rooted to the sediment, totally submerged; free submerged plants, which develop floating submerged in the water (Moura & Henry-Silva 2018).

Given the diversity and the distribution in the ecosystem, macrophytes play an important ecological role in lentic environments, providing an attractive environment for fauna development (from vertebrates to several invertebrates), either as shelter, or as feed (Dhir 2015). Besides its important role contributing to nutrient cycling, some macrophytes, especially the free-floating, rooted submersed and emerged, are effective in pollutant removal (Shah *et al.* 2015).

The colonization of aquatic macrophytes is associated with the availability of dissolved nutrients, light, temperature, alkalinity, salinity, river discharge and speed, which together act on these communities (Chen & Wang 2019). In fact, the control of the hydrological regime results in changes in biological fresh water communities and in the physicochemical conditions of the water (Howard *et al.* 2016), creating different environments, allowing the occurrence of greater species diversity.

Hydrological changes frequently occur in large rivers worldwide, reflecting on shifts along the channel by means of water impoundment, either for the use in electric power generation, or for human consumption, irrigation, flood control, navigation, and leisure. In the São Francisco River, the past fifty years were marked by the establishment of hydroelectric plants throughout its channel, which significantly altered the hydrosedimentological dynamics of this ecosystem (Rocha *et al.* 2018), leading to increased occurrence of erosion in its banks, which demands the implementation of mitigation works regarding these environmental threats (Andrade *et al.* 2018).

Another consequence is the instability of the soil aggregates after vegetation removal, which contributes to erosive processes (Machado *et al.* 2018; Oliveira *et al.* 2009). In order to mitigate the damage caused by erosion, scientists have developed engineering techniques combined with ecological knowledge on plant species that contribute to the roots mechanical reinforcement for erosion control (Holanda *et al.*, 2007; Holanda *et al.*, 2009; Araújo-Filho *et al.* 2017).

Costa *et al.* (2020) stated the importance of vegetation in the riverbanks erosion control, and also Machado *et al.* (2018) showed in their work the importance of knowing the species morphological characteristics, in order to enable positive performance in slope stabilization. This shows that soil bioengineering techniques favor erosion control and increased biodiversity related to aquatic plant species. The objective of this work was to evaluate the temporal and spatial richness of the macrophytes communities on the slopes of the São Francisco River margins associated to use of soil bioengineering techniques.

MATERIAL AND METHODS

Collection Area

The study was carried out on the right margin of the São Francisco River, in the municipality of Amparo de São Francisco coordinates W 36º50`25.335" and S 10º13`34.081", in Sergipe state, Northeastern Brazil. The climate was characterized As type (tropical, with two well defined seasons, dry summer and rainy winter), according to the Peel *et al.* (2007) classification, with average annual rainfall of 744 mm year^{-1} and temperature of 25°C (INMET 2015).

The floristic survey on the slope was carried out monthly from April 2015 to September 2015, along the riverbank. Ten plots 30 x 30 cm were randomly installed and macrophytes with the presence of a flower were removed in each plot. All flowery individuals found on the slope and in places immediately associated with the slopes, that is, close to the river channel, were taken for later identification.

The collection sites were chosen considering the development of macrophytes communities at the slope toe in the São Francisco River, after the implementation of some soil bioengineering techniques as a result of a favorable hydrosedimentological environment. The Vegetated Riprap, the Cribwall, and Vetiver grass (*Chrysopogon zizanioides* (L.) Roberty) contour lines were considered among the techniques used in the experimental area. These techniques promote erosion control, stabilize the slopes, and provide environment for flora development and shelter for the aquatic fauna (Araujo-Filho *et al.* 2013).

Sample collection

The collections of botanical material were carried out in plots along the 200 m extension of the river bank. The collection sites were: Vegetated Slope (A); Vegetated Riprap (B); Eroded Slope (C), Cribwall (D); Vetiver grass Contour Line (E) (Fig. 1).

Among the collection sites, three of them (B, D and E) are composed by soil bioengineering techniques (Araujo-Filho *et al.* 2013). Site "A", identified as Vegetated slope, is characterized as an area covered by native vegetation, with strong presence of aquatic macrophytes; Site "B", the Vegetated Riprap, comprises one of the soil bioengineering techniques, implanted at the slope toe in 2011 composed by rock materials with different diameters, and was vegetated with species of local flora, and also populated with other species resulting from seed dispersal by fauna and the wind; Site "C", the Eroded Slope, had different number of plant individuals at its toe, depending on the rainfall and river discharge during the collection period; Site "D", the Cribwall, is another soil bioengineering technique, which consists of the stabilization of the river slope with wooden logs, clamps and living material, implanted in September 2013, and was also vegetated with a great number of macrophytes at its toe; Site "E", the Vetiver grass Contour Line, consisted of seedlings of vetiver grass planted in contour lines, following the concavity of the river margin. Plant collection was carried out using a canoe at low speed, with concomitant photographic and iconographic records.

The preparation of the collected plant material followed conventional methods, such as drying and exsiccate methods (Rodrigues *et al.* 2017). After that, the material was taken to the Herbarium – ASE of the Universidade Federal de Sergipe, for identification. The taxonomic identification was carried out by comparing the collected material. In addition, specialized studies and experts references were used (Pott & Pott 2000; Lorenzi 2008; Souza & Lorenzi 2008).

Analyzes

In order to evaluate the biodiversity richness data of the study sites, we used the richness estimation method from the sample data (Cullen *et al.* 2006). Also using the accumulation curve, the richness of the aquatic macrophytes species was verified at the sampling sites, and was estimated by non-parametric indexes. These indexes were based on the presence or absence of the species (Chazdon *et al.* 1998), using the Estimates software (Colwell 1997). Among the estimators, Chao2, Jacknife (Jack1), and Bootstrap were selected once they have been used in studies with macrophytes, based on a similar collection methodology (Bini *et al.* 2001).

Figs. 1. A-E. Collection sites of aquatic microphytes at Amparo de São Francisco. **A.** Vegetated Slope; **B.** Vegetated Riprap; **C.** Eroded Slope; **D.** Cribwall; **E.** Vetiver Grass Contour Line.

The Jaccard Index was applied using the PasT software to estimate a similarity matrix between the sampling periods and the sampling sites, as an indicator of the degree of temporal stability in relation to the community composition. To compare the macrophytes communities identified among the collection sites, a temporal patterns at the sampling periods was performed, allowing the comparison by the Tukey test ($p < 5\%$), using the statistical software SISVAR (Ferreira 2011).

RESULTS AND DISCUSSION

Sixty six aquatic macrophytes species were recorded, distributed in 23 families (Tab. 1), showing the richness of species of the São Francisco River banks.

Other studies in different water systems report the occurrence of macrophytes as long as there are conditions for the development of such species (Araújo *et al.* 2012), who evaluated the richness and diversity of aquatic macrophytes in Caatinga biome springs, and found 52 species distributed in 25 families.

When we studied species lifeforms, 83% species were found amphibious, *i.e.*, they are adapted to variations in water level, considering that the riverbanks were identified as the interface between the aquatic and terrestrial environment, enabling a wide variety of species (Sponchiado & Schwarzbold 2009). We also identified submerged species (5%), emerged species (5%), rooted submerged species (1%), and free floating species (6%). These are differentiated distribution patterns, in agreement with the studies by Bianchini Junior *et al.* (2010) and Mormul *et al.* (2010).

The presence of the species *Salvinia auriculata* Aubl. var. auriculata, *Pistia stratiotes* var. obcordata (Schleid.) Engl. and *Eichhornia crassipes* (Mart.) Solms in every collection shows their invasive character. Despite the hydrological changes, with the decrease of the river discharge and lowering of the water level, these species maintained their population with an remarkable occurrence. Moura-Junior (2012), conducting the studies in the Cursai and Tapacurá reservoirs, state of Pernambuco, also identified the maintenance of these species in two distinct periods of hydrological changes. These species have morphophysiological plasticity, which allows them to occupy continental ecosystems and brackish water (Moura Júnior & Cotarelli 2019).

Significant difference ($p < 0.05$) was observed for richness between sampling sites. The Vegetated slope site presented 69 species, while the Vetiver grass Contour Line presented 30 (Fig. 2).

This reflects the less favorable conditions for the species development in the Vetiver grass Contour Line, since it presents a sandy soil with less favorable edaphic, ecological and geomorphological conditions for macrophytes, because they are in the concave stretches of the riverbank, where erosion is more active, noticed by higher erosive rates.

The species accumulation curve (Fig. 3) shows the observed richness in contrast with the estimated richness.

Table 1. Aquatic macrophyte species in the study area at Amparo de São Francisco. Biological forms: Amphibious (AM), Free (FR), Rooted Submerged (SUB ROT), Free floating (FFLU) and Emerged (EM)

Family	Specie	Life Form	Richness	Voucher
Amaranthaceae	*Alternanthera tenella* Colla	AM	1	ASE 33516
Araceae	*Pistia stratiotes* L.	FFLU	4	ASE 33604
Asteraceae	*Emilia fosbergii* Nicolson.	AM	3	ASE 33579
	Blainvillea dichotoma (Murray) Stewart	AM	1	ASE 33585
	Tilesia baccata (L.f.) Pruski	AM	1	ASE33558
	Emilia sonchifolia (L) DC. ExWight	AM	3	ASE 33542
	*Eclipta prostrata (*L) L.	AM	2	ASE 33530
	Porophyllum ruderale (Jacq.) Cass	AM	5	ASE 33510
	*Mikania cordifolia (*L.f.) Willd	AM	6	ASE 33501
	*Conyza cf. bonariensis (*L.) Cronquist	AM	1	ASE 33508
	Ageratum conyzoides L.	AM	7	ASE 33520
	Tridax procumbens L.	AM	1	ASE 33548
	Pluchea sagittalis (Lam.) Cabrera	AM	2	ASE 33523
	Melanthera latifolia(Gardner) Cabrera	AM	3	ASE 33557
	Synedrella nodiflora (L.) Gaertn	AM	1	ASE 33545
Convolvulaceae	*Jacquemontia* sp.	AM	2	ASE 33575
	Ipomoea asarifolia (Desr.) Roem. & Schult.	AM	3	ASE 33506
Cucurbitaceae	*Momordica charantia* L.	EM	3	ASE 33546
Cyperaceae	*Cyperus surinamensis* Rottb.	AM	5	ASE 33513
	Cyperus blepharoleptos Steud.	EM	2	ASE 33568
	Cyperus compressus L.	AM	2	ASE 33569
	Cyperus odoratus L.	AM	10	ASE 33559
Euphorbiaceae	*Euphorbia hyssopifolia* (L.)	AM	2	ASE 33550
Fabaceae	*Centrosema pascuorum* Mart. ex Benth.	AM	2	ASE 33529
	Aschynomene sensitive Sw.	AM	16	ASE 33511
	*Sesbania virgata (*Cav.) Pers	AM	1	ASE 33534
	Crotalaria incana L.	AM	2	ASE 33573
	Vigna adenantha (G. Mey.) Marechal *et al*.	AM	2	ASE 33525
	Crotalaria pallida Aiton	AM	1	ASE 33528
	Macroptilium lathyroides (L) Urb.	AM	3	ASE 33535
	Vigna sp.	AM	2	ASE 33526
	Senna obtusifolia (L) H.S. Irwin & Barneby	AM	1	ASE 33552
	Chamaecrista sp.	AM	3	ASE 33527
	Mimosa pigra L	AM	3	ASE 33532
	Mimosa pudica L.	AM	2	ASE 33549
Hydrocharitaceae	*Apalanthe granatensis* (Humb. & Bonpl) Planch	SUB ROT	12	ASE 33563
	Najas guadalupensis (Spreng.) Magnus	SUB ROT	2	ASE 33563
Hydroleaceae	*Hydrolea spinosa* L.	AM	3	ASE 33531
Juncaceae	*Juncus* sp.	EM	5	ASE 33577
Lamiaceae	*Hyptis brevipes* Poit.	AM	1	ASE 33551
Malvaceae	*Waltheria indica* L.	AM	1	ASE 33600
Onagraceae	*Ludwigia helmintorrhiza* (Mart.) O. Hara	FFLU	10	ASE 33571
	Ludwigia octovalvis (Jacq.) P.H. Raven	AM	3	ASE 28107
	Ludwigia leptocarpa (Nutt.) O. Hara	AM	6	ASE 33537
	Ludwigia nervosa (Poir)	AM	1	ASE 33515

Table 1. Cont.

Family	Specie	Life Form	Richness	Voucher
Passifloraceae	*Piriqueta racemosa (*Jacq.) Sweet	AM	1	ASE 33499
	Piriqueta cistoides (L) Griseb	AM	2	ASE 33601
	Turnera subulata Sm	AM	3	ASE 33500
Plantaginaceae	*Stemodia maritima* L.	AM	3	ASE 33524
Poaceae	*Paspalum millegrana* Schrad	AM	3	ASE 29543
	Megathyrsus maximus Jacq. B.K. Simon & S.W.L. Jacobs	AM	1	ASE 33565
	Rugoloa pilosa (Sw.) Zuloaga	AM	1	ASE 33605
	Urochloa decumbens (Stapf) R.D. Webster	AM	4	ASE 33518
	Hymenachne pernambucensis (Spreng.) Zuloaga	SUB ROT	8	ASE 33555
	Urochloa sp.	AM	1	ASE 33602
	Steinchis malaxum (*Sw*) Zuloaga.	AM	1	ASE 33561
	Pennisetum sp.	AM	1	ASE 33539
	Pennisetum setosum (Sw.)Rich.	AM	1	ASE 33512
Pontederiaceae	*Pontederia crassipes* (Mart.) Solms	FFLU	25	ASE 33495
Potamogetonaceae	*Potamogeton pusillus* L.	SUB ROT	1	ASE 33583
Rubiaceae	*Borreria verticillata* (L.) G. Mey	AM	1	ASE 33509
	Pentodon pentandru s(K. Schum. &Thonn) Vatke	AM	1	ASE 33564
Salviniaceae	*Salvinia auriculata* Abl.	FFLU	20	ASE 33497
Sphenocleaceae	*Phenoclea zeylanica* Gartn	AM	1	ASE 33572
Verbenaceae	*Lantana camara* L.	AM	1	ASE 33576
	Stachytarpheta angustifolia Mill Vahl	AM	2	ASE 33533

Among the used estimators, Jack1 and Chao2 present higher number of estimated species than collected species. The bootstrap estimator is the most similar to the actual collection values. The collected species at the Vetiver grass Contour Line site presented values more similar to those of the estimators, while at the Vegetated Riprap site the number of estimated species was higher than the collected, noting that the same pattern was maintained for the other sites. Lolis & Thomaz (2011) also identified underestimation patterns of species at the sampling sites.

The similarity analysis (ANOSIM) showed significant differences in the composition of macrophytes communities between some of the sampling sites (Tab. 2).

Among the sites where significant differences were detected, the Vegetated Slope and the Cribwall sites, and Vegetated Slope and Vetiver grass contour line sites should be highlighted; however, there was species overlap. Observing the similarity analysis, it was clear that the macrophytes communities in the Vegetated Slope and in the Cribwall are quite similar. This is a characteristic related to nearby areas, which enables the homogeneity of species, due to their dispersing agents. Other studies have also found species overlap among sampling sites. Rodrigues (2017), in Guarapiranga dam, São Paulo, identified different patterns in the composition of macrophytes in different banks. Almeida (2012) also found differences in the macrophytes composition between sampling periods, with species overlap. These factors can be directly related to the river water level, and wind speed, creating problems to the colonization of macrophytes, specially the floating and submerged ones.

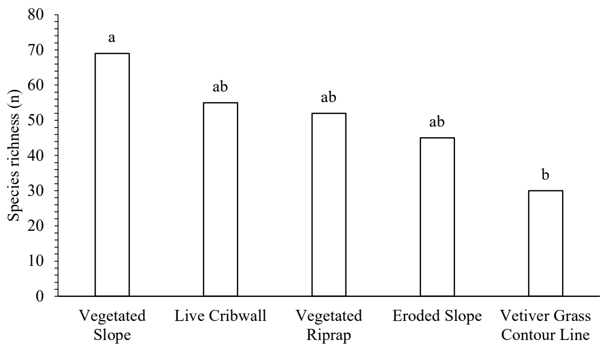

Fig. 2. Species richness of aquatic microphytes sampling sites at Amparo de São Francisco.

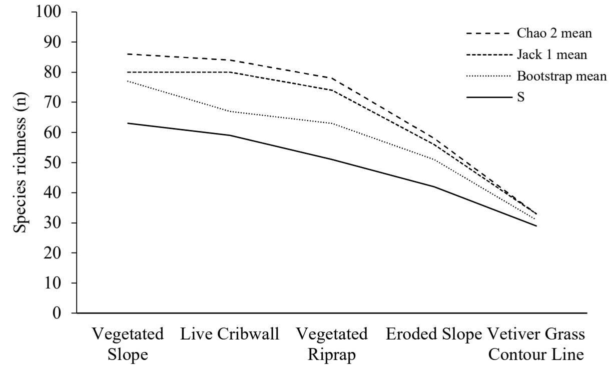

Fig. 3. Observed and estimated species accumulation curve at the sampling sites in municipality of Amparo de São Francisco, Sergipe state, 2014.

Table 2. Similarity analysis (ANOSIM) for macrophytes communities at the sampling sites in the municipality of Amparo de São Francisco, Sergipe state, 2014. sites (*p<0.05)

Sampling sites			R	P value
Vegetated Slope	X	Vegetated Riprap	0.2139	0.04
Vegetated Slope	X	Eroded Slope	0.1907	0.07
Vegetated Slope	X	Cribwall	0.4907	0.001*
Vegetated Slope	X	Vetiver grass Contour Line	0.3056	0.02*
Vegetated Riprap	X	Eroded Slope	0.1185	0.18
Vegetated Riprap	X	Cribwall	0.1972	0.05
Vegetated Riprap	X	Vetiver grass Contour Line	0.1204	0.10
Eroded Slope	X	Cribwall	0.2056	0.06
Eroded Slope	X	Vetiver grass Contour Line	-0.075	0.77
Cribwall	X	Vetiver grass Contour Line	0.2343	0.02

CONCLUSIONS

Asteraceae, Fabaceae, Poaceae families were predominant in the community of aquatic macrophytes and Amphibious was the predominant life form.

The Vegetated Slope site presented the greatest richness of species among the sampling sites, confirming the importance of slope protection, an attractive environment to other species.

In the species accumulation curve, the estimated value was higher than the collected value, and the boostrap values are closer to the actual values of the collection.

The species diversity confirms the importance of this community in ecological succession.

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