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Non-native and invasive alien plants on fluvial islands in the São Francisco River, northeastern Brazil

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Abstract: This paper is the result of a survey of the alien flora present on fluvial islands in the São Francisco River, northeastern Brazil. The floristic similarities between the islands wereassessed, as well as the relationship between area size and species richness. The study covered eight islands in the São Francisco River Valley and was carried out in a period of eight months. Thirty one alien species were registered, six of them (*Amaranthus viridis*, *Calotropis procera*, *Cenchrus ciliaris*, *Enneapogon cenchroides*, *Prosopis pallida* and *Ricinus communis*) present on all islands. The highest number of invasive alien species (26) was recorded on Massangano Island. The floristic similarity between the islands varied between medium and very high, while the number of alien species present was positively correlated with area size. The study demonstrates that the biodiversity on these eight fluvial islands is endangered, especially due to the presence of alien species capable of invading natural areas.

Key words: biological invasion, invasive alien species, island ecosystems, dry forest, Caatinga

INTRODUCTION

Fluvial islands are defined as land areas in the course of rivers surrounded by water (adapted from IBGE, 2004). Despite their importance for ecological reasons, these islands are not considered Permanent Preservation Areas (APP), which represent fragile habitats under legal protection in the Brazilian Forest Code (Law n° 12.651, 25 May 2012).

The fluvial islands in the São Francisco River have been targets of unplanned human occupation and unsound resource use for at least two centuries. Degraded areas currently cover most of the islands, favoring the establishment and spread of opportunistic species, and especially invasive alien species (Mack *et al*. 2000; Bohn *et al*. 2004; Alston and Richardson 2006). Many of these species can impact indigenous species, the physical environment, human or animal health, agriculture or cattle breeding, causing economic, social and environmental problems (Parker *et al*. 1999; Williamson 1999; Mooney and Hobbs 2000; Naylor 2000; Levine *et al*. 2003; Zalba and Ziller 2007; Fabricante *et al*. 2012). Studies to identify invasive alien species, especially in vulnerable ecosystems like islands, are needed to guide management programs.

This study was aimed at developing a register of alien species on fluvial islands in the São Francisco River. It was assumed that area size would be related to species richness, and that area size and distance between the islands influenced alien species floristic similarity. Testing these hypotheses clarified biological invasion trends in these island ecosystems and should help prevent biological invasions on other islands.

MATERIALS AND METHODS

Study site

The islands selected for the survey are located in the São Francisco River Valley, between the cities of Petrolina (Pernambuco) and Juazeiro (Bahia), in the northeastern region of Brazil, in the Caatinga biome (Table 1; Figure 1). The local climate type is BSh, or hot semi-arid, according to the Köppen classification, with an annual rainfall of 530 mm and average annual temperatures of 26.5°C. The soils are sandy and the vegetation is composed by Caatinga species and the typical elements of riparian forest with super-dominance of *Inga vera* Willd species.

The islands have a similar history of use and human influence. They were first populated in the mid-nineteenth century, when agriculture and livestock practices for subsistence were established, especially the cultivation of fruit, vegetables and grains, as well as goat, sheep and, in lower proportions, cattle breeding. Only a strip narrower than 10 m wide at the edges of the islands are occupied by riparian forests. No significant remains of Caatinga vegetation were observed (J.R. Fabricante, personal observation).

Table 1. List of islands in the survey, area (size in hectares) and geographic coordinates.

Islands	Area (ha)	Geographic coordinates
Rodeadouro	30	09°27′54.88″ S, 040°34′44.95″ W
Massangano	210	09°27′24.46″ S, 040°33′52.50″ W
Maroto	5.5	09°26′32.32″ S, 040°32′44.30″ W
Country	4	09°24′45.24″ S, 040°31′09.85″ W
Fogo	4.2	09°24′21.77″ S, 040°30′14.55″ W
Jatobá (I)	110	09°25′01.63″ S, 040°28′20.91″ W
Jatobá (II)	5.9	09°24′31.99″ S, 040°27′44.27″ W
Jatobá (III)	35	09°24′12.65″ S, 040°27′26.25″ W

Figure 1. Spatial location of the studied islands in the São Francisco River (northeastern region of Brazil). Source: Google Earth.

Data collection

Samples of alien species in flower or fruitification were collected by active search (pathway method as per Filgueira *et al.* 1994) out between April and November 2013. Only alien species with recruitment, *i.e.*, with capacity for autonomous establishment, were considered in the study.

The plant samples collected were prepared as exsiccates and deposited in the "Vale do São Francisco Herbarium" (HVASF). The taxonomic classification was based on the APG III System (2009), while the spelling of species author names was based on the Species List of Brazilian Flora (2013). Floristic lists included plant habit (herb, vine, shrub or tree, according to Font-Quer [1975]), geographic origin (Duarte *et al.* 2000; Quijano and Pino 2007; Schneider 2007; Silva *et al.* 2007; Biondi and Macedo 2008; Ferreira *et al.* 2009; Oladipupo *et al.* 2009; Sanz-Elorza *et al.* 2010; Vilarreal *et al.* 2010; Araújo *et al.* 2011; Guglieri-Caporal *et al.* 2011; Fabricante and Siqueira-Filho 2012; Fabricante 2013a, 2013b, 2013c, 2014; Shirasuna *et al.* 2013), and habitat of establishment (agricultural, ruderal, or natural). Agricultural sites include pasture and cropland areas; ruderal sites represent areas under human influence, such as backyards, gardens, sidewalks, or streets; and natural sites cover the other types of environment, including patches of indigenous vegetation in several conservation conditions.

Data analysis

To assess floristic similarity between the islands, the binary Jaccard coefficient (Sj) (Müller-Dombois and Ellemberg 1974) was used. Values ranging from 0–0.25 were considered as low similarity, 0.26–0.5, medium, 0.51–0.75, high and 0.76–1, very high. The analyses were performed using the MVSP 3.1© software (Kovach 2005).

The correlation (ρ) between floristic similarity and geographical distance between islands and between floristic similarity and island size was determined using the Mantel test (Mantel 1967), with 1,000 randomizations. The Past 2.17c© program (Hammer *et al.* 2001) was used to perform the analysis.

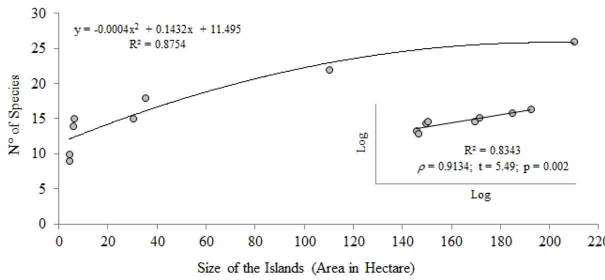

Figure 2. Regression analysis (main graph) and Pearson correlation (r) (secondary chart) between species richness and island size in the São Francisco River (northeastern region of Brazil).

The relationship between area size (ha) and alien species richness was analyzed through a regression and correlation analysis (with logarithmic data) using the linear Pearson correlation coefficient (ρ) (Rodgers and Nicewander 1988), whose significance was verified by a t ($p \leq 0.05$) test (Lehmann 1997). The software used was BioEstat 5.3© (Ayres *et al.* 2007).

The Arrhenius species-area relationship (1921) (SAR) was established. For this purpose, constant "c" values were calculated ($c = A^{-z}$), as well as the slope value "z" (z = log Y/log X) from the power function ($S = cA^z$), where "S" is the number of species and "A" is the area. These calculations were performed using Microsoft Excel software.

RESULTS

The survey resulted in a list of 31 alien plant species in 28 genera and 16 families (Table 2). The most represented family was Poaceae, with 12 species (38.7%), followed by

Table 2. List of families and alien plant species recorded in the São Francisco River fluvial islands (northeastern Brazil), with habit (herb, vine, shrub or tree); origin (country or continent); sites (A - agricultural site; R - ruderal site; N - natural area); Island (I - Rodeadouro; II - Massangano; III - Maroto; IV - Country; V - Fogo; VI - Jatobá (I); VII - Jatobá (II); VIII - Jatobá (III) and Voucher number in Vale do São Francisco Herbarium (HVASF). The number one means the presence of the species.

Family/ Species	Habit	Origin	Sites	Island								Voucher
				I	II	III	IV	V	VI	VII	VIII	
Amaranthaceae												
Amaranthus spinosus L.	herb	Central America	A, R	—	1	—	—	—	—	—	—	20870
Amaranthus viridis L.	herb	Caribbean	A, R	1	1	1	1	1	1	1	1	20019
Anacardiaceae												
Mangifera indica L.	tree	Asia	A, R	—	1	—	—	—	—	—	—	20878
Apocynaceae												
Calotropis procera (Aiton) W.T.Aiton	shrub	Africa, Asia	A, R	1	1	1	1	1	1	1	1	20011
Catharanthus roseus (L.) Don	herb	Madagascar	R	—	—	—	—	—	1	—	1	20858
Asteraceae												
Cosmos sulphureus Cav.	herb	Central America	R	1	—	—	—	—	—	—	—	20023
Combretaceae												
Terminalia catappa L.	tree	Asia	R, N	1	1	—	—	—	—	—	—	20876
Commelinaceae												
Commelina benghalensis L.	herb	Asia	A, R	—	1	—	—	—	1	1	—	20864
Cucurbitaceae												
Cucumis anguria L.	vine	Africa	A, R	—	1	—	—	—	—	—	—	20872
Momordica charantia L.	vine	Africa, Asia	A, R, N	1	1	1	1	—	1	—	1	20020
Cyperaceae												
Cyperus rotundus L.	herb	India	A, R	—	1	—	—	—	1	1	1	20857
Euphorbiaceae												
Ricinus communis L.	tree	Africa	A, R, N	1	1	1	1	1	1	1	1	20018
Fabaceae												
Leucaena leucocephala (Lam.) de Wit	tree	Mexico	A, R, N	—	1	—	1	1	—	—	—	20868
Prosopis pallida (Humb. and Bonpl. ex Willd.) Kunth	tree	America	A, R, N	1	1	1	1	1	1	1	1	13199
Meliaceae												
Azadirachta indica A.Juss.	tree	India	R	1	1	—	1	—	1	—	—	20024
Myrtaceae												
Psidium guajava L.	tree	Central America	A, R	—	1	—	—	—	—	—	1	20877
Nyctaginaceae												
Boerhavia diffusa L.	herb	India	A, R	—	—	1	—	—	1	1	1	11773
Papaveraceae												
Argemone mexicana L.	herb	Mexico	A, R	—	1	—	—	—	—	—	—	20869
Plantaginaceae												
Plantago major L.	herb	Europe	A, R	—	1	—	—	—	—	—	—	20880
Poaceae												
Aristida adscensionis L.	herb	Africa	A, R, N	—	—	—	—	—	1	—	1	20856
Cenchrus ciliaris L.	herb	Africa, India and Indonesia	A, R, N	1	1	1	1	1	1	1	1	20010
Cenchrus echinatus L.	herb	Central America	A, R	1	1	1	—	1	1	1	1	20017
Dactyloctenium aegyptium (L.) Willd.	herb	Africa	A, R	1	1	1	—	—	1	1	1	20014
Digitaria ciliaris (Retz.) Koeler	herb	Asia	A, R	1	1	1	—	—	1	—	—	20015
Echinochloa colona (L.) Link	herb	Europe, Asia	A, R, N	—	—	—	—	—	1	—	—	20855
Enneapogon cenchroides (Roem. and Schult.) C.E. Hubb.	herb	Africa	A, R, N	1	1	1	1	1	1	1	1	20008
Eragrostis cilianensis (All.) Vignolo ex Janch.	herb	Europe	A, R, N	—	1	—	—	—	1	1	1	20854
Eragrostis tenella (L.) P.Beauv. ex Roem. and Schult.	herb	Africa	A, R	1	1	1	—	1	1	1	1	20021
Megathyrsus maximus (Jacq.) B.K.Simon and S.W.L.Jacobs	herb	Africa	A, R, N	—	1	—	—	—	—	—	—	20885
Melinis repens (Willd.) Zizka	herb	Africa	A, R, N	1	1	1	—	—	1	1	1	20006
Sorghum arundinaceum (Desv.) Stapf	herb	Africa	A, R, N	—	1	1	1	—	1	1	1	20881
Total				**15**	**26**	**14**	**10**	**9**	**21**	**15**	**18**	

Table 3. Floristic similarity between fluvial islands in the São Francisco River. Values of Sj (Jaccard) ranging from 0–0.25 indicate low similarity, 0.26–0.5, medium, 0.51–0.75, high, and 0.76–1, very high. Islands: I - Rodeadouro; II - Massangano; III - Maroto; IV - Country; V - Fogo; VI - Jatobá (I); VII - Jatobá (II); VIII - Jatobá (III).

Island	I	II	III	IV	V	VI	VII	VIII
I	—	high	high	medium	medium	High	medium	medium
II	0.519	—	medium	medium	medium	High	high	high
III	0.706	0.481	—	medium	high	High	high	high
IV	0.471	0.385	0.5	—	high	medium	medium	medium
V	0.5	0.346	0.533	0.583	—	medium	medium	medium
VI	0.565	0.567	0.667	0.409	0.364	—	high	very high
VII	0.5	0.519	0.706	0.389	0.5	0.714	—	high
VIII	0.5	0.517	0.684	0.4	0.421	0.773	0.737	—

Amaranthaceae, Apocynaceae, Cucurbitaceae, and Fabaceae, with two species each (6.4%). The other families were represented by only one taxon each (3.2%).

Because of the abundance of grasses (38.7%), herbs were the most representative group (67.7 %), followed by trees (19.4%), shrubs (6.4%) and vines (6.4%) (Table 1). Most of the species recorded are indigenous to the African continent (41.9%). All species were observed in ruderal areas, 27 (87.1%) in agricultural areas, and 13 (41.9 %) in natural areas (Table 2).

The alien plant species *Amaranthus viridis* L., *Calotropis procera* (Aiton) W.T.Aiton, *Cenchrus ciliaris* L., *Enneapogon cenchroides* (Roem. and Schult.) C.E. Hubb., *Prosopis pallida* (Humb. and Bonpl. ex Willd.) Kunth, and *Ricinus communis* L. were present on all islands. The islands with the highest number of alien plant species were Massangano, with 26 species (83.9%), and Jatobá (I) with 21 species (67.7%), followed by Jatobá (III) with 18 species (58.1%) (Table 2).

The floristic similarity between islands varied widely. The highest similarity was observed between Jatoba (I) and Jatoba (III) (Sj = 0.773) and between Jatobá (II) and Jatobá (III) (Sj = 0.737). The lowest degree of similarity was found between the Massangano and Fogo Islands (Sj = 0.346) (Table 3). The values of the Mantel test show the absence of dependence between floristic similarity and distance between islands (ρ = 0.2829; p = 0.0769), and between floristic similarity and island size (ρ = 0.2502; p = 0.1938).

The best regression analysis model adjusted to the data was quadratic or polynomial of order 2 (F = 228.5; p = 0.0002). The correlation between the species richness and island size was positive and significant (ρ = 0.9134; t = 5.49; p = 0.002; Figure 2). The values of "c" and "z" were 0.916 and 0.2111, respectively.

DISCUSSION

The survey resulted in a list of 31 alien plant species, with herbs the most representative group. Only six species were found on all the islands, however the floristic similarity between the islands was medium to high. The correlations between floristic similarity and distance, as well as floristic similarity and area size between islands were not significant. The correlation between species richness and island size was positive.

Twelve alien plant species (38.7%) found in the islands are listed in the I3N Brazil national Invasive Alien Species Database managed by the Horus Institute for Environmental Conservation and Development (Base de Dados Nacional de Espécies Exóticas Invasoras - Instituto Hórus de Desenvolvimento e Conservação Ambiental, 2014). They are: *Aristida adscensionis* L., *Azadirachta indica* A.Juss., *Calotropis procera*, *Cenchrus ciliaris*, *Cyperus rotundus* L., *Leucaena leucocephala* (Lam.) de Wit., *Mangifera indica* L., *Melinis repens* (Willd.) Zizka, *Momordica charantia* L., *Psidium guajava* L., *Ricinus communis*, and *Terminalia catappa* L.

The other alien plant species found in the islands are not included in the Brazilian database, however, their presence is well known in other parts of the planet. For example, (i) *Argemone mexicana* L. is common in tropical and subtropical areas all over the world (CABI 2014) and has a history of invasion in South Africa (Henderson 2001); (ii) *Catharanthus roseus* (L.) Don is present in East Africa (BioNET-EAFRINET 2014a), invasive in Kenya and established in parts of Uganda (BioNET EAFRINET 2014b); (iii) *Cenchrus echinatus* L. occurs in Hawaii, USA (CABI 2014) and is considered weedy or invasive in most tropical and temperate countries (ISSG Global Invasive Species Database 2010); (iv) *Cosmos sulphureus* Cav. occurs in Texas and California, USA (Invasive Plant Atlas of the United States 2014), as well as in Tennessee, where it has not been placed on the invasive species list (Tennessee Exotic Plant Pest Council 2009); (v) *Cucumis anguria* L. is invasive in several Pacific islands and in Florida, USA, as well as in the Reunion Islands in the Indian Ocean (PIER 013); (vi) *Dactyloctenium aegyptium* (L.) Willd. is a species introduced to all continents, but only registered as invasive in Arizona and in Florida, USA (CABI 2014); (vii) *Echinochloa colona* (L.) Link has been introduced to all continents, but there is no history of invasion although it is widespread in some countries (CABI 2014); (viii) *Eragrostis cilianensis* (All.) Vignolo ex Janch. is found all over the USA and considered a weed in Arizona, but there is no concrete data on invasiveness (USGS 2014); (ix) *Eragrostis tenella* (L.) P.Beauv. ex Roem. and Schult. is established in New Zealand and invasive in Taiwan (MPI 2014; Taiwan Invasive Species Database 2014); (x) *Sorghum arundinaceum* (Desv.) Stapf is invasive on several islands in the Pacific Ocean (PIER 2010).

Of all the alien species registered in this study, only *Aristida adscensionis*, *Echinochloa colona*, *Eragrostis cilianensis*, *Momordica charantia* and *Sorghum arundinaceum* were present in natural areas in the islands surveyed. Due to its history of invasion elsewhere, *Sorghum arundinaceum* is recommended for inclusion in the I3N Brazil Invasive Alien Species Database managed by the Horus Institute, while the others require further monitoring. Species that have been widely introduced but have no history of invasion anywhere might establish as ruderal plants, not necessarily becoming invasive. Risk assessments of these species can help define the need to control them before they are actually able to invade. The other species in the study were present in limited distribution in agricultural or ruderal sites.

In a recent survey carried out in Caatinga areas in a project for the Integration of the São Francisco valley (PISF), 10 (32.3%) of the species registered in this survey were not reported by Fabricante and Siqueira-Filho (2012): *Catharanthus roseus*, *Commelina benghalensis* L., *Cosmos sulphureus*, *Cucumis anguria*, *Cyperus rotundus*, *Mangifera indica*, *Plantago major* L., *Psidium guajava*, *Sorghum arundinaceum* and *Terminalia catappa*. Of the alien plants registered in Caatinga by Almeida et al. (2014), 13.65% were present in the islands surveyed. However, three species reported here (*Catharanthus roseus*, *Cenchrus echinatus* L. and *Plantago major*) were not mentioned by these authors. This reinforces the importance of more studies on invasive alien species, and testifies to the need of intensifying efforts to build more consistent invasive species lists in natural areas in Brazil to support management and conservation efforts.

Some brief research on the List of Brazilian Flora Species showed that, among the genera registered on the islands, only *Cenchrus*, *Commelina*, *Cucumis*, *Cyperus*, *Digitaria*, *Eragrostis*, and *Psidium* have indigenous representatives in the Caatinga. According to Rejmánek (1996), there is evidence that alien species of genera not represented in the indigenous flora show a greater likelihood to become invasive. For instance, 22 of the alien species found on the islands (70.9%) belong to genera not represented in Caatinga.

The similarity was perceived due to the presence of a significant number of species that are widespread on the islands. The alien species present on at least four of the islands represent more than half (54.8%) of the species listed.

The species with widespread distribution on the islands also present extensive distribution in other parts of the country, except for *Enneapogon cenchroides* and *Prosopis pallida,* which are so far restricted to Caatinga habitat (Fabricante 2013a; 2013b). Apart from the recognized plasticity of these species, some of them are still part of governmental incentive programs, which has aided their spread in the region (propagule pressure; see Williamson and Fitter 1996; Parker and Reichard 1998). Among these species, *Prosopis* sp. stands out due to its forage, timber and firewood uses (Andrade *et al*. 2010), as well as *Ricinus communis*, used for biofuel (Tabile *et al*. 2009), and *Cenchrus ciliaris*, used for forage (Silva *et al*. 1984).

None of the variables analyzed (geographical distance between islands and island size) was significantly correlated with floristic similarity. Similarity turned out random to the set of data analyzed. There is, however, a need for other analyzes to allow a better comprehension of this issue.

As expected, the correlation results (area × species richness) show that the increase in alien species richness is proportional to island size in the case of the islands surveyed. The low richness of indigenous species and the poor conservation condition of the areas explain these results, as the increase in island area also represents an increase in degraded sites suitable for the establishment of alien species. Disturbance and low species richness are relevant factors that facilitate biological invasion (Williamson 1996).

The tendency observed in the stabilization of species richness in the larger islands is probably explained by the limited number and abundance of alien species in the Caatinga region. Many alien species registered in the Caatinga by Fabricante and Siqueira-Filho (2012) still present small populations in restricted distributions.

The species-area relationship presents a recognized and well-known standard in Ecology (Arrhenius 1921; MacArthur and Wilson 1963; Connor and McCoy 1979; Rosenzweig and Ziv 1999; Ney-Nifle and Mangel 2000; Turner and Tjorve 2005). Begon *et al.* (2006: 617) present a list of "z" values found in several studies in arbitrary continental areas, islands and oceanic islands. The values c and z estimated in this study indicate that an increase of 100% in island size corresponds to an increase of 92% in the number of alien species. The inverse relationship can also be considered: decrease of area × reduction of species richness. It is valid for this context, as alien species benefit from disturbed sites. In theory, reducing the area available for alien species through ecological restoration should lead to a decrease in invaded area. Field studies and adaptive management should be carried out to verify the outcome.

The results found in this study demonstrate that these fluvial islands should be managed for conservation, especially because of the presence of alien species capable of establishing or invading natural areas where they can impact resilience through competition or allelopathy, or the availability of water resources and other ecosystem services.

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