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Population structure and effects by the invasive exotic indian-almond over autochthonous vegetation from a sandbank

Estrutura populacional e efeitos causados pela exótica invasora chapéu-de-sol sobre a vegetação autóctone de uma Restinga

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Abstract

In the face of the severe effects caused by biological invasions, this study aimed at evaluating the population structure and impacts caused by the invasive exotic species *T. catappa* L. over native plant composition, richness and diversity. The study area is located at Atalaia Beach, Aracaju, Sergipe, Northeastern Brazil, and comprises sandbank sites. In order to evaluate the population structure of this invasive exotic species and its impacts on the biota, pertinent statistics were carried out. The results demonstrated that *T. catappa* shows density of 9,480 ind.ha^{-1}, being 8,430 ind.ha^{-1} for non-adults and 1,050 ind.ha^{-1} for adults, and self-regenerating population. The average species richness for invaded (I) areas and non-invaded (NI) were 6.1 ± 2.42 and 9.7 ± 2.45, respectively. The average abundance of individuals in NI was 1,057.6 ± 432.85 and 184.9 ± 126.66 for I. The diversity and the equability were 2.38 and 0.66 in I and 2.86 and 0.75 in NI, respectively. Thus, *T. catappa* causes significant impacts on species composition and richness, abundance and autochthonous diversity.

Keywords: biological invasion, ecology, environmental impacts.

Resumo

Diante dos graves efeitos causados pelas invasões biológicas, este trabalho teve como objetivo avaliar a estrutura populacional e os impactos causados pela espécie exótica invasora *T. catappa* L. sobre a composição, riqueza e diversidade de plantas nativas. A área de estudo está localizada na praia de Atalaia, Aracaju, Sergipe, Nordeste do Brasil, e compreende uma área de Restinga. Para avaliar a estrutura populacional dessa espécie exótica invasora e seus impactos na biota, foram realizadas análises estatísticas pertinentes. Os resultados do estudo demonstraram que *T. catappa* apresenta densidade de 9.480 ind.ha^{-1}, sendo 8.430 ind.ha^{-1} para regenerantes e 1.050 ind.ha^{-1} para adultos, e população autorregenerante. A riqueza média de espécies para áreas invadidas (I) e não invadidas (NI) foi de 6,1 ± 2,42 e 9,7 ± 2,45, respectivamente. A abundância média no NI foi de 1.057,6 ± 432,85 e 184,9 ± 126,66 para o I. A diversidade e a equabilidade foram 2,38 e 0,66 em I e 2,86 e 0,75 em NI, respectivamente. Assim, *T. catappa* causa impactos significativos na composição e riqueza de espécies, abundância e diversidade autóctone.

Palavras-chave: invasão biológica, ecologia, impactos ambientais.

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Introduction

As a priority area for biodiversity conservation (Hotspot) due to the huge amount of endemic species that it shelters and the devastation of its habitat (Myers, 1988; Myers *et al.,* 2000; Mittermeier *et al.,* 2011), the Atlantic Forest has about 7,000 endemic plant species and is composed by a set of ecosystems, among them sandbank (Stehmann *et al.,* 2009). From an ecological perspective, the term sandbank refers to vegetation communities under marine influence that occur in the sandy plains along the entire Brazilian coast (Waechter, 1985; CONAMA, 1996; Sugiyama, 1998; IBGE, 2012).

The sandbank is extremely important due to different functions it performs in the ecosystem, its vegetation is responsible for the substrate fixation, protecting it against erosive agent action, mostly wind, as well as supplying resources to the local fauna (Lamêgo, 1974; Assumpção and Nascimento, 2000; Scherer *et al.,* 2005). It has a great vegetation richness with nearly 2,591 species (Lista de Espécies da Flora do Brasil, 2017), however it has suffered intense environmental degradation caused by anthropogenic activities (Holzer *et al.,* 2004, Santos-Filho, 2009). In Brazil, the situation is not different, several studied areas showing certain degradation degree (Santos and Souza, 2010; Santos and Vilar; 2012, Melo *et al.,* 2013).

The continuous degradation condition that sandbank sites are exposed to, provides biota decrease and its structural components disorder (Holzer *et al.,* 2004) favoring processes of biological invasion (BI) (Almeida-Júnior *et al.,* 2007; Santos-Filho, 2009; Cantarelli *et al.,* 2012; Queiroz *et al.,* 2012), since disturbed environments, with low diversity and richness, tend to be more susceptible to them.

The BIs are considered the second greatest challenge to global biodiversity (IUCN, 2000), and also are responsible for significant changes in natural environments. Their impacts are diverse, such as changes in food chains, nutrient cycling and plant productivity (Ziller and Galvão, 2002). In addition, the indirect impacts caused by BIs, such as breaking mutualistic relations are often neglected, which lead to the loss in extent of total damage caused (Rogers *et al.,* 2017).

In Brazil, there are few studies on BI in sandbank, especially from *Terminalia catappa* L. (Sanches, 2009; Rojas *et al.,* 2012; Costa, 2013). The species commonly called beach-almond tree or indian-almond is a native tree from Malaysia that tolerates different edaphic and climatic conditions (Thomson and Evans, 2006), being considered invasive exotic in several parts of the world and Brazil (Sanches *et al.,* 2007; Leão *et al.,* 2011; I3n Brasil, 2017). There are two versions on how it entered in Brazil: The first one said to have been made through seeds brought along with sand used on Portuguese ship ballast during colonization period; the second version is that parts of these individuals were brought along with ballast water (Sanches *et al.,* 2007).

In the face of the severity effects caused by biological invasions and this subject information lack for Sergipe coast, this study aimed to evaluate the population structure and impacts caused by the invasive exotic *species T. catappa* over native plants composition, richness and diversity.

Materials and methods

Study area

The present study was carried out in Atalaia beach, Aracaju, Sergipe (10° 58'8.85 "S; 37 ° 2'7.38" W – average altitude of 0 m), which has approximately 40 ha and shows signs of anthropogenic disturbance, such as compacted soils, sewage and garbage from different sources (França and Rezende, 2010). Its vegetation is essentially composed by herbaceous and some arboreal species.

The Coastal region climate is humid with average temperature between 24ºC and 26ºC (UFS-SEPLAN, 1979). In Sergipe coast, there are two distinct climatic zones distinguished by temperature and humidity, *i.e.* humid Megatherm with 1600 mm of annual precipitation and dry semi-humid with 1,000-1,200 mm (SEPLAG, 2011). Its soils result from quaternary sediments, especially from the Holocene, where marine dystrophic quartz sands and podzolic soils predominate (Santos and Andrade, 1992).

Data sampling

The study sites were ten plots of 10 x 10 m at invaded sites (I) by *T. catappa* and another 10 plots with the same size at non-invaded sites (NI), but with similar biophysical characteristics of the first ones and as close as possible to them. An evaluation of the biophysical characteristics was performed on each plot at the time they were placed. Within each plot, all individuals with height ≥ 15 cm of all species regardless of habit were identified and accounted. In addition, aiming to analyze their population structure, it DNS (diameter at soil level) and total height from all *T. catappa* individuals were measured using pachymeter and tape measure. In addition, they all were classified in two ontogenetic stages: adults (those that had reproductive material or remnants of them at the time of sampling); regenerating (individuals with no characteristics from previous stage).

Structure analysis of *Terminalia catappa* population

The absolute density (AD) (Kent and Coker, 1992) and the spatial distribution pattern were calculated for each ontogenetic stage, as well as for the total population according to Morisita dispersion index (Morisita, 1962), and the significance assessed by chi-square test (X^2) (Young and Young, 1998). The invasive exotic individuals were also distributed in diameter and hypsometric frequency classes ranging from 1 cm to 1 m for DNS and height, respectively.

Analysis of the invasive exotic effect on autochthonous vegetation

Mann-Whitney tests helped to verify the existence of differences in median number of species and individuals between invaded and non-invaded environment plots (Zar, 1999) as well as boxplot diagrams (Cleveland, 1994) were used to demonstrate data behavior.

The diversity in each site was estimated by Shannon-Weaver index (H') (Magurran, 1998) just as the equability by Pielou index (E) (Pielou, 1977). Differences in diversity were verified by the t test ($p \leq 0.05$) (Lehmann, 1997).

In order to analyze floristic similarity between invaded and non-invaded sites, the Bray-Curtis coefficient was used (Brower and Zar, 1984). The cofenetic correlation coefficient adjusted the degree compilation analyzes (Sokal and Rohlf, 1981). To test the existence of differences on species abundance and composition between invaded and non-invaded sites, multivariate NMDS (non-metric multidimensional scaling) and ANOSIM (oneway) permutation tests were performed (10,000 permutations) (Clarke, 1993). The analyzes were performed using software MVSP 3.1 © (Kovach 2005) and Past 2.17c © (Hammer *et al.,* 2001).

Results

Structure analysis of *Terminalia catappa* population

The population density was 9,480 ind.ha^{-1}, being 8,430 ind.ha^{-1} for non-adults and 1,050 ind.ha^{-1} for adults. The Morisita dispersion index revealed that population (total) has an aggregated spatial distribution pattern (total – Id = 1.82, X2 = 787.72, p <0.0001, regenerating – Id = 2.09, X2 = 925.68, p <0.0001, and adults – Id = 1.51, X2 = 62.14, p <0.0001) as well as each ontogenetic stage.

DNS and average height were 0.51 ± 1.37 cm and 1.28 ± 3.76 m, respectively. For both parameters, a higher accumulation of individuals in the first frequency classes was observed, with a gradual decrease in the following classes, resulting on exponential curves in inverted "J" (Figure 1).

Analysis of the invasive exotic effect on autochthonous vegetation

In total, 13,349 individuals were sampled, of which 10,576 belonged to NI and 2,773 to I (Table 1). From the latter, 948 were from invasive exotic *T. catappa*.

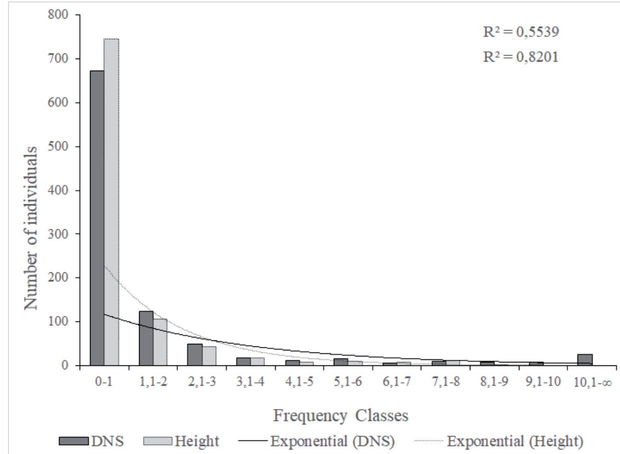

Figure 1. Distribution of abundance of individuals of *Terminalia catappa* L. in diameter and hypsometric frequency classes in a sample area of 1000 m.

The average species richness for I and NI were 6.1 ± 2.42 and 9.7 ± 2.45, respectively (Figure 2). The average abundance in NI was 1,057.6 ± 432.85 and 184.9 ± 126.66 for I (Figure 3). At I, the abundance values for *T. catappa* were 94.8 ± 91.1, with 84.3 ± 93.12 being regenerating and 10.5 ± 8.51 adults.

Based on results for Mann-Whitney test, there were significant differences between species medians for I and NI plots (median I = 5, median NI = 10, U = 13.5, Z = 2.76, p = 0, 0029) (Figure 2). Differences were also observed on median of individuals among environments, being this much higher value in NI (median I = 144.5, median NI = 988, U = 0, Z = 3.78, p <0.0001) (Figure 3).

The diversity of Shannon-Weaver (H') and the Pielou equability (E) were, respectively, 2.38 and 0.66 in I and 2.86 and 0.75 in NI. According to t test (t = 17.8, p <0.01) there are significant differences between the studied environments, being mathematically greater in I. The Bray-Curtis value was 0.107 and the ANOSIM permutation test revealed significant differences between the environments (p<0.0001). According to the dendrogram, two large groups are observed, one composed of plots from the invaded environment and another from the non-invaded environment (Figure 4). Thus, I plots were floristically more similar to each other than to NI plots and the opposite is proportionally true. NMDS showed a tendency to separate sample units I to NI plots (Figure 5), corroborating the observed results so far.

Discussion

The absolute density results of *T. catappa* are alarming when compared to other invasive alien species. In a study by Andrade *et al.* (2009), approaching *Prosopis ju-*

Table 1. List of species sampled in an area of sandbank, Orla de Atalaia, Aracaju, northeastern Brazil. I = invaded sites; NI = non-invaded sites. (*) Does not have a registration number.

Family	Species	I	NI	Record
Amaranthaceae	*Alternanthera tenella* Colla	1	0	*
	Alternanthera littoralis P. Beauv	0	8	37751
Araliaceae	*Hydrocotyle bonariensis* Lam.	4	668	37748
Asteraceae	*Bulbostylis* sp.	0	622	*
Capparaceae	*Cynophalla hastata* (Jacq.) J.Presl	30	0	*
	Cynophalla flexuosa (L.) J.Presl	24	12	*
Cleomaceae	*Hemiscola aculeata* (L.) Raf.	0	2	*
Combretaceae	*Terminalia catappa* L.	924	0	*
	Conocarpus erectus L.	1	4	37000
Commelinaceae	*Commelina erecta* L.	118	0	*
Convolvulaceae	*Ipomoea pes-caprae* (L.) R.Br.	21	79	*
Cucurbitaceae	*Momordica charantia* L.	0	14	*
Cyperaceae	*Cyperus rotundus* L.	133	168	*
	Cyperus ligularis L.	42	39	37749
	Cyperus sp.	199	168	*
	Cyperus sp.	31	324	*
Fabaceae	*Clitoria laurifolia* Poir.	78	970	37004
	Indgofera microcarpa Desv.	14	16	*
	Chamaecrista sp.	0	230	*
	Macroptilium lathyroedes (L.) Urb	3	26	*
	Crotolaria retusa L.	69	558	36999
	Canavalia rosea (Sw.) DC.	21	91	*
	Desmanthus virgatus (L.) Willd.	11	0	*
Family	**Species**	**I**	**NI**	**Record**
	Macroptilium panduratum (Mart. ex Benth.) Marechal & Baudet	28	37	37745
	Mimosa pudica L.	0	44	*
	Centrosema pascuorum Mart. ex Benth.	0	4	36994
Gentianaceae	*Schultesia doniana* Progel	0	8	36993
Malvaceae	*Sida urens* L.	0	22	*
Nyctaginaceae	*Boerhavia diffusa* L.	1	0	*
Onagraceae	*Ludwigia erecta* (L.) H.Hara	0	475	*
Passifloraceae	*Passiflora foetida* L.	23	171	37756
Phyllanthaceae	*Philantus niruri* L.	102	106	*
Plantaginaceae	*Stemodia maritima* L.	13	87	37760
	Bacopa monnieri (L.) Pennell	0	238	37002
Poaceae	*Apochloa lutzii* (Swallen) Zuloaga & Marrone	536	2441	37753
	Paspalum maritimum Trin	4	0	*
	Cynodon sp.	0	618	*
	Echinochloa colona (L.) Link	107	797	*
	Cynodon dactylon (L.) Pers.	150	0	*
	Cenchrus enchinatus L.	1	1	*
	Dactylotenium aegyptium (L.) Wild	0	10	*
	Sporobolus virginicus (L.) Kunth	0	631	37747
	Morphospecies 1	0	369	*
Pontederiaceae	*Eichornia* sp.	0	66	36996
Portulacaceae	*Portulaca halimoides* L.	1	29	*
Rubiaceae	*Morinda citrifolia* L.	19	0	*
Family	**Species**	**I**	**NI**	**Record**
	Staelia virgata (Link ex Roem. & Schult.) K.Schum.	6	57	*
	Leptoscela rueloides Hook.f.	4	0	37760
Solanaceae	*Solanum palinacathum* Dunal	5	0	*
	Physalis angulata L.	4	2	36997
Turneraceae	*Turnera pumilea* L.	13	125	*
Verbanaceae	*Stachytarpheta cayennensis* (Rich.) Vahl	0	1	37003
Indet. Family	Morphospecies 2	31	40	*
	Morphospecies 3	0	168	*
	Morphospecies 4	0	18	*
	Morphospecies 5	1	4	*
	Morphospecies 6	0	8	*

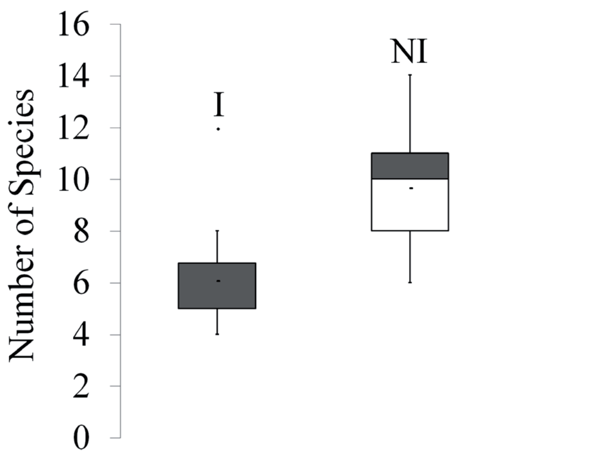

Figure 2. Species richness in an area of sandbank, Orla de Atalaia, Aracaju, northeastern Brazil. The Box represents 50% of the sample, where blank the first quartile and gray the third; the dash, the arithmetic mean; the diamonds and the asterisk, the extreme values. I: invaded e NI: non-invaded.

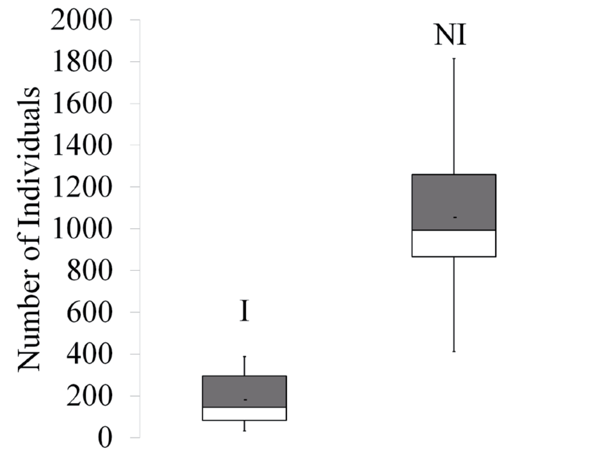

Figure 3. Abundance of individuals per species. The Box represents 50% of the sample, where blank the first quartile and gray the third; the dash, the arithmetic mean; the diamonds and the asterisk, the extreme values. I: invaded e NI: non-invaded.

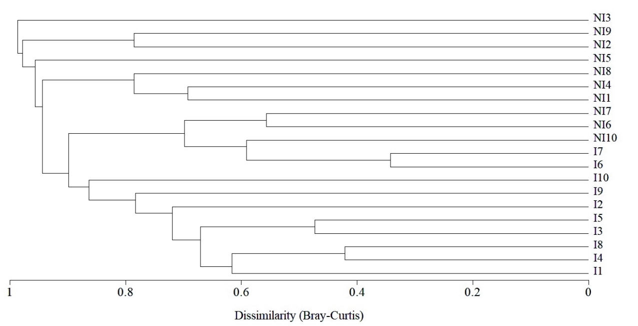

Figure 4. Dissimilarity dendrogram (Bray-Curtis) obtained by a presence/absence matrix, of the parcels sampled in an area of sandbank, Aracaju, northeastern Brazil. I1-I10: plots of the Invaded area (I); NI1-NI10: plots of the Non-Invaded area (NI).

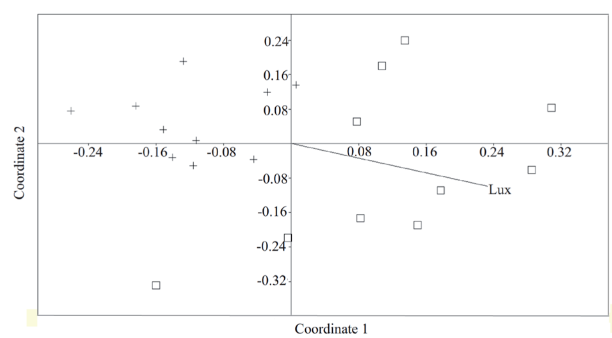

Figure 5. Analysis of non-metric multidimensional scaling (NMDS) by Bray-Curtis. Crosses = sample units of the invaded site by *Terminalia catappa*; squares = sample units of the non-invaded sites. Stress = 0.2.

liflora (Sw.) DC. in the Caatinga, the density obtained (2,072 ind.ha^{-1}) was much lower. Similar results were obtained in a study performed by Fabricante *et al.* (2012) with *Artocarpus heterophyllus* Lam in the Atlantic Forest (2,391 ind.ha^{-1}). When comparing the density of *T. catappa* with densities of each species occurring in NI, this number is also much higher. In relation to other sandbank areas in Brazil, *T. catappa* also exceeds the total density observed in these areas. In a study with arboreal component of sandbank site conducted by Scherer *et al.* (2005) in Rio Grande do Sul, this value (1,023 ind.ha^{-1}) was almost ten times lower than those obtained for *T. catappa* population in this study. Compared to the research by Montezuma and Araújo (2007) in a sandbank area in southeast Brazil, *T. catappa* density (9,480 ind.ha^{-1}) was almost three times from those authors (3,522 ind.av). These results demonstrate that *T. catappa* is a very aggressive exotic invasive and, in addition, its high density may indicate one of its dominion strategies.

The aggregate distribution is a typical pattern in plants, the dispersion of which is mainly done by animals (Janzen, 1976). Other factors may also explain the species aggregate distribution. According to Leite (2001), this pattern may be related to environmental conditions and resource availability. In addition, Legendre and Fortin (1989) state that there are several ways to produce energy, which results in an irregular distribution of resources explaining the aggregation of species. Thus, the distribution pattern of *T. catappa* can be explained in part through its form of dispersion, which may be, animals, especially bats, and marine currents (Nakanishi, 1988; Rosa, 2004). Furthermore, the species is adapted to several types of soil, but prefers sandy, well-drained and aerated soils (Thomson and Evans, 2006). Other factors still allow *T. catappa* to colonize different sites due to its phenotypic plasticity, easy and rapid germination and development (Sakai *et al.,* 2001; Rejmánek *et al.,* 2005).

The diameter and hypsometric distribution for *T. catappa* individuals in inverted "J" suggest that the population is self-regenerating (Costa and Mantovani, 1995; Nascimento *et al.,* 2004; Amaral *et al.,* 2009; Silva *et al.,* 2012). In practice, this indicates the need for intervention to inhibit the expansion of the biological invasion at the study area. The mechanical control through the uprooting of seedlings or chemical control by cutting at the base of the trunk, followed by application of herbicide, has been suggested as a method of management (I3n Brazil, 2017). In addition, trunk annealing using herbicide at the base of the ring may also be effective (I3n Brazil, 2017). For this, the annealing must be done at a height of 0.5 m from the soil level along the circumference of the stem, removing all the bark (I3n Brazil, 2017).

In relation to changes caused by *T. catappa* on biota, other studies presented similar results. At Caatinga, Pegado *et al.* (2006) demonstrated that invasion by *Prosopis juliflora* (Sw.) DC. caused flora homogenization, besides reducing native biodiversity. Ziller and Galvão (2002) evaluated the impacts caused by two pine species (*Pinus elliottii* Engelm and *Pinus taeda* L.) in Steppe vegetation in Paraná, where a decrease on native flora was observed. Studies done in Atlantic Forest of the Paraíba, Fabricante *et al.* (2012) demonstrated that *Artocarpus heterophyllus* Lam. modified floristic composition on invaded environments in relation to the natural one. Thus, it is clear that regardless the invasive exotic or biome/ecosystem studied, BIs may result in substantial perturbations on an environment.

In addition, *T. catappa* causes native biota decrease and consequent homogenization of the flora (Ziller, 2001). It is known that invasive exotic species have characteristics that increase their success when they invade environments, such as high breeding rates, dispersion, absence of natural enemies and better nutrient use performance as well as light use (Rejmánek *et al.,* 2005; Funk and Vitousek, 2007). The results point to a stable and self-regenerating population that is strongly adapted to the environment conditions.

Ecological characteristics of *T. catappa* may explain disparities in richness and abundance of individuals among the studied environments. Such differences may still be explained by the morphological adaptations of their fruits that allow their dispersion through water, as well as the easy germination of their seeds and fruit production after three years of development (Nakanishi, 1988; Thomson and Evans, 2006). All this makes *T. catappa* an excellent colonizer. This species is able to develop easily under different soil and climatic conditions, and it is resistant to wind and salt spray (Thomson and Evans, 2006). In this way, it manages to colonize and develop in most lands. Another important factor is the *T. catappa* leafy crown, resulting an environment with abiotic conditions different from those commonly found in sandbank, which produce negative biological responses in native species germination and development (Carnevale and Montagnini, 2002; Gandolfi *et al.,* 2007). For sandbank vegetation that is essentially composed by helophytes (Carrasco, 2003), this factor should be one of the main reasons for these results. In addition, *T. catappa* shows allelopathy and inhibits roots development of other plants, and the allelochemicals are found in the leaves and fruits, meaning that even their litter has toxins (Baratelli, 2006; Baratelli *et al.,* 2012).

These results are worrying, especially due to the exclusion of 17 species from invaded sites. These excluded species play very important ecological, economic and even social roles, such as dune fixation, providing food for local fauna, as well as resources for manufacturing, medicine and even for human consumption (Santos and Rosário, 1988; Gandolfo and Hanazaki, 2011; Miranda and Hanazaki, 2008; Santos *et al.,* 2009). Faced to this, it is possible for species to be extinct locally even before their existence become known in such environments.

Conclusion

It is possible to conclude that *T. catappa* has significant impacts on species composition and richness, abundance of individuals and autochthonous diversity. It leads to a decrease of about 80% in the abundance of individuals, in addition to the extinction of 16 species. Thus, it is urgent to take actions aimed to control *T. catappa* at the study site.

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