Environ Monit Assess (2017) 189: 234
DOI 10.1007/s10661-017-5908-4

Impact of collection on bark regeneration from *Stryphnodendron rotundifolium* Mart. in northeastern Brazil

Ivanilda Soares Feitosa · André Sobral · Júlio Marcelino Monteiro · Elcida Lima Araújo · Ulysses Paulino Albuquerque

Received: 15 October 2016 / Accepted: 21 March 2017 / Published online: 25 April 2017

Abstract The growing commercial demand for products with medicinal use has caused overexploitation of several plant species worldwide. To prevent the decline of these populations, the collection of these resources should be done in a sustainable way considering the time of its replacement in natural stocks. This study was designed to identify the relationship between different intensities of extraction of bark from the trunk of *Stryphnodendron rotundifolium* Mart. and its regeneration speed. For this, we selected two areas of Cerrado in the Northeast of Brazil, where a monitoring experiment with duration of 24 months was performed. This experiment consisted in simulating different extractive damage to assess the regeneration of bark. In each area, we selected 20 individuals, among which four treatments with five repetitions were implemented. The data showed that in both study areas, the trees regenerated their shells faster when subjected to higher collection intensities. However, this regeneration was not related to variations in rainfall in the environment.

Keywords Ethnobiology · Human ecology · Non-timber products · Medicinal plants · Bark harvesting · Brazilian savanna

I. S. Feitosa · A. Sobral · U. P. Albuquerque (✉)
Department of Biology, Laboratory of Ecology and Evolution of Social-ecological Systems, Federal Rural University of Pernambuco (UFRPE), Recife, PE CEP: 52171-900, Brazil
e-mail: upa677@hotmail.com

J. M. Monteiro
Department of Biology, Federal University of Piauí (UFPI), Floriano, PI CEP: 64800-000, Brazil

E. L. Araújo
Department of Biology, Laboratory of Plant Ecology of Natural Ecosystems, Federal Rural University of Pernambuco (UFRPE), Recife, PE CEP: 52171-900, Brazil

Introduction

Many plant species that have a high value for the trade of medicinal plants are threatened because of predatory extraction. In the Brazilian Cerrado, this activity is partly responsible for the extinction of several species (Zardo 2008). Bark is among the main products collected in this type of trade (Feitosa et al. 2014). Based on this demand, collecting these resources becomes excessive frequently, leading to the decline of these plants populations or even to death (Shahabuddin and Prasad 2004). This condition will depend on the amount of bark removed, the plant's ability to withstand the aggression, and regeneration of the removed structure (Peters 1994). Although some studies evaluated the collection of bark made in various local communities (Monteiro et al. 2005; Ferreira Júnior et al. 2012; Feitosa et al. 2014), little is known about the recommended amounts for a sustainable harvesting of the species and how long they take to regenerate the extracted resources (Baldauf and Santos 2014).

Among the many methods that are used to remove bark of these plants, we highlight the direct methods, in which extractors collect the bark of living parts of individuals, more precisely from the trunks (Filizola and Sampaio 2015). In order to perform a sustainable harvesting of this resource, not only the collection method must be evidenced, it is also necessary to determine a maximum limit to be removed (Delvaux et al. 2010). Cunningham and Mbenkum (1993), studying *Prunus africana* (Hook. F.) Kalkman, introduced a collection protocol for the species, in which extractors could only remove the bark in "ribbons" in opposite sides of the trunk, and collections above the first branch of the canopy were not allowed.

Using the correct method of collection favors the reconstitution of the extracted part. Normally, the plant can regenerate the explored area, yet each species has a different regeneration time for each tissue type. Plants that exhibit latex production in large quantities tend to regenerate faster, since the regeneration process starts with the production of this substance (see Baldauf and Santos 2014). Besides the production of latex, other factors also influence the time of bark regeneration, such as the availability of water (Biggs 1986). The bark regeneration in the rainy season tends to be higher than in the dry season, as well as trees occurring in open areas tend to regenerate faster than those occurring in enclosed areas (Filizola and Sampaio 2015). Although environmental conditions are considered factors that can influence the regeneration time, it is believed that the intensity of the damage caused in these individuals is the major responsible for the differences that occur in their regeneration responses (Cunningham 2001). Therefore, deeper and more extensive damages are associated with higher rates of regeneration (see Baldauf and Santos 2014).

This study used *Stryphnodendron rotundifolium* Mart. as a model for this. The stem bark of the species of this genus are explored in various regions of the Cerrado in Brazil (Borges and Felfili 2003; Filizola and Sampaio 2015). Its commercial value is related to the compound produced by its secondary metabolism, tannins (Meira et al. 2013). In humans, the presence of this substance provides some recognized biological activities and confirmed as anti-inflammatory (Sanches et al. 2005; Macedo et al. 2007). Individuals of the genus *Stryphnodendron* Mart. present shrub to tree sizes with twisted stem and branches presenting barks with rough surface. The branches are covered with little foliage presenting sparse and irregular canopy (Scalon 2016). *Stryphnodendron* is a genus that presents deciduous trees, losing their leaves during the months of June and July, returning to sprout in late August. The flowering of the species of this genus usually starts in September and fruiting occurs in November (Scalon 2016). In folk medicine. they are widely used against inflammatory processes (Souza et al. 2007) and wound healing (Feitosa et al. 2014). According to some studies, these properties are associated with species of this genus due to its high content of tannins (Ardisson et al. 2002). The study was conducted in a community located in the Northeastern semiarid region, and assessed the impact of the collection of bark on the rate of regeneration of *S. rotundifolium* Mart individuals. For this, it was hypothesized that individuals subjected to different intensities of collection, can differ in their rate of recovery from the damage. Thus, the aims of this study were (i) to compare the regeneration rate between the different damage intensities, (ii) to monitor the bark regeneration rates over 2 years between the different damage intensities, and (iii) to assess the influence of rain volume in the bark regeneration rate over the years.

Thus, this work brings important information about the process of regeneration of a greatly exploited species in the Northeast semi-arid region. This new information is essential for establishing less aggressive collection methods as well as for access to regeneration rates and whether they are influenced by different damage intensities and environmental conditions.

Material and methods

Study area

The study area is located in the Araripe National Forest–FLONA (07° 28′ 38″ S and 39° 36′ 33″ W), located in Chapada do Araripe in the state of Ceará, northeastern Brazil. The FLONA has an area of approximately 38,262.326 ha and covers the following vegetation types: Cerrado, Cerradão, rainforest, and Carrasco. Presents tabular relief with altitudes ranging from 870 to 974 m (Cavalcanti and Lopes 1994). The soils of the Chapada do Araripe are yellow and red-yellow latosol, which are very deep soil, well drained and of great physical condition (IBAMA 2005). The region is characterized by rainy tropical climate with temperatures ranging from 14 to 26 °C, with 5–7 dry months (Cavalcanti and Lopes 1994), and average annual rainfall of 1000 mm (Costa 1998). The region has been studied by our groups for at least 7 years with different approaches related to the uses of the landscape and sociobiodiversity resources (Sousa Júnior et al. 2013; Feitosa et al. 2014; Lozano et al. 2014; Campos et al. 2015; Reinaldo et al. 2015; Cavalcanti et al. 2015a, b; Crepaldi et al. 2015; Sousa Júnior et al. 2016; Campos et al. 2016; Silva Neto et al. 2016; Silva et al. 2014, 2015, 2016, 2017).

The Cerrado presents an area of 16,327.805 ha inside the FLONA, which represents 42.67% of the total area. The vegetation consists of dense vegetation areas to large glades with bare soils or under a sparse covering of grass; these dense vegetation areas present twisted trees of medium and small sizes, with sparse branches, rough and cracked barks, and a dense shrub understory (Lima 1983). Its individuals present rectilinear and/or tortuous and very branched trunk and can reach the average height of 11 m.

Experimental design and data sampling

Two areas of Cerrado in the Araripe National Forest were selected for the study. These two study areas were selected for data comparison, in order to decrease the chance the results are only an intrinsic response of the area in question.

Because of the intense collection of bark of this plant, and thus a high probability to affect the study, the areas for the selection of species needed to be of difficult access to the local population. Thus, two distant areas of the main extractive local community were selected. The selection of the areas followed the criteria of being of difficult access to extractors, with the reason that the experiment could not be affected by their presence. Once chosen the areas, in each area 20 individuals of *S. rotundifolium* Mart. were selected. These individuals had to be within the minimum criterion for inclusion of diameter, greater than or equal to 30 cm at 1.3 m height, which is the minimum viable measure for regeneration studies (see Delvaux et al. 2010). Individuals were monitored from June 2013 to May 2015 (24 months), assessing the time of regeneration of bark under the influence of collection intensity and rainfall.

To evaluate the time of regeneration of the bark, a simulation treatment of bark extraction was performed following the protocol proposed by Monteiro et al. (2011). In each area were conducted in the same period, four treatments with five repetitions (total of 20 individuals in each area), in which the bark were extracted in the following dimensions, I: 10 × 2 cm (20 cm^2); II: 6 × 5 cm (30cm^2); III: 8 × 5 cm (40 cm^2) and IV: 10 × 5 cm (50 cm^2) (Fig. 1). All extractions of bark were performed at 1.3 m height. To set up the experiment, the bark and inner bark of the individuals, that comprise the rhytidome and the secondary phloem, were removed. After collection of the bark, it has been drawn fixed points on both sides of the scar, in a horizontal direction, from which measurements of the regenerated barks were monthly taken (Delvaux et al. 2010). To obtain complete regeneration, the average value of the three measurements taken from both sides of the scar were calculated. The areas of the regenerated barks were obtained by the growing of the edges because the individuals selected in this study showed that standard of regeneration of the tissues, characteristic of individuals, undergoes deep damage. The measurements of monthly regeneration of the individuals were performed in millimeters using millimeter paper suitable for this function. Subsequently, the data in millimeters were converted into centimeters for the analysis.

Data analysis

The Kruskal-Wallis test was applied to test for differences between the monthly amounts of bark regeneration on different damage intensities (treatments) over the 2 years of monitoring. To assess whether there is a correlation between the monthly bark regeneration and monthly rainfall, we used the Spearman correlation. The rainfall data were obtained from the data sheet provided by FUNCEME/CE (Fundação Cearense de Metereologia e Recursos hídricos (FUNCEME) 2017). For all statistical analysis the software Bioestat 5.0. (Ayres et al. 2007) was used.

Results

Table 1 presents the analysis of the descriptive statistics of each of the treatments in the two studied areas. In area 1, the first treatment, 20cm^2, did not differ from any other. The second treatment (T2 30 cm^2), differed significantly from treatments 40 and 50 cm^2 ($p < 0.05$; H 23.46) (Table 2). The treatments that presented the faster bark regeneration compared with the others were 40 and 50 cm^2, presenting no differences between each other. (Table 2). While, in area 2, the second treatment (30 cm^2) differed significantly from the third (40cm^2) ($p < 0.05$). The third treatment (40 cm^2) differed

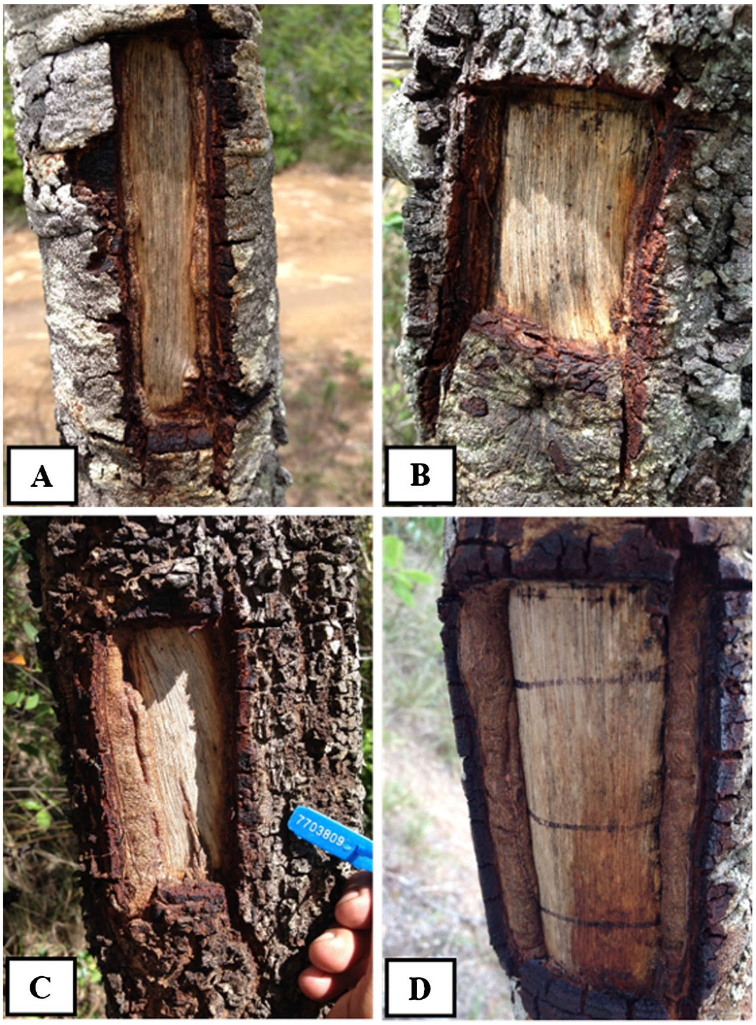

Fig. 1 Details of *Stryphnodendron rotundifolium* Mart. individuals, simulating extractivism damages of stem bark, selected in the two areas of Cerrado, in the Araripe National Forest, Ceará, Brazil. **a** Treatment I (10 × 2) 20 cm^2 **b** Treatment II (6 × 5) 30 cm^2, **c** Treatment III (8 × 5) 40 cm^2, **d** Treatment IV (10 × 5) 50 cm^2

significantly from the fourth (50cm^2). The damage classes that presented the most remarkable results were 30 and 50cm^2 ($p < 0.05$; H 19.60) (Table 2).

In area 1, regeneration rates of classes 40 and 50 cm^2 were the highest among the four treatments (Fig. 2a), which showed the monthly average values of 2.66 and 1.99 cm^2/month, respectively. The individuals present in these two classes also showed the highest growth of the edge of the bark at the end of the 24 months of monitoring (Fig. 2b). The individuals present in these classes were the first to begin the process of regeneration after the damage (2 months), while those from classes 20 and 30 cm^2 took 3 months to present the first signs of tissue regeneration. At the end of the experiment, the classes 40 and 50 cm^2 were also those that presented the highest amount of regenerated bark (6.7 and 4.5 cm^2), respectively. Twelve months after the beginning of the experiment (May 2014), the individuals of these two classes already presented more than half of the regenerated area and had doubled the growth of edge in the second year of monitoring.

At the end of the first year of monitoring, we observed the presence of six dead individuals, one (20 cm^2), one (30 cm^2), three (40 cm^2), and one (50 cm^2). All individuals' deaths were observed in March. At the end of the experiment, it was observed that none of the 20 individuals studied in area 1 presented 100% of regenerated bark.

In area 2, the treatment classes that presented higher regenerating rates were 30 and 50 cm^2 (Fig. 3a). Unlike the area 1, individuals from 40 cm^2 class did not have the highest bark regeneration rates. Individuals from class 30 cm^2 presented monthly regeneration of 1.97 cm^2/month, followed by 50 cm^2 class with

Table 1 Descriptive statistics of the bark regeneration values of *Stryphnodendron rotundifolium* Mart. in each of the treatments simulating extractivism damages (T1 20 cm^2, T2 30 cm^2, T3 40 cm^2, T4 50 cm^2) in two Cerrado areas in the Araripe National Forest, Ceara, Brazil. Area 1-Malhada Bonita; Area 2-Alojamento

	Treatment	Mean	Standard error	Coefficient of variation	Median	Variance
Area 1	T1	13.10	1.69	63.53%	14.29	69.28
	T2	6.59	0.71	53.01%	7.63	12.20
	T3	16.87	1.72	50.09%	20.43	184.29
	T4	19.40	2.28	57.66%	20.03	125.18
Area 2	T1	17.14	2.01	57.68%	17.96	97.86
	T2	24.12	2.77	56.28%	25.52	184.29
	T3	9.48	1.02	52.93%	9.46	25.20
	T4	23.95	3.03	62.11%	23.19	221.27

2.39 cm^2/month. The individuals present in these classes at the end of the experiment also showed the highest amount of regenerated bark (4.4 and 6.5 cm^2), respectively, obtaining the highest edge growth (Fig. 3b). Except for the individuals of 50 cm^2 class, all other initiated the regeneration of the tissues immediately in the second month after the damage. Twelve months after the beginning of the experiment (May 2014), individuals in class 30 cm^2 already presented half of the regenerated area, while the Class 50 cm^2 already had more than half of the regenerated final bark. In the second year of observation, there was the presence of one dead individual in class 50 cm^2. At the end of the experiment, it was observed that none of the 20 individuals studied in area, two showed 100% of the regenerated bark, as well as individuals in the area 1.

When the bark regeneration rate and the monthly rainfall over the 24 months were included in the analysis, there was no significant correlation between the variables in the area 1: 20 cm^2 (rs = 0.03, p = 0.87), 30 cm^2 (rs = 0.20, p = 0.33), 40 cm^2 (rs = 0.10, p = 0.63), and 50 cm^2 (rs = 0.07, p = 0.73); in the area 2: 20 cm^2 (rs = 0.10, p = 0.62), 30 cm^2 (rs = 0.90, p = 0.67), 40 cm^2 (rs = −0.21, p = 0.3), and 50 cm^2 (rs = 0.09, p = 0.66).

Thus, in the area 1, regeneration rates occurred independent of the rain volume in the month in question. This pattern was observed in all treatments. March of the first year of monitoring presented the largest volume of rain. However, in that month, individuals had regeneration rates similar to those months that presented no even a millimeter of rain (Fig. 4). In some cases, the regeneration rate within a class was even higher in the month that had zero rainfall, as it is the case of class 50 cm^2.

In area 2, as well as in area 1, the rates of regeneration are not related to the volume of precipitation. In the month with the highest rainfall (467.9 mm), the four treatments presented very low levels of regenerated bark. On the other hand, three of the four treatments had one of its biggest regeneration values in the month that had only 14 mm of rainfall (Fig. 4).

Table 2 Results of the analysis of variance of bark regeneration of *Stryphnodendron rotundifolium* Mart. in different treatments simulating extractivism damages (T1 20 cm^2, T230 cm^2, T340 cm^2, T450 cm^2) in two Cerrado areas in the Araripe National Forest, Ceara, Brazil. Area 1-Malhada Bonita; Area 2- Alojamento

	Area 1	Area 2
Kruskal Wallis test values	H 23.46 $p < 0.0001$	H 19.60 $p < 0.0002$
T1 × T2	$p > 0.05$	$p > 0.05$
T1 × T3	$p > 0.05$	$p > 0.05$
T1 × T4	$p > 0.05$	$p > 0.05$
T2 × T3	$p < 0.05$	$p < 0.05$
T2 × T4	$p < 0.05$	$p > 0.05$
T3 × T4	$p > 0.05$	$p < 0.05$

Discussion

Bark regeneration of *S. rotundifolium* Mart.

Our data indicate that trees regenerate faster their shells when the damage is more intense. The pattern of regeneration of the bark of *S. rotundifolium* occurs from the edges, which according to Baldauf and Santos (2014) is related to a pattern of more extensive and deep damage. In this type of pattern, there is the regeneration of living tissues throughout the edge of the extracted region, unlike other patterns in which regeneration starts in the center or along it (Mariot et al. 2014). This probably happens because in deeper damage, there is no traces of

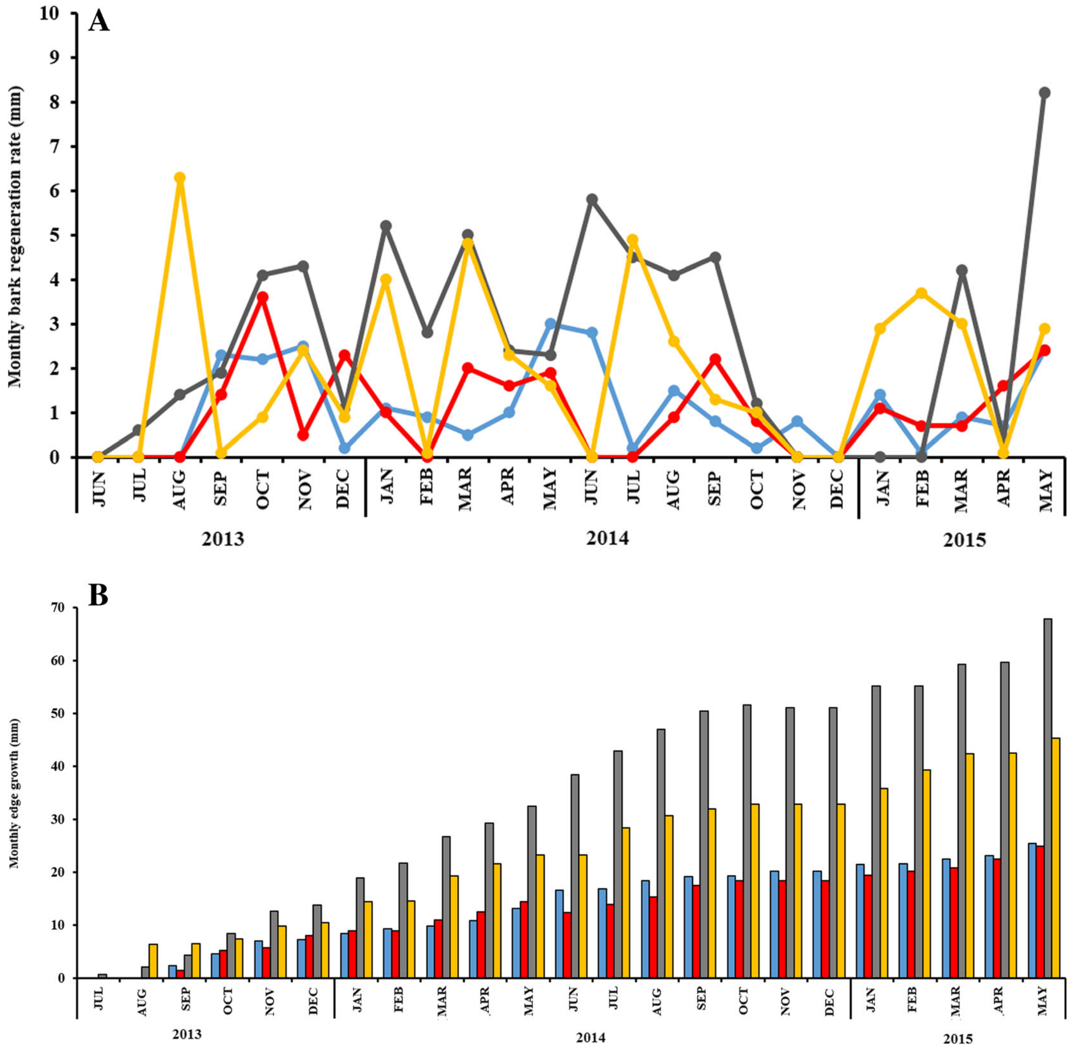

Fig. 2 **a** Monthly total bark regeneration rates. **b** Monthly edge growth of *Stryphnodendron rotundifolium* Mart. Individuals on area 1. **I** (,):10 × 2 cm (20 cm^2), **II** (,): 6 × 5 cm (30cm^2), **III** (,): 8 × 5 cm (40 cm^2), **IV** (,): 10 × 5 cm (50 cm^2)

living tissue for its central regeneration. Based on this pattern, it is believed that the growth of the edge was higher in individuals present in the last classes in response to higher damage intensity, since these individuals have much larger areas to be recovered. These results are in disagreement with the results obtained by Baldauf and Santos (2014), which showed no difference between the different bark removal levels in individuals of *Himatantus drasticus* (Mart.) Plumel located in the same area of the present study. This disagreement is probably due to the types of tissues extracted in both studies. Although different intensities of collection were performed in *H. drasticus*, all were made externally, with the exclusive removal of the rhytidome in order to simulate the extraction performed by the extractivists of the region. The authors argue that the removal of this outer layer does not prevent the interruption of the nutrient flow. In the case of *S. rotundifolium* were extracted the rhytidome, bark (including phloem) and the cambium (remaining only the xylem), are also simulating the collection practices in the same region. Unlike *H. drasticus*, the extraction in individuals of *S. rotundifolium* reaches inner layers, which affects their functioning since the phloematic tissues are removed. This difference in collection practices of both species is due to the type of associated medical use. The bark of *S. rotundifolium* is used for making tea and dye, while in *H. drasticus,* the product used by the extractivists is the latex, which is obtained through removal of the rhytidome.

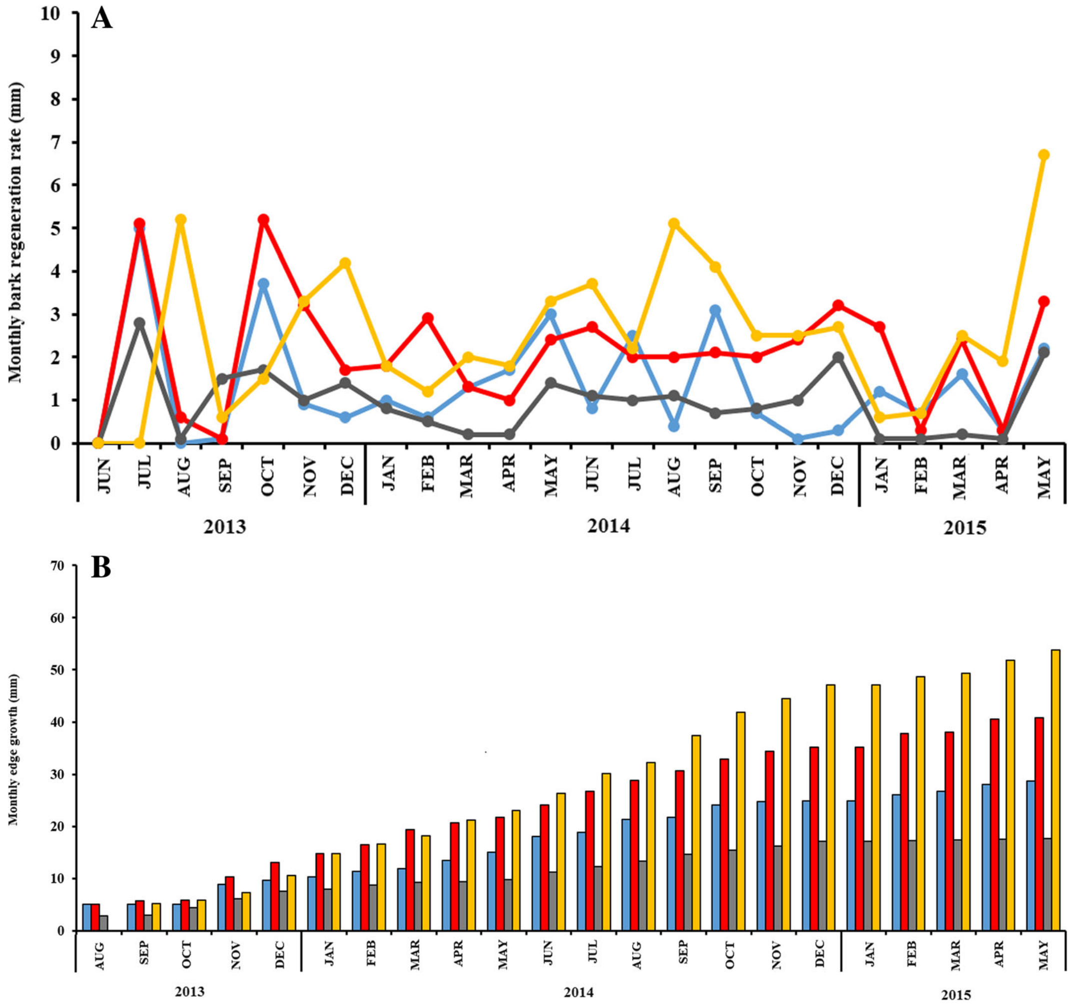

Fig. 3 **a** Monthly total bark regeneration rates. **b** Monthly edge growth of *Stryphnodendron rotundifolium* Mart. Individuals on area 2. **I** (blue line, blue box):10 × 2 cm (20 cm²), **II** (red line, red box): 6 × 5 cm (30cm²), **III** (grey line, grey box): 8 × 5 cm (40 cm²), **IV** (yellow line, yellow box): 10 × 5 cm (50 cm²)

Other species also respond by regenerating their tissues faster when they are subjected to higher intensities of collection. *Myracrodruon urundeuva* Allemão is a medicinal species relatively resilient to their bark removal, recovering rapidly after the damage. In a study by Monteiro et al. (2011), it was observed differences in bark regeneration rates, observing that the major classes of damage were those that had better recovery rates of its individuals.

The absence of bark in individuals can leave them vulnerable to the actions of microorganisms, since its function is to protect individuals against such pathogens (Filizola and Sampaio 2015). Thus, it is believed that the high regeneration of bark when subjected to greater damage intensities is an urgent response to regenerate their tissues in order to protect them. In the bark, predominantly, there is the production of tannins that together are responsible for protecting the trees against the actions of microorganisms, already mentioned (Meira et al. 2013).

Although it was observed that the classes with higher damage intensities had a higher rate of regeneration, in area 2, a class with lower collection intensity had higher regeneration values. This is due to the individual variations within this class, and this fact caused the general values of the class to rise.

Throughout the experiment, it was observed the death of some individuals. There are several species with a great capacity to resist against damage. A study performed with *Stryphnodendron adstrigens*, observed the death of several individuals after the removal of the

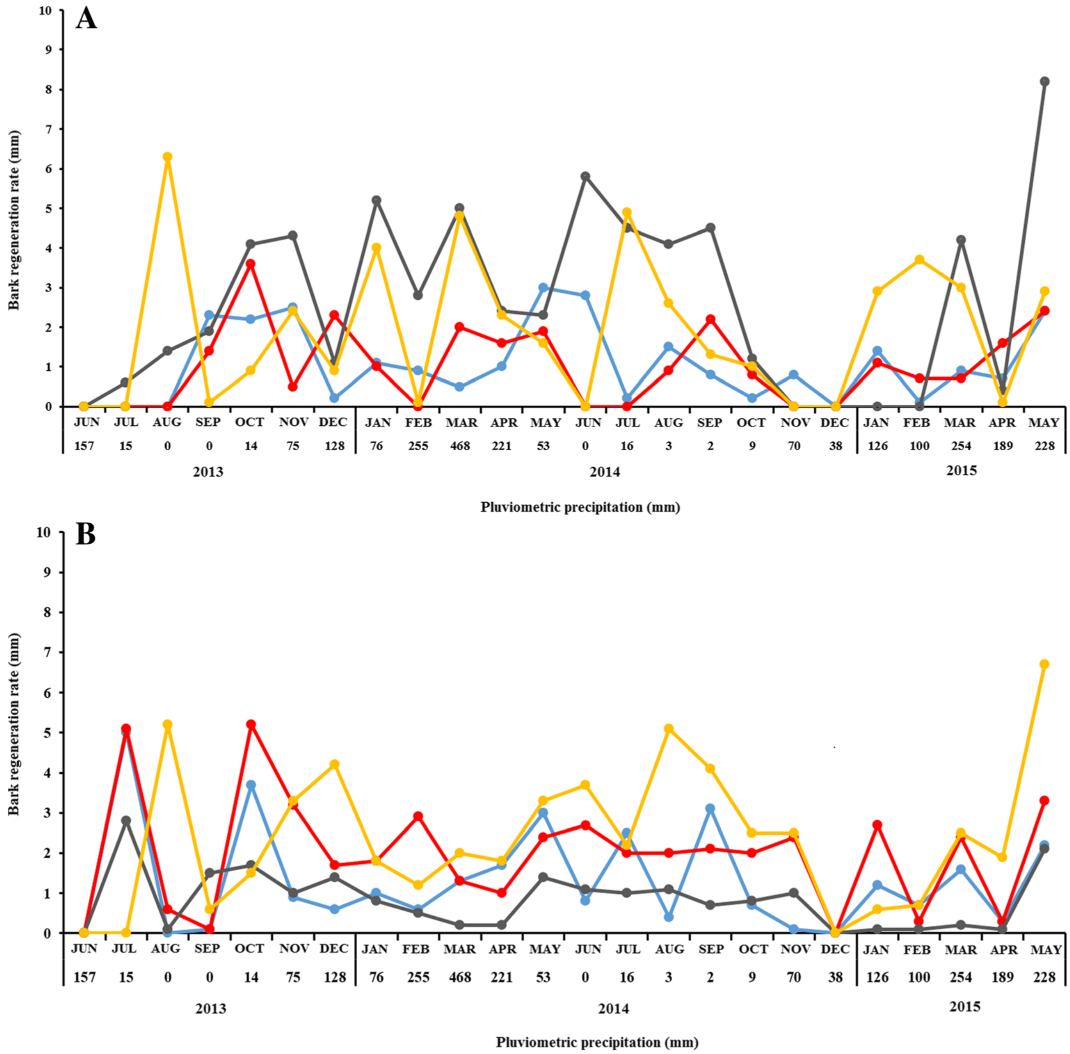

Fig. 4 **a** Monthly bark regeneration rates of *Stryphnodendron rotundifolium* Mart. and its relation with the monthly precipitation in area 1 (**a**) and in area 2 (**b**). **I (—◆—):**10 × 2 cm (20 cm^2), **II (—◆—):** 6 × 5 cm (30cm^2), **III (—◆—):** 8 × 5 cm (40 cm^2), **IV (—◆—):** 10 × 5 cm (50 cm^2)

bark (Borges and Felfili 2003). In contrast, there are species that exhibit high resistance, such as the species already mentioned above *M. urundeuva* Allemao, which presents high tissue regeneration rates, having 100% of the bark regenerated in less than 2 years (see Monteiro et al. 2011). Another species that has a great recovery after the damage is *Prunus africana*, which because of this characteristic was studied by Cunningham and Mbenkum (1993), and from that study, it was designed a sustainable harvesting plan for extractors in the African Region. This difference between species and even between individuals according to Schumann et al. (2010), is related to the tolerance of each to the collection vary according to their different stories of life and the environmental conditions that they experience. That is, within a plant population, individuals may respond differently to damage, by rapidly regenerating or by not resisting the damage.

Patterns of bark regeneration and precipitation

When assessing the bark regeneration between the four treatments during the 24 months, it was observed that individuals present in damage classes with higher intensities have also been the first to initiate their tissues regeneration process. They were also those that at the end of the experiment had higher regenerated bark values. Nevertheless, none of the individuals present in the four treatments had 100% of regenerated bark. These data are contrary to those reported by Monteiro et al. (2011), who found that most of the *M. urundeuva* individuals in all classes, 6 months later presented more than half of regenerated bark. It is believed that this difference in regeneration time between species is due to the ability of each to resist against different levels of damage and recover their tissues. According to Filizola and Sampaio (2015), some species regenerate faster than others, such as the aroeira-do-sertão (*M. urundeuva* Allemao) that after 2 years has all of regenerated bark, when it is removed a small area of 5 cm wide and 10 cm long. Conversely, the janaguba (*H. drasticus*) need three more years for the regeneration of its damaged tissues, since in this period less than half of the bark of individuals are regenerated. Baldauf and Santos (2014), found that of the 120 individuals of *H. drasticus* damaged, none had fully regenerated its tissue after a period of 3 years.

The delay of individuals to react to the damage and the form of tissue growth may be a result of the patterns of collection in not manipulated situations. In most cases observed in the field, the extractivists collect the bark along with the inner bark where the nutrients transport tissues of the plant are located. Some species, such as *S. rotundifolium*, initiate their regeneration by forming calluses on the surface of the edges of the damaged area. Others regenerate over the entire laminar surface (Delvaux et al. 2013), such as *H. drasticus*. According to Baldauf and Santos (2014), this type of regeneration is the common pattern. In this type of growing, living tissues such as the vascular cambium, the phloem, grow from the edge towards the center.

Unlike the intensity of the damage, it was observed that precipitation was not related to the regeneration rate. A similar result was obtained by Monteiro et al. (2011), who also found no seasonal differences in bark regeneration of *M. urundeuva*. These results were contrary to those found in the literature, which indicate that rainfall along with the temperature are factors that influence on the bark regeneration (Biggs 1986; Baldauf and Santos 2014). Baldauf and Santos (2014) tested the effect of seasonality on the regenerative capacity of *H. drasticus* and observed that the rainy season favors the regeneration of bark of this species. *H. drasticus* presents a pattern of regeneration in which the bark regrows throughout the affected area, differently from the pattern observed in the species of the present study, which is characterized by the regeneration of the edges of the extracted part. Thus, it is believed that the fact that the seasonality is not related to the regeneration of individuals of *S. rotundifolium* is related to their pattern of regeneration, because according to Baldauf and Santos (2014), the rainy season seems to favor the species with laminar regeneration patterns, while the dry season favors the species with growth through their edges. Therefore, precipitation does not appear to be a limiting factor in regeneration of bark of *S. rotundifolium* individuals.

Suggestions for collection and sustainable use of the species *S. rotundifolium* Mart.

According to the data, *S. rotundifolium* is moderately tolerant to bark collection. Although some treatments have presented different rates of regeneration, what is observed is that at the end of the 24 months of monitoring, none of the individuals in the two areas among the four treatments had 100% of their bark regenerated. This indicates that they require a longer time without collecting in order to have their bark collected again. Since the classes that had higher regeneration rates were those with higher damage intensities, it is important to test this variable "intensity" again in the future.

Like other species of the Cerrado, *S. rotundifolium* has a rough bark, with the presence of rhytidome in adult individuals that protects them against insect attack, mechanical shocks, and even against the fire which is common in the Cerrado (Martins and Nakagawa 2008). Thus, the extraction of the bark influence not only in the sap transportation processes, but leaves it vulnerable to various types of external agents. Due to the importance of this resource, especially for the function of protection against fire, it is important to suggest some measures for better collection and sustainability of the practice. Cunningham and Mbenkum (1993) observed that the species *Prunus africana* (Hook f.) Kalkman presented a great ability to resist against damage. Therefore, they proposed a sustainable collection, in which the extractors were allowed to remove bark ribbons on opposite sides of the plant always below the branches. In the case of the target species of this study, although it was not our aim to analyze the interference of flowering in the regeneration of bark collection, it is recommended not to remove bark of upper branches, in which the flowers will be arranged, since individuals can allocate resources for flowering instead of regeneration of the bark.

It is concluded that individuals of *S. rotundifolium* in this study responded faster to larger damages. That is, the bark regeneration rate was higher as the damage also increased, especially for the of 40 and 50 cm^2 classes. The bark regeneration pattern present in individuals is associated with a given type of damage. Rainfall does not favor the regeneration of *S. rotundifolium* bark; this is related to its regenerative pattern since small rain volumes favor individuals with patterns of growth by the edge. Considering the dimensions of bark extracted by the extractivists are generally much higher than those found here; no collection is recommended for a period of at least 36 months in individuals that have had bark extracted, so that they can fully recover from the damage. The findings of this study showed that species with a pattern of regeneration from the edges appear not to be influenced by rainfall and that is important for semi-arid species. Based on the information obtained, a management plan for *Stryphnodendron rotundifolium* Mart can be elaborated.

Acknowledgements We thank all the people from the Horizonte community who contributed to this study; the colleagues of the Laboratory of Ecology and Evolution of Social-Ecological Systems (LEA) that contributed to the collection of data; CAPES for the scholarship Granted to IF, and CNPq for the research productivity scholarship Granted to UPA and ELA. We also thank the Science and Technology Funding Agency of the State of Pernambuco (Fundação de Amparo Ciência e Tecnologia do Estado de Pernambuco–FACEPE) for the financial support (APQ-1264-2.05/10).

References

Ardisson, L., Godoy, J. S., Ferreira, L. A. M., Stehmann, J. R., & Brandão, M. G. L. (2002). Preparação e caracterização de extratos glicólicos enriquecidos em taninos a partir das cascas de *Stryphondendron adstringens* (Mart.) Coville (Barbatimão). *Revista Brasileira de Farmacognosia, 12*(1), 27–34.

Ayres, M., Ayres Júnior, M., Ayres, D. L., & Santos, A. A. S. (2007). *BioEstat 5.0: Aplicações estatísticas nas áreas das ciências biológicas e médicas*. Belém: Sociedade Civil Mamirauá.

Baldauf, C., & Santos, F. A. M. (2014). The effect of management systems and ecosystem types on bark regeneration in *Himatanthus drasticus* (Apocynaceae): recommendations for sustainable harvesting. *Environmental Monitoring Assessment, 186*, 349–359.

Biggs, A. R. (1986). Phellogen regeneration in injured peach tree Bark. *Annals of Botany, 57*, 463–470.

Borges, H. C., & Felfili, J. M. (2003). Avaliação dos níveis de extrativismo da casca de barbatimão [*Stryphnodendron adstringens* (Mart.) Coville] no Distrito Federal, Brasil. *Revista Árvore, 27*(5), 735–745.

Campos, L. Z. O., Albuquerque, U. P., Peroni, N., & Araújo, E. L. (2015). Do socioeconomic characteristics explain the knowledge and use of native food plants in semiarid environments in Northeastern Brazil? *Journal of Arid Environments, 115*, 53–61.

Campos, L. Z. O., Nascimento, A., Albuquerque, U., & Araújo, E. L. (2016). Criteria for native food plant collection in Northeastern Brazil. *Human Ecology*. doi:10.1007/s10745-016-9863-4.

Cavalcanti, A. C., & Lopes, O. F. (1994). *Condições edafo-climáticas da chapada do Araripe e viabilidade de produção sustentável de culturas*. Brasília: EMBRAPA-SPI 42p.

Cavalcanti, M. C. B. T., Ramos, M. A., Araújo, E. L., & Albuquerque, U. P. (2015a). Implications from the use of non-timber Forest products on the consumption of wood as a fuel source in Human-dominated semiarid landscapes. *Environmental Management, 56*, 389–401.

Cavalcanti, M. C. B. T., Campos, L. Z. O., Sousa, R. S., & Albuquerque, U. P. (2015b). Pequi (*Caryocar coriaceum* Wittm., Caryocaraceae) oil production: A strong economically influenced tradition in the Araripe region, northeastern Brazil. *Ethnobotany Research and Applications, 14*, 437–452.

Costa, V.D. (1998). Conhecendo o Araripe: recursos hídricos. In *Projeto de proteção ambiental e desenvolvimento sustentável da APA-Chapada do Araripe e da Biorregião do Araripe* (pp. 618–715). Crato: MMA/FUNDETEC; 3

Crepaldi, C. G., Campos, J. L. A., Albuquerque, U. P., & Sales, M. F. (2015). Richness and ethnobotany of the family Euphorbiaceae in a tropical semiarid landscape of Northeastern Brazil. *South African Journal of Botany, 102*, 157–165.

Cunningham, A. (2001). *Applied ethnobotany. People and plants conservation manual*. London: Earthscan Publications Ltd.

Cunningham, A. B., & Mbenkum, F. T. (1993). Sustainability of harvesting *Prunus africana* bark in Cameroon. Paris, Unesco. *People and plants working paper, 1*, 1–30.

Delvaux, C., Sinsin, B., & Damme, P. V. (2010). Impact of season, stem diameter and intensity of debarking on survival and bark re-growth pattern of medicinal tree species, Benin, West, Africa. *Biological Conservation, 143*, 2664–2671.

Delvaux, C., Sinsin, B., Damme, P. V., & Beeckman, H. (2013). Size of conducting phloem: The "key" factor recovery of 12 tropical medicinal tree species. *Flora, 208*, 111–117.

Feitosa, I. S., Albuquerque, U. P., & Monteiro, J. M. M. (2014). Knowledge and extractivism of *Stryphnodendron rotundifolium* Mart. In a local community of the Brazilian savanna, Northeastern Brazil. *Journal of Ethnobiology and Ethnomedicine, 10*, 64.

Ferreira Júnior, W. S., Siqueira, C. F. Q., & Albuquerque, U. P. (2012). Plant stem bark extractivism in the northeast semi-arid region of Brazil: a new aport to utilitarian redundancy model. *Evidence-based Complementary and Alternative Medicine*. doi:10.1155/2012/543207.

Filizola, B. C., & Sampaio, M. B. (2015). *Boas Práticas de Manejo para o Extrativismo Sustentável de Cascas*. Brasília: Instituto, Sociedade, População e Natureza 108 p.

Fundação Cearense de Metereologia e Recursos hídricos (FUNCEME) 2017. Disponível em <http://www.funceme.br/. Accessed in 8 Oct 2016.

Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA) (2005). Plano de Manejo da Floresta Nacional do Araripe. 312p. Crato.

Lima, M. F. (1983). *Mapeamento e demarcação da floresta nacional do Araripe*. Fortaleza: IBDF/FCPC/UFC 30p.

Lozano, A., Araújo, E. L., Medeiros, M. F., & Albuquerque, U. P. (2014). The apparency hypothesis applied to a local pharmacopoeia in the Brazilian northeast. *Journal of Ethnobiology and Ethnomedicine, 10*, 2.

Macedo, F. M., Martins, G. T., Rodrigues, C. G., & Oliveira, D. (2007). A Triagem fitoquímica do Barbatimão [*Stryphnodendron adstrigens* (Mart) Coville]. *Revista Brasileira de Biociências, 5*, 1166–1168.

Mariot, A., Mantovani, A., Reis, M.S. (2014). Bark harvesting systems of Drimys brasiliensis Miers in the Brazilian Atlantic Rainforest. *Anais da Academia Brasileira de Ciências, 86*(3), 1315–1326.

Martins, C. C., & Nakagawa, J. (2008). Germinação de sementes de *Stryphnodendron adstrigens* (Mart.) Coville de diferentes origens submetidas a tratamentos para superação de dormência. *Revista Árvore, 32*(6), 1059–1067.

Meira, M. R., Cabacinha, C. D., Figueiredo, L. S., & Martins, E. R. (2013). Barbatimão: Ecologia, Produção de Tanino e Potencial Sócio Econômico na Região Norte Mineira. *Enciclopédia Biosfera, Centro de Científico Conhecer, 9*(16), 466–494.

Monteiro, J. M., Albuquerque, U. P., Araújo, E. L., & Amorim, E. L. C. (2005). Taninos: Uma abordagem da química à ecologia. *Quimica Nova, 28*(5), 892–896.

Monteiro, J. M., Lins Neto, E. M. F., Araújo, E. L., Amorim, L. C., & Albuquerque, U. P. (2011). Bark regeneration and tannin content in *Myracrodruon urundeuva* Allemão after simulation of extractive damages-implications to management. *Environmental Monitoring Assessment, 180*, 31–39.

Peters, C. M. (1994). *Sustainable harvest of non-timber plant resources in tropical moist forest: an ecological primer*. Washington, DC: Biodiversity Support Program.

Reinaldo, R. C. P. S., Santiago, A. C. P., Medeiros, P. M., & Albuquerque, U. P. (2015). Do ferns and lycophytes function as medicinal plants? A study of their low representation in traditional pharmacopoeias. *Journal of Ethnopharmacology, 175*, 39–47.

Sanches, A. C. C., Lopes, G. C., Nakamura, C. V., Dias Filho, B. P., & Mello, J. C. P. (2005). Antioxidant antifungal activies of extracts and condensed tannins from *Stryphnondendron obovatum* Benth. *Revista Brasileira de Ciências Farmacêuticas, 41*(1), 101–107.

Scalon, V. R. (2016). *Stryphnodendron in* lista de espécies da Flora do Brasil. Jardim botânico do Rio de Janeiro. (http://floradobrasil.jbrj.gov.br/2010/FB083734). Accessed in 8 Nov 2016.

Schumann, K. Wittig, R. Thiombiano, A., Becker, U., Hahn, K. (2010) Impact of land-use type and bark-and leaf-harvesting on population structure and fruit production of the baobab tree (*Adansonia digitata L.*) in a semi-arid savana, West Africa. *Forest Ecology and Management, 260*, 2035–2044.

Shahabuddin, G., & Prasad, S. (2004). Assessing ecological sustainability of non-timber forest produce extraction: the Indian scenario. *Conservation and Society, 2*(2), 235–250.

Silva Neto, B. C., Nascimento, A. L. B., Schiel, N., Nóbrega Alves, R. R., Souto, A., & Albuquerque, U. P. (2016). Assessment of the hunting of mammals using local ecological knowledge: an example from the Brazilian semiarid region. *Environment, Development and Sustainability*. doi:10.1007/s10668-016-9827-2.

Silva, J. S., El-deir, A. C. A., Moura, G. J. B., Alves, R. R. N., & Albuquerque, U. P. (2014). Traditional ecological knowledge about dietary and reproductive characteristics of Tupinambis merianae and *Hoplias malabaricus* in semiarid Northeastern Brazil. *Human Ecology, 46*, 901–911.

Silva, R. R. V., Gomes, L. J., & Albuquerque, U. P. (2015). Plant extractivism in light of game theory: a case study in northeastern Brazil. *Journal of Ethnobiology and Ethnomedicine, 11*, 1–7.

Silva, T. C., Peroni, N., Medeiros, M. F. T., & Albuquerque, U. P. (2016). Folk classification as evidence of transformed landscapes and adaptative strategies: a case study in the semiarid region of northeastern Brazil. *Landscape Research*. doi:10.1080/01426397.2016.1258047.

Silva, R. R. V., Gomes, L. J., & Albuquerque, U. P. (2017). What are the socioeconomic implications of the value chain of biodiversity products? A case study in Northeastern Brazil. *Environmental Monitoring and Assessment, 189*, 64.

Sousa Júnior, J. R., Albuquerque, U. P., & Peroni, N. (2013). Traditional knowledge and management of *Caryocar coriaceum* Wittm. (Pequi) in the Brazilian savanna, Northeastern Brazil1. *Economic Botany, 6*(3), 225–233.

Sousa Júnior, J. R., Collevatti, R. R., Lins Neto, E. M. F., Peroni, N., & Albuquerque, U. P. (2016). Traditional management affects the phenotypic diversity of fruits with economic and cultural importance in the Brazilian savanna. *Agroforestry Systems*. doi:10.1007/s10457-0005-1.

Souza, T. M., Severi, J. A., Silva, V. Y. A., Santos, E., & Pietro, R. C. L. R. (2007). Bioprospecção de atividade antioxidante e antimicrobiana da casca de *Stryphnodendron adstrigens* (Mart.) Coville (Leguminosae-Mimosoidae). *Revista de Ciências Farmacêuticas Básica e Aplicada, 28*(2), 221–226.

Zardo, R. N. (2008). *Efeito do impacto da extração do pequi (Caryocar brasiliense) no cerrado do Brasil central.* Master Science Dissertation, University of Brasília, Brazil, 50p.