http://dx.doi.org/10.1590/1519-6984.18715

Spondias tuberosa Arruda (Anacardiaceae), a threatened tree of the Brazilian Caatinga?

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Received: November 4, 2015 – Accepted: May 6, 2016 – Distributed: August 31, 2017
(With 2 figures)

Abstract

Spondias tuberosa Arr., a fructiferous tree endemic to the northeast Brazilian tropical dry forest called Caatinga, accounts for numerous benefits for its ecosystem as well as for the dwellers of the Caatinga. The tree serves as feed for pollinators and dispersers as well as fodder for domestic ruminants, and is a source of additional income for local smallholders and their families. Despite its vantages, it is facing several man-made and natural threats, and it is suspected that *S. tuberosa* could become extinct. Literature review suggests that *S. tuberosa* suffers a reduced regeneration leading to population decrease. At this juncture *S. tuberosa* cannot be considered threatened according to the International Union for Conservation of Nature Red List Categories and Criteria, as it has not yet been assessed and hampered generative regeneration is not considered in the IUCN assessment. The combination of threats, however, may have already caused an extinction debt for *S. tuberosa.* Due to the observed decline in tree density, a thorough assessment of the *S. tuberosa* population is recommended, as well as a threat assessment throughout the entire Caatinga.

Keywords: Spondias tuberosa, natural regeneration, conservation, IUCN red list, Caatinga.

Spondias tuberosa Arruda (Anacardiaceae), uma árvore ameaçada de extinção da Caatinga?

Resumo

Spondias tuberosa Arr., é uma árvore frutífera endêmica da Caatinga, floresta seca tropical localizada no Nordeste do Brasil. A árvore traz diversos benefícios para o ecossistema e para a população local. Ela serve de alimento tanto para polinizadores e dispersores quanto para ruminantes domésticos e é fonte de renda extra para os agricultores familiares da região. Apesar de seus benefícios, esta árvore enfrenta várias ameaças naturais e antrópicas que podem levar a sua extinção. A revisão da literatura científica sugere que *S. tuberosa* sofre de reduzida capacidade de regeneração, o que leva à diminuição da população. Todavia, *S. tuberosa* não é considerada uma espécie ameaçada de extinção de acordo com as categorias e critérios da Lista Vermelha da União Internacional para a Conservação da Natureza, já que a espécie ainda não foi avaliada e capacidade regenerativa reduzida não é considerado critério pelo UICN. A combinação de ameaças, entretanto, pode já ter levado ao débito de extinção da *S. tuberosa*. Devido ao declínio observado da densidade das árvores, recomenda-se uma avaliação completa da população de *S. tuberosa* e uma avaliação de todas as ameaças sofridas pela árvore na Caatinga.

Palavras-chave: Spondias tuberosa, regeneracao natural, conservação, lista vermelha da UICN, Caatinga.

1. Introduction

The Red List of Threatened Species™ provided by the International Union for Conservation of Nature, (IUCN), is considered the most authoritative and objective system for categorizing the extinction risk of species (Hambler and Canney, 2013; Hoffmann et al., 2008; Rodrigues et al., 2006). IUCN structures the degree of risk of extinction of species into nine categories (IUCN, 2012). Eight of these nine categories are assigned only after an evaluation of species in situ. In case no evaluation took place species remain in the category *Not Evaluated* and in case data remain insufficient after evaluation species are assigned to *Data Deficient*. Species are evaluated against criteria with quantitative thresholds for geographic range and population size, structure and trends (IUCN, 2012) and if sufficient data are at hand assigned to one of the remaining seven categories ranging from *Least Concern* to *Extinct*. Species that meet the criteria for *Critically Endangered*, *Endangered* or *Vulnerable* are considered threatened (IUCN, 2012). A authoritative and objective system such as the IUCN red list is an important tool, beyond informing about the conservation of species, for identifying sites for conservation action on local as well as on regional level, to manage natural resources on national and international level, and to evaluate and monitor the state of global biodiversity (Rodrigues et al., 2006).

Spondias tuberosa Arruda is an andromonoecious deciduous tree of the family Anacardiaceae, that is endemic to the Caatinga, a seasonally dry tropical forest (SDTF) of northeast Brazil (Lima, 1996; Nadia et al., 2007; Prado and Gibbs, 1993). Its local name Umbuzeiro or Imbuzeiro is derived from the tupi-guarani indigenous word *ymb-u* which denotes *the tree that gives water* (Barreto and Castro, 2010; Epstein, 1998) in reference to a physiological adaption. *S. tuberosa* forms root-tubers, which are able to store water, minerals, and organic solutes (Cavalcanti et al., 2010; Duque, 2004; Epstein, 1998; Lima, 1996). This adaption permits its survival during the dry season (Cavalcanti et al., 2010; Silva et al., 2008), and to initiate the flowering and leaf flush before onset of the wet season (Lima Filho, 2007; Machado et al., 1997). Due to these early signs of life in the otherwise dormant Caatinga at the end of the dry season, the tree is worshipped by indigenous tribes in spiritual rituals (Monteiro, 2007). Still today the majority of the Caatinga dwellers consider *S. tuberosa* a sacred tree (Lins Neto et al., 2010). The flowering of the entomophily and self-incompatible flowers in the late dry and the early wet season makes it an important and unique food resource for pollinators as well as for nectar sucking animals (Almeida et al., 2011; Machado et al., 1997; Nadia et al., 2007). Its fruits, the Brazilian plum, and leaves serve as fodder for small mammals as well as domestic sheep and goats (Barreto and Castro, 2010; Cavalcanti et al., 2004, 2009a; Resende et al., 2004). In the human diet the fruit is consumed fresh or processed as juice, sweets, jam, ice cream, and *umbuzada* (fruit pulp boiled with milk and sugar) (Narain et al., 1992; Lins Neto et al., 2010). Borges et al. (2007) state that during the fruit season, fruit picking and selling is a main source of earnings for the Caatinga dwellers, and can contribute significantly to household income (Barreto and Castro, 2010; Drumond et al., 2001; Reis et al., 2010). Fruit picking is virtually limited to extractivism as hardly any plantations have been established (Narain et al., 1992; Neves et al., 2004; Neves and Carvalho, 2005). Moreover, *S. tuberosa* is used in traditional medicine and shows potential for its use in academic medicine (Albuquerque et al., 2007; Albuquerque and Oliveira, 2007; Almeida et al., 2010; Ferreira Júnior et al., 2011; Lins Neto et al., 2010; Silva et al., 2011).

S. tuberosa occurs throughout the entire Caatinga biome, which covers approximately 845,000 km^2 (Lima, 1996; IBGE, 2015). Documented natural stand density ranges from 0.3 to up to 9 trees per hectare (see Table 1). Based on the publications below, the theoretical total population of *S. tuberosa* ranges from 21 million up to 630 million individuals within the Caatinga. Modeling *S. tuberosa* distribution within the Caatinga revealed that only 7% of its population occur in existing conservation areas (Ferreira, 2014).

Regardless of the ecological, economic, and cultural benefits of *S. tuberosa*, concerns have been raised that the population of *S. tuberosa* is declining. In the early 1990s the Brazilian Corporation of Agricultural Research (Embrapa) pointed out that *S. tuberosa* may be in danger of extinction due to current agricultural land-use practices within the Caatinga (Embrapa, 1991). Albuquerque (1999) provided scientific backing for Embrapa's postulation by monitoring vegetation dynamics in a Caatinga area for six years under various grazing intensities. Although adult trees were present in the study area the researcher found neither seedlings nor saplings of *S. tuberosa*. In this study we focus and review international and national literature dealing with determining factors that pose a direct threat to the natural generative regeneration of *S. tuberosa*. This may support decision makers to establish protection measures and conservation strategies for the emblematic species of the Caatinga.

Table 1. Stand density of *Spondias tuberosa* in the Caatinga according to different authors.

Stand density (trees ha^{-1})	Author	Year of publication	State*
3.0	Albuquerque et al. (1982)	1982	PE
9.0	Drumond et al. (1982)	1982	PE
3.0	Albuquerque and Bandeira (1995)	1995	PE
0.9	Machado et al. (1997)	1997	PE
1.8 (1982)/ 2.8 (1984)	Albuquerque (1999)	1999	PE
Occur locally in anthropogenic zones	Albuquerque and Oliveira (2007)	2007	PE
7.6 undisturbed/ 3.4 disturbed Caatinga	Cavalcanti et al. (2008a)	2008a	BA/PE
0.6	Albuquerque et al. (2011)	2011	PE
1.3 undisturbed/ 0.3 disturbed Caatinga	Bitterwolf (2014)	2014	PE

* Federal states: PE = Pernambuco; BA = Bahia.

2. State of Research

We searched Scopus (operated by Elsevier, Amsterdam) using the default search in the database and combined each of the search terms *Spondias tuberosa* L., *Spondias mombin* L., *Spondias purpurea* L., *Magnifera indica* L., and A*nacardium occidentale* L. with *in Article Title* or *in Abstract*. Despite the regional importance, only a limited number of scientific research work on *S. tuberosa* has been published. In comparison with other genera of the Anacardiaceae family most *Spondias* species seem to be under-researched (see Figure 1). This can be partly explained by the wide distribution and economic importance of mango (*M. indica*) and cashew (*A. occidentale*). In the Brazilian context *S. mombin*, *S. purpurea* and *S. tuberosa* have, however, an equally high potential for agro-industrial exploitation (Silva Junior et al., 2004; Almeida et al., 2007). Actually, in northeastern Brazil the profit of *S. tuberosa* fruit yield of 3.8 million USD in 2012 was almost double as high as that of *A. occidentale* (IBGE, 2015). In contrast, since 1980 almost tenfold more scientific journal articles on *A. occidentale* have been published than on *S. tuberosa* according to Scopus (see Figure 1). Expanding the search to include the ScienceDirect, Google Scholar, and SciElo databases, a total of about 100 articles focusing on *S. tuberosa* were published within the same time frame. Of these articles about 40% are available only in Portuguese language with an English abstract. In nine of all 100 reviewed publications on *S. tuberosa* concerns about weak natural regeneration were directly or indirectly raised, but only five actually investigated underlying reasons and causes. The need to investigate the population dynamics of *S. tuberosa* to identify potential threats and protective measures is, however, well recognized. Since at least eight on-line magazine articles and blog entries broach the issue of the reduction in *S. tuberosa* density and hampered natural regeneration (Moser, 2013; ECOD, 2013; Cavalcanti, 2007, 2013; Bartaburu, 2013; Cavalcanti and Resende, 2005).

3. Factors Reported Constraining the Natural Regeneration of *Spondias tuberosa*

Several constraints are known to hamper the natural generative regeneration in plants. These constraints could be abiotic, such as shade, excess light, heat, water stress, and flooding, or biotic, such as allelopathy, browsing, herbivores, seed predation, and soil-borne pathogens (Guariguata and Pinard, 1998; Kitajima and Fenner, 2000; Harmer, 2001; Harrington and Bluhm, 2001; McLaren and McDonald, 2003; Torres et al., 2008). Further, anthropogenic constraints such as land-use, fuel-wood and timber extraction as well as the extraction of non-timber products are also known to negatively impact natural generative regeneration (Lykke, 1998; Bhuyan et al., 2003; Ræbild et al., 2007; Pare et al., 2009; Avocèvou-Ayisso et al., 2009; Schumann et al., 2011). Studies provide evidence that when multiple biotic and abiotic constraints are present, the negative effects on regeneration of seeds can be amplified (Gutiérrez-Granados et al., 2011). Detailed constraints as reported in the literature that may interfere with the natural regeneration of S. tuberosa are summarized below.

3.1. Pests

98% of seeds from fallen fruits of *S. tuberosa* have been reported to be infested by the grubs from the seed beetle *Amblycerus dispar* Sharp, 1885, thereby the harmed embryo is unable to germinate (Cavalcanti et al., 2008b, 2009a; Cavalcanti and Resende, 2004). Whereas fruits collected directly from the tree did not show any infestation. Since the seeds collected from the tree were stored for 30 days before being checked for infestation,

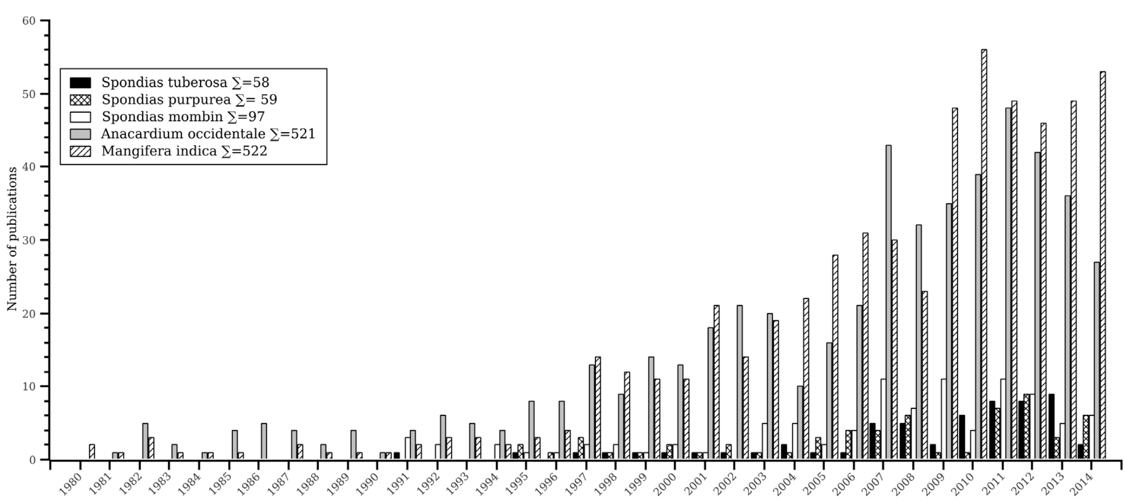

Figure 1. Publications of five Anacardiaceae per year according to Scopus database between 1980 and 2015. The query searched for the scientific name of the species in the article title or abstract.

Cavalcanti and Resende (2004) assume the infestation takes place on the seed rain before dispersal and not on the tree. Bitterwolf (2014) observed an infestation rate of 100% of seeds collected in 1 m^2 plots underneath the canopy of 25 trees during his field survey. The author only collected seeds from the ground, which was not cleared before the fruit season, and therefore was not possible to know the timing and location of infestation. It is not known whether the infestation of *A. dispar* increased recently and became a new problem for the *S. tuberosa* regeneration. Besides the seed beetle affecting germination rate, other insects are reported to harm *S. tuberosa* during the critical seedling stage and continue to affect the survival of seedlings (Cavalcanti et al., 2006). The insects known to damage *S. tuberosa* seedlings are *Phasmatodea* sp. Jacobson & Bianchi, *Diabrotica specosa* Germar, *Megalopyge lanata* Stoll, *Cryptotermes* spp., *Pinnaspis* spp. Cockerell (Neves and Carvalho, 2005). Further, two pathogenic fungi are associated with *S. tuberosa, Colletotrichum gloeosporioides* (Penz.) Sacc., and *Guignardia* sp. (Freire and Bezerra, 2001; Tavares et al., 1998). Detailed studies on the nature and degree of *S. tuberosa* damage caused by these insects and fungi are still lacking.

3.2. Restricted seed dispersal

The dispersal of *S. tuberosa* seeds occurs exclusively through zoochory. Seeds are carried by native animals, such as gray brocket (*Mazama gouazoubira* F.), black-rumped agouti (*Dasyprocta prymnolopha* W.), collared peccary (*Pecari tajacu* L.), fox (*Dusicyon thous* L.), yellow armadillo (*Euphractus sexcinctus* L.), argentine black and white tegu (*Tupinambis merianae* L.), greater rhea (*Rhea americana* L.) and white-naped jay (*Cyanocorax cyanopogon* Wied) (Barreto and Castro, 2010; Cavalcanti et al., 2009a; Cavalcanti and Resende, 2003; Azevedo et al., 2013). The non-native, human introduced cattle (*Bos taurus* L.) and goat (*Capra hircus* L.) are also reported dispersing seeds of *S. tuberosa* (Barreto and Castro, 2010; Griz and Machado, 2001).

Among the mentioned natural dispersers *M. gouazoubira* and *P. tajacu* are the most important (Cavalcanti et al., 2009a). While both species were formerly omnipresent in the biome, today they are found only in a few municipalities (Oliveira et al., 2003), which indicates a process of severe population reduction of these dispersers within the Caatinga. Cavalcanti et al. (2009b) suppose that is due to severe pressure from hunting. Thus, the results of Cavalcanti et al. (2009a) suggest that the dispersal of *S. tuberosa* in areas of undisturbed Caatinga is restricted due to the lack of natural dispersers. In addition *E. sexcinctus* is experiencing severe hunting pressure as well (Alves et al., 2009). As stated in Alves et al. (2009) wild animals have still a great nutritional importance for low-income families in the Caatinga, consequently hunting remains a common activity despite its illegality in regions of extreme poverty. Therefore Barreto and Castro (2007) recommended a reduction of hunting wild animals within the Caatinga as a protection measure for the wild population of *S. tuberosa*. This can be only achieved by better law enforcement in order to stop commercial hunting as well as for non-food purposes (Alves et al., 2009).

According to the cited literature the restricted seed dispersal is one of the key reasons for low natural regeneration of *S. tuberosa* in the Caatinga.

3.3. Climate change

The area which comprises today's Caatinga underwent a natural climatic change. Based on analysis of pollen in a peat bog sequence Oliveira et al. (1999) identified a humid period from 10,990-8,910 yr B.P. with pollen from taxa which occur in the present day Amazonian and Atlantic forests. From 8,910 yr B.P. onwards the climate got drier as indicated by increasing density of pollen from SDTF vegetation. Acceleration in this shift towards a more semiarid climate was observed from 4,240 yr B.P. until present, which lead to the dominance of SDTF vegetation (Oliveira et al., 1999). This historical trend towards a drier environment in the Caatinga may continue due to man-made climate change. The Intergovernmental Panel on Climate Change (IPCC, 2007a) stated: that due to increased atmospheric concentrations of greenhouse gases, extreme weather events such as extreme droughts, intensification of hot extremes and heat waves have increased in frequency and severity and are more likely in the future. Most likely the semi-arid Brazilian Northeast will suffer a decrease of water resources due to climate change and the semi-arid vegetation will tend to be replaced by arid-land vegetation (IPCC, 2007b). This may also affect the survival, natural regeneration, and persistence of *S. tuberosa* in the current extension of the Caatinga biome. Higher temperatures will also accelerate drought-induced tree mortality (Adams et al., 2009). In addition, droughts and dry conditions within SDTF reduce seed germination and increase seedling mortality (Blain and Kellman, 1991; McLaren and McDonald, 2003). For *S. tuberosa* in particular Cavalcanti et al. (2006) observed reduced germination and seedling survival in months with little or no precipitation. Lima et al. (2015) observed a little seedling survival of planted *S. tuberosa* seedlings, due to under-average precipitation during the experiment the authors stated. Recurring dry years took place in the Caatinga throughout the entire 19th Century (Untied 2005), but Silva (2004) observed a trend towards a drier climate in the Brazilian Northeast within the most recent 30 years. The ongoing environmental degradation may even intensify this trend within the Caatinga as modeled by Oyama and Nobre (2004). Based on precipitation data available at Agência Pernambucana de Águas e Clima – APAC (2015) the trend observed by Silva (2004) could be supported for the Caatinga in Pernambuco (PE). At four of six weather stations, the least-squares linear regression indicates a slightly decreasing trend in annual precipitation over the last 75 years (see Appendix A).

Besides germination and seedling survival the fruit set of *S. tuberosa* is also affected by the soil water regime. Cavalcanti et al. (2011) demonstrated the positive effect of additional irrigation on bloom and fruit set, thus decreasing precipitation may lead to reduced fructification of *S. tuberosa*. Precipitation in the beginning of the rain season from November to December is especially important for the development of fruits (Cavalcanti et al., 2011). Therefore, natural generative regeneration of *S. tuberosa* may be impeded by reduced seed germination and seedling mortality on the one hand, and on the other hand due to reduced fructification.

3.4. Browsing

Browsing by *Capra hircus*, the domestic goat, impacts the natural generative regeneration of *S. tuberosa* in two ways. First, Caatinga sites disturbed by grazing, and browsing, show a strong decline in number of *S. tuberosa* seeds, 1004 seeds/m^2 on undisturbed Caatinga sites versus 31 seeds/m^2 on disturbed Caatinga sites (Cavalcanti et al., 2009a). The authors argue that the decline in number of seeds is caused by *C. hircus* as they feed on fruits of *S. tuberosa* and export the seeds out of Caatinga sites into a night-time enclosure. An individual goat can take up over 130 kg of Brazilian plum during one fruit season from January until April which represents an export of approximately 10,000 fruits (Resende, et al., 2004). Second, *C. hircus* also feed on seedlings and saplings of *S. tuberosa.* On disturbed Caatinga sites 62% of 1000 planted *S. tuberosa* seedlings were marred by *C. hircus,* which reduced the seedling survival to 22% within three consecutive years (Cavalcanti et al., 2009b). Cavalcanti et al. (2009a) did not find any seedling of *S. tuberosa* on Caatinga sites with evidence of *C. hircus* browsing impact. As *C. hircus* impedes dispersal, and damages seedlings, it hinders the natural generative regeneration and causes the disappearance of *S. tuberosa* in disturbed Caatinga sites (Cavalcanti et al. 2009a, b). Furthermore, it has been reported that sheep (*Ovis aries* L.) significantly feeds on Brazilian plum (Martinele et la., 2010; Resende et al., 2004). Recently, Siqueira Filho (2012) expressed concerns about browsing pressure which may affect the natural regeneration of *S. tuberosa*.

On undisturbed Caatinga sites, the dispersers of *S. tuberosa*, *P. tajacu* and *E. sexcinctus* affect *S. tuberosa* seedlings negatively by browsing as well (Cavalcanti et al., 2009b, 2006). On an undisturbed Caatinga site 14% of 1000 planted seedlings of *S. tuberosa* were damaged by *E. sexcinctus* and 7% were damaged by *T. tajacu* (Cavalcanti et al., 2009b). The damage on *S. tuberosa* seedlings caused by *E. sexcinctus* is especially severe, since it excavates and feeds on the root-tubers which kills the seedling (Cavalcanti et al., 2009b, 2006). Since *P. tajacu* and *E. sexcinctus* interfere with the dispersal of *S. tuberosa* due to their absence, we assume the browsing impact of both is rather insignificant.

4. Potential Factors Which May Constrain the Natural Regeneration of *Spondias tuberosa*

Two further anthropogenic factors, wood extraction and fruit picking, may also account for hampered natural generative regeneration of *S. tuberosa.* Even though both factors are not referenced in *S. tuberosa* literature to date.

4.1. Wood extraction

Despite a draft law filed in 2004, which would ban lumbering of *S. tuberosa* (Duarte, 2004), it has been reported that *S. tuberosa* wood is still used as fuelwood or used for charcoal production (Lins Neto et al., 2010; Silva et al., 2009). Wood extraction accounts for reduced natural generative regeneration as shown by Bhuyan et al. (2003) in an Indian tropical forest. They observed decreasing regeneration with increasing human-impact, and in highly disturbed sites no regeneration was recorded. However, Jurisch et al. (2013) observed a positive effect of human disturbance on the seedling survival in an African savanna due to reduced competition for light, water, and nutrients. At this point, neither the status of the draft law is known nor the extent and effect of wood extraction on *S. tuberosa*.

4.2. Fruit picking

Fruit picking must also be considered a potential constraint for natural generative regeneration of *S. tuberosa.* In 2012 the yield of the Brazilian plum, 7979 t, was harvested by fruit picking from naturally occurring *S. tuberosa* (IBGE, 2015). It can be assumed, that harvesting is much higher, since a significant amount of Brazilian plum is consumed directly within rural communities or sold via farm gate or at roadside (Barreto and Castro, 2010; Lins Neto et al., 2010) which is not recorded by the official survey. Hence, fruit picking may reduce the seed rain of *S. tuberosa* and reduction of the natural generative regeneration is a consequence. For instance, Avocèvou-Ayisso et al. (2009) observed a decline in total seedlings and saplings of African butter tree (*Pentadesma butyracea* Sabine), a multipurpose tree in the African tropical forest, as well as reduced generative regeneration due to high fruit harvesting intensity. Yet, the impact of fruit extractivism on *S. tuberosa* needs to be further investigated, reaching reliable data on fruits exported out of the Caatinga.

5. Conclusion

This review highlights the various constraints of natural generative regeneration *S. tuberosa* is exposed. Since the reported constraints are successively combined and maybe even amplify themselves the natural regeneration of *S. tuberosa* appears severely disturbed. For instance, logging amplified seed predation and storm disturbance facilitated herbivore attacks on seedlings of big-leaf mahogany (*Swietenia macrophylla* King) (Gutiérrez-Granados et al., 2011). A trend towards a drier climate in the Brazilian Northeast may reduce the fructification of *S. tuberosa.* Additionally, the popularity of animal husbandry as well as fruit picking results in an export of its fruits and seeds out of the Caatinga, which reduces the share of *S. tuberosa* seeds within the seed pool of the Caatinga. The significantly reduced number of seeds of *S. tuberosa* remaining on Caatinga sites is exposed to the risk of seed predation by the seed beetle *A. dispar* and the number of germinable seeds is drastically reduced (see Figure 2). According to Guariguata and Pinard (1998) seed predation is a major constraint for tree regeneration in neotropical forests. Due to the decreased abundance of natural dispersers the remaining seeds with intact embryos will not be dispersed appropriately and the formation of new populations is very unlikely. With little and erratic precipitation, intact seeds have difficulties meeting favorable environmental conditions for their germination. If the trend in decreasing precipitation proves true, meeting these favorable conditions will be even more difficult. Thus, *S. tuberosa* is potentially affected twice by climate change; a drier environment will reduce fructification and hamper germination. In case germination takes place and the seedling emerges, *S. tuberosa* needs to pass another bottleneck in its generative regeneration, the seedling stages. In this stage, *S. tuberosa* is exposed to high browsing pressure on disturbed Caatinga sites. In the seedling stage the natural regeneration of trees is especially sensitive to browsing (Gill, 1992; Harmer, 2001; Côté et al., 2004). Both, the abundance of browsers and the abundance of seedlings affects the success of the natural regeneration (Gill, 1992). Accordingly, the reported browsing of *C. hircus* has a stronger impact on the natural regeneration, as the number of seedlings of *S. tuberosa* is reduced due to a reduced share in the seed pool, hampered dispersal and germination constraints compared to a situation without reduced seedling abundance. As seen for the trend towards a drier climate, *C. hircus* interferes twice with the natural regeneration of *S. tuberosa* as well. This multi-factorial disturbance of the natural regeneration may cause a serious extinction debt for *S. tuberosa*.

Although strong evidence support the fear of a hampered generative regeneration of *S. tuberosa*, it cannot be considered threatened according to IUCN criteria at this juncture. *S. tuberosa* has not yet been evaluated and a hampered generative regeneration is not considered in the ICUN assessment. It maintains the status of *Not Evaluated* in IUCN red list (IUCN, 2012, 2014). In case of *S. tuberosa*, neglecting the generative regeneration in the assessment of IUCN might be irrelevant, since it is assumed that the regeneration via re-sprouting after disturbance is of greater importance than generative regeneration in SDTFs (Vieira and Scariot, 2006). There is currently no literature about whether the hampered generative regeneration *de facto* affects the *S. tuberosa* population. So far only concerns were stated. However, knowledge regarding factors which constrain the regeneration of *S. tuberosa* is still partly lacking or rudimentary (see Table 2), which highlights the need for further research. Additionally, the population density and the strong variation in the population density over time should be investigated closely, especially in other regions of the Caatinga. All publication which assessed the tree density of *S. tuberosa* were carried out almost exclusively in the state Pernambuco (see Tabel 1).

We suggest a large-scale thorough assessment of the *S. tuberosa* population in the Caatinga with focus on an allometric and age structure assessment as well as its spatial distribution. Ideally, a comparison with historical data should be included in order to obtain information about temporal alteration. The early bloom of *S. tuberosa* in the otherwise dormant Caatinga may result in distinctive spectral and textural signals, and remote sensing could a promising tool for a large-scale assessment. Such an approach, when proven applicable and incorporated into a geographical information system (GIS), could be used to evaluate the status of *S. tuberosa* for the IUCN red list, and as a basis for future assessments of spatial and temporal population dynamics, triggered by climate change for instance. The remote sensing also may help to identify areas with high protection value for *S. tuberosa*. It also must be verified whether the impeding biotic and abiotic factors described above apply to the entire Caatinga and to which extent these factors affect *S. tuberosa*. Therefore, we recommend additionally the installation of surveillance plots within the Caatinga for ground-based assessment, in which the damaged caused by insects and fungi on *S. tuberosa* as well as the effect of climate change on germination, seedling survival, bloom, and fruit set of *S. tuberosa* could be observed.

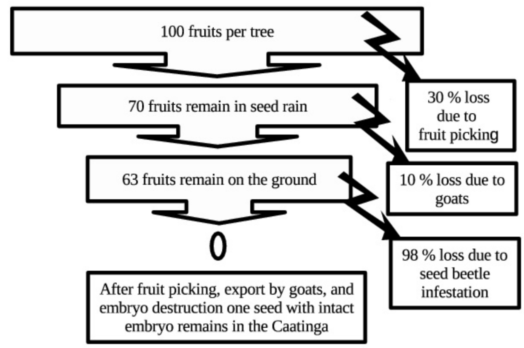

Figure 2. Assumed reduction of germinable seeds of *Spondias tuberosa* due to fruit picking, seed export of goats and seed beetle infestation within Caatinga. 100 fruits per tree is an exemplary figure and the percentage for the loss due to fruit picking and goats are assumed.

Table 2. Selected factors influencing the natural regeneration of Spondias tuberosa, their potential damage and state of knowledge.

Threat	Potential damage[1]	State of knowledge[2]
Seed predation by beetle	+++	+
Herbivorous insects	+	-
Restricted natural dispersal	++	0
Drier climate	+++	0
Browsing pressure	+++	+
Wood extraction	++	-
Fruit picking	++	-

[1]: + = little potential damage; ++ = intermediate potential damage; +++ =high potential damage. [2]: – = little or no knowledge. 0 = basic knowledge; + =good knowledge.

Acknowledgements

This work was supported by the German-Brazilian joint research project INNOVATE (Interplay between the multiple uses of water reservoirs via innovative coupling of substance cycles in aquatic and terrestrial ecosystems). The project is funded by the German Federal Ministry of Education and Research (BMBF) under project number 01LL0904B. The first author would also like to thank for support by the Foundation fiat panis Ulm, Germany.

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Appendix A. Trend in annual precipitation.

Figure 1A. Trend in annual precipitation from 1937 until 2013 for six stations in Pernambuco, data for Petrolândia not available for all consecutive years (APAC, 2015). Continues line represents least-squares linear regression with its R^2 in bold, dashed line represents polynomial regression of 6th degree with its R^2 in regular font.