Articles

SEED PREDATION OF *ARAUCARIA ANGUSTIFOLIA* BY *SAPAJUS NIGRITUS*

Luana Pagno[1], José F. Cândido Jr[1] , Carlos R. Brocardo[2,3]

[1]Laboratório de Zoologia de Vertebrados e Biologia da Conservação, Universidade Estadual do Oeste do Paraná (UNIOESTE), 2069 Rua Universitária, Jardim Universitário, Cascavel 85819-110, Paraná, Brazil, E-mail: <pagnoluana@gmail.com>
[2]Laboratório de Biologia da Conservação, Department of Ecology, Universidade Estadual Paulista, 1515, Avenida 24, Rio Claro 13506-900, São Paulo, Brazil
[3]Instituto Neotropical: Pesquisa e Conservação, Curitiba, Paraná, Brazil, E-mail: <carlosbrocardo@hotmail.com>

Abstract

In this study, we quantified seed predation of the Paraná Pine (*Araucaria angustifolia*) by black capuchin monkeys (*Sapajus nigritus*), in order to better understand their impact on forest regeneration. This study was conducted in an Araucaria forest fragment in the state of Paraná, Brazil. We marked 31 female Paraná pines and counted the seed cones, which ranged from 0 to 20 per tree (Mean = 5, SD ± 5.06). We recorded 88 predated cones, with an average of 2.35 ± 3.83 per tree. During the study period the monkeys only ate seeds from immature cones. The reason why the monkeys fed only on immature seeds may have been related to the scarcity of mature seeds and other resources. Comparing the seasons, we found a significant difference in the number of predation events between them. Cone predation on the top of each female Paraná pine was proportional to crop size, and totaled 57% of all cone production, which may have an impact on regeneration of this endangered gymnosperm. Thus, the ecological role played by the capuchin monkeys can be seen as going beyond seed dispersal, showing that this species may influence forest recruitment negatively through pre-dispersal seed predation.

Key Words: Araucaria forest, capuchin monkeys, pre-dispersal, Paraná pine.

Resumo

No presente estudo, objetivamos quantificar a predação de sementes de pinheiro-do-Paraná (*Araucaria angustifolia*) por macaco-prego (*Sapajus nigritus*), para melhor entender o impacto desses primatas sobre a regeneração florestal. Este estudo foi realizado em um fragmento de floresta Araucária no estado do Paraná, Brasil. Nós marcamos 31 fêmeas de pinheiro-do-Paraná e contamos as pinhas com sementes. Estas variaram de 0 à 20 por árvore (média = 5. EP ± 5.06). Nós registramos 88 pinhas predadas, com uma média de 2.35 ± 3.83 por árvore. Durante o período do estudo, os macacos-prego apenas consumiram pinhas imaturas. A razão pela qual os macacos-prego devem ter consumido apenas pinhas imaturas pode estar relacionada com a escassez de sementes maduras e também de outros recursos. Encontramos diferença significativa no número de eventos de predação de sementes entre estações do ano. A predação de pinha no topo de cada árvore fêmea de pinheiro-do-Paraná foi proporcional ao tamanho da copa, e totalizou 57% de toda produção de pinha, o que pode impactar na regeneração dessa gimnosperma ameaçada. Dessa forma, o papel ecológico desempenhado pelos macacos-prego pode ser visto como indo além da dispersão de sementes, mostrando que tal espécie pode influenciar negativamente no recrutamento florestal através da predação de sementes antes da dispersão.

Palavras-Chave: floresta de Araucária, macaco-prego, pré-dispersão, pinheiro-do-Paraná.

Introduction

Alteration and occupation of natural habitats by humans have caused biodiversity loss (Hansen *et al.,* 2004), although apparently certain species have benefited from this interference. Among them is *Sapajus nigritus* (Goldfuss, 1809 Primates, Cebidae), popularly known as the black capuchin monkey, which can adapt to altered environments (Rocha, 2000). Capuchin monkeys can utilize diverse habitats and their home range is usually large, between 150 and 293 ha, but they can also survive in smaller areas of approximately 12–80 ha, depending on the food distribution and its availability (Vilanova *et al.*, 2005; Bicca-Marques *et al.,* 2006). They are omnivores with a diet based on 60 to 70% of fruits and seeds, and 20 to 30% of animal matter, among other foods such as roots, flowers, leaves,

shoots and apical meristems (Galletti and Pedroni, 1994; Ludwig *et al*., 2005; Ludwig *et al.,* 2006; Brocardo *et al.,* 2010). Combining a diverse diet and ease of adaptation, this species is considered a "problem" primate for many authors (Rocha, 2000; Santos *et al*., 2007). In times of fruit scarcity, they increase their consumption of alternative resources from plantations located around the forest fragments, ranging from maize, cassava roots and even *Pinus* spp. (Galetti and Pedroni, 1994; Rocha, 2000; Ludwig *et al.,* 2006, Santos *et al*., 2007). Within forest habitats they increase the consumption of *Euterpe edulis* and *Geonoma* spp. apical meristems in response to scarcity of other food sources (Souza and Martins, 2006; Brocardo *et al.,* 2010). Although widely known as a seed disperser (Galetti and Pedroni, 1994), monkeys of the genus *Sapajus* can cause some negative impacts on plant recruitment through herbivory of adult and young plants (Santos *et al.,* 2007; Brocardo *et al.,* 2010) and seed predation (Peres, 1991; Galetti and Pedroni, 1994). In fact, seed predation can be the only action performed by capuchin monkeys on particular plant species, as observed for *Cariniana micrantha* (Peres, 1991). And this also seems to be the case of relationship between black capuchin monkeys (*Sapajus nigritus*) and the Paraná pine trees (*Araucaria angustifolia*).

Paraná pine, which belongs to the Araucariaceae family, is a large dioecious gymnosperm (up to 50 m tall and 3 m in diameter at breast height - dbh) occurring in Brazil and Argentina, where it is limited to the Araucaria forest of subtropical and temperate climes (Hueck, 1953). In this forest, the Paraná pine is the dominant species; the mean adult density can reach 3,000 ind./km² (Mantovani et al*.,* 2004; Paludo et al., 2011). It is vulnerable due to logging (Mantovani et al*.,* 2004; Thomas, 2013). It takes about two years for the seed cone to become completely mature, reaching maturity generally between April and July (Mantovani et al., 2004). Its seeds, known as "pinhões" in Brazil, have a reddish-brown bark and are a valuable source of carbohydrates, proteins and lipids, for humans, domestic animals and wildlife. Seed predators include jays, parrots, agoutis, pacas, tapirs, deer, rats, porcupines, peccaries, and howler and capuchin monkeys. This plant is considered, therefore, a key resource for wildlife (Vieira and Iob, 2009). The dispersal of its seeds also depends on animals, such as agoutis (*Dasyprocta azarae*) (Brocardo and Galetti, 2014), squirrels (*Guerlinguetus ingrami*) (Bordignon and Monteiro-Filho, 2000), and plush-crested jays (*Cyanocorax chrysops*) (Brocardo and Galetti, 2014), which disperse the "pinhões" through scatter-hoarding behavior (synzoochory *sens*u Correa et al., 2015).

In spite of the intrinsic relationship between Paraná pine and animals, studies on the regeneration of this plant species have only given secondary focus to its interaction with seed dispersers and predators (Paludo *et al*., 2011). Herein we present the first study to quantify the consumption of seeds of Paraná pine by black capuchin monkeys, which will help to better understand the impact of this primate on Araucaria forest regeneration.

Materials and Methods

We carried our study at the "Danilo Galafassi" Municipal Park (DGMP), located in Cascavel, Paraná state, Brazil (24º 57'21" S, 53º 27'19" W), comprising an area of 17.91 ha of Araucaria forest (Fig. 1). Despite the small area, the park is connected with another forest fragment, the "Paulo Gorski" Ecological Park (PGEP), comprising approximately 100 ha of both primary and secondary native forest. In these two areas, the population of capuchin monkeys must have been isolated for approximately 30–35 years ago, since urbanization, with no connection to other areas (Brocardo, 2013). The region is located 730–780 m.a.s.l., and a subtropical climate, Cfa according to the Köppen classification, with 1,800–2,000 mm annual rainfall, no dry season, and a mean annual temperature of 19 to 21°C (Castella and Britez, 2004).

Observations were carried out between March 2013 and March 2014, with at least three field surveys a month of a minimum of one hour each (no schedule on rainy days). In all, we sampled 71 days, with a total of 150 hours of observation. We monitored the behavior of monkey groups during seed consumption using 7×35 mm binoculars. We initially marked the bole (at 1.3 m off the ground) of productive female pines with metal plates (3.0 × 3.0 cm) to verify the seed consumption by monkeys. We quantified and recorded the cones on each marked pine tree canopy.

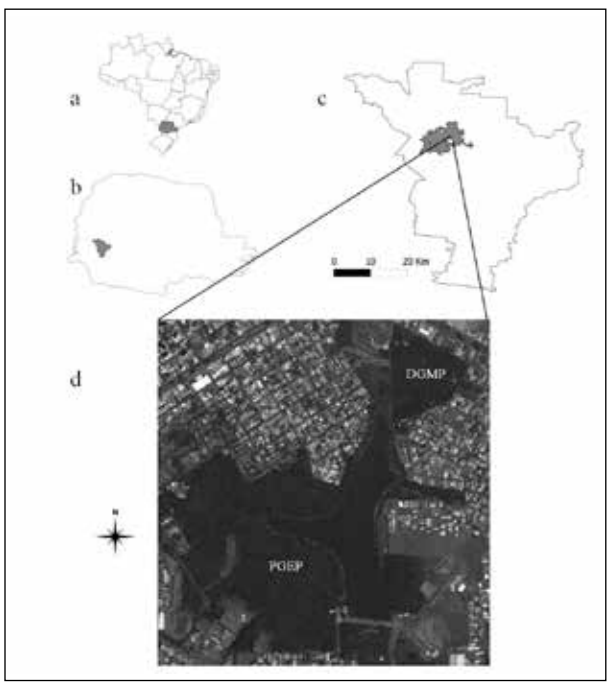

Figure 1. Study area. a) Paraná (gray) in Brazil, b) location of Cascavel municipality (gray) in Paraná state, c) emphasis on urban area (gray) of Cascavel and location of the sampled area; d) Danilo Galafassi Municipal Park (DGMP) and Paulo Gorski Ecological Park (PGEP). Image modified from Google Earth.

We considered all events of seed consumption or felling of immature pine cones caused by monkeys as predation events (negative impact on tree seed production), since immature seeds felled to the ground cannot be recruited. We analyzed the predation frequency between the seasons using the chi-square test, because capuchin monkeys can alter their diet in response to food scarcity (Ludwig et al., 2006; Brocardo et al., 2010).

Primates prefer trees with large crops (Janson et al., 1986, Stevenson, 2004), a fact related to foraging optimization, so when they act as seed predators, the impact will be proportional to seed production (Peres, 1991). We therefore expected that the impact of activities of the black capuchin monkeys on Paraná pine cones would be proportional to the crop size. Linear regression was used to test whether the predation events were related to crop size.

Results

The monkeys were observed for a total of 21 hours, and seed consumption was recorded for 3 h and 35 min. Thirty-four individuals were recorded in the largest group, which included an alpha male and some immature individuals. One to ten animals (subgroups) were recorded in other events. A density of 28 individuals/km² was estimated for the DGMP and PGEP areas combined (approximately 118 ha; see Fig. 1).

The capuchin monkeys eat the Paraná pine seeds by first removing the cone from the parent plant and then bite it open to get the seeds, which they bite open to access the endosperm (Fig. 2). When there is no endosperm, they just grab another seed and repeat the process. After having opened and consumed a pine cone, the monkeys eat another, and so on until their hunger is satiated or they give up. Also, pine cones sometimes end up falling from the top of the tree. Events of seed consumption typically lasted ten minutes on average.

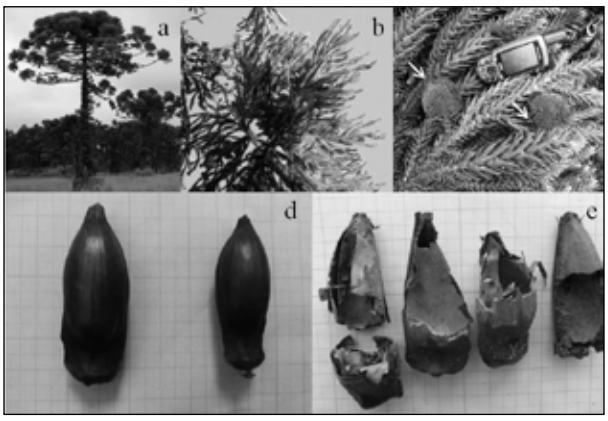

Figure 2. a) Adult Paraná pine b) seed cones in a branch c) Detail of immature seed cones between spiny leaves of *A. angustifolia*; d) intact mature "pinhões"; e) mature seed provided to captive black capuchin monkeys (d and e: scale is 1 cm)

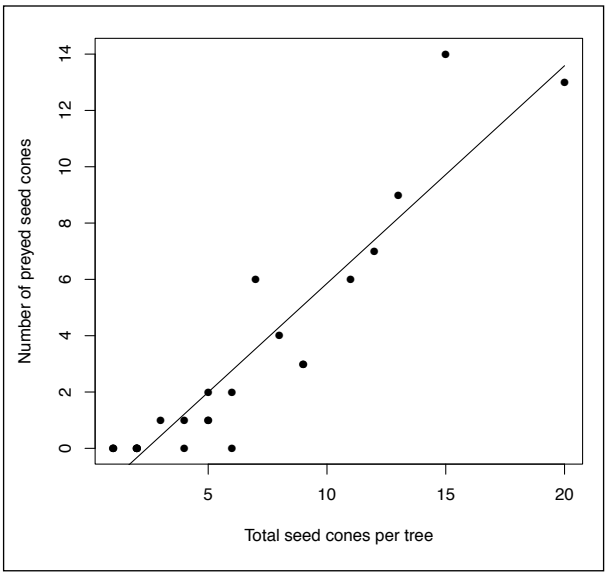

Figure 3. The relation between the number of Paraná pine cones in the canopy and the cones preyed upon by the capuchin monkeys.

We marked 31 female pines and the number of seed cones ranged from 0 to 20 per tree (mean = 5, SD ± 5.06). We counted 88 predated cones, an average of 2.35 ± 3.83 per tree. We did not record any consumption of mature cones, only immature seeds were consumed by the monkeys. The canopy with the largest number of cones also had the largest number of predated cones ($y = 0.772x - 1.87$, $R^2 = 0.87$) (Fig. 3).

According to the comparison between seasons (chi-square test), we found a significant difference in the number of depredation events between the four seasons ($X^2 = 89.72$, DF= 3, p-value < 0.01); 6 predated cones in the summer (December–March), 15 in the autumn (March–June), 60 in the winter (June–September), and 7 in the spring (September–December). In the winter, the consumption was greater than expected, while in the other seasons it was smaller. Considering the total number of cones counted (n=155), the capuchin monkeys impacted 57% of *Araucaria angustifolia* seed production in the study area.

Discussion

Paraná pine seeds are an important source in the diet of capuchin monkeys during autumn and winter in the Araucaria forest. In this forest, there is a reduced number of fruiting species during wintertime, when the "pinhões" are considered key resources for many frugivorous animals (Vieira and Iob, 2009). While *A. angustifolia* is often a dominant species where occurs, which disqualifies it as a keystone plant (*sensu* Power et al. 1996; Peres, 2000), its high importance for providing resources to several animal species in shortage periods may be used to classify it as a keystone plant (*sensu* Galetti et al. 1999; Stevenson, 2005).

Although the consumption of these seeds is more energetically advantageous when they are mature, apparently

monkeys prey upon seeds before maturation due to lack of other resources in the environment, especially during the winter period, when fruit production in the Araucaria forest is low (Vieira and Iob, 2009). Thus the consumption of immature "pinhões" by capuchin monkeys may be related to the use of alternative sources (Brocardo et al. 2010). Fragments such as our study site tend to present lower tree species richness, which in turn represent lower quantity and quality of resources for frugivorous species (Tabarelli et al., 1999, Chiarello, 2000), imposing behavioral and ecological adaptation pressure on capuchin monkeys (Ludwig et al., 2006; Pinto et al., 2009). In an Araucaria forest fragmented landscape, the increase in damage to *Pinus* trees caused by black capuchin monkeys was related to the food shortage period in the natural forest, mainly in winter (Mikich and Liebsch, 2014). The use of *Pinus* by *S. nigritus* in Araucaria forest region demonstrates how degraded the fragments of this forest currently are (Mikich and Liebsch 2014), because to obtain phloem sap and tissue from *Pinus* the monkeys suffer serious damage to their incisor teeth, that in turn affects their health and survival (Delgado, 2013).

The low cone production in our study site also may have influenced the consumption of immature seeds owing to the absence or low abundance of mature seeds. In another area located in São Paulo state, the "Carlos Botelho" State Park, an Atlantic Forest continuous area where stretches of planted *Araucaria angustifolia* are present (Brocardo et al. 2012), we observed *Sapajus nigritus* consuming only mature "pinhões" (CR Brocardo, pers. obs.). The Paraná pine seed production in our study area was lower than that found by Mantovani et al. (2004), who obtained 13 ± 7.6 and 19 ± 9.4, respectively in 2001 and 2002 in "Campos do Jordão" State Park , São Paulo state. We only recorded a mean of 5 ± 5.06 per tree. It is known that seed crop in *Araucaria angustifolia* varies between years (Souza et al., 2010), thus in years of greater seed production, the monkeys may prefer to prey on mature seeds. However, even large seed production can be proportionality impacted by monkeys. Our data demonstrated that predation of cones was related to crop size (Fig. 3). The green color of the cone seed can make the visual location by monkeys difficult when they are in other trees, but large crops are probably more conspicuous (Fig. 2 a–c). Even on a female Paraná pine, the capuchin monkeys may have difficulty locating cones due to the architecture of this tree, where the cones are inserted on tips of branches, between spiny leaves (Fig. 2 b–c).

For *Cariniana micrantha* (Lecythidaceae), an Amazonian tree, the seed predation impact exerted by capuchin monkeys was also related with crop size. The total damage on reproductive potential was 99.6% (69.5% predated seeds and 30.1% unviable seeds felled) (Peres, 1991). Although the impacts of capuchin monkeys are smaller on *A. angustifolia* seed production (57% of the cones) than on *C. micrantha*, they are still very high, affecting over half of the seed production. As capuchin monkeys are the most common monkey species within Araucaria forest fragments (Brocardo and Cândido-Jr, 2012), this primate may be contributing significantly to low Paraná pine recruitment (e.g., Paludo et al., 2011). Besides the impacts caused by monkeys, the extensive harvesting of "pinhões" for human consumption seriously affect Paraná pine regeneration (Souza et al., 2010). Furthermore, mature pine seeds fall directly below the parent plant, where they are eaten by mammals on the ground (Vieira and Iob, 2009; Brocardo and Galetti, 2014). Agoutis (*Dasyprocta azarae*) are abundant in the study area (Brocardo, unpubl. data) and, although they are seed dispersers (scatter-hoarding), in small forest patches they may also be the main terrestrial seed predators of these pines (Ribeiro and Vieira, 2013). Therefore, only a few seeds can escape predation and contribute to recruitment. Interventions are needed to ensure Paraná pine regeneration, such as collecting seeds for seedling production and subsequent transplantation in the area.

In conclusion, the ecological role played by capuchin monkeys goes beyond seed dispersal (positive influence on plant recruitment), demonstrating that primates may also affect forest recruitment negatively through pre-dispersal seed predation (Izawa, 1979; Peres, 1991; Stevenson et al., 2000; Stevenson, 2007).

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