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The regeneration of Brazil nut trees in relation to nut harvest intensity in the Trombetas River valley of Northern Amazonia, Brazil

Ricardo Scoles [a,*], Rogério Gribel [b,1]

[a] Universidade Federal do Oeste do Pará, Av. Vera Paz, s/n°, Salé, CEP 68135-110 Santarém, PA, Brazil
[b] Instituto Nacional de Pesquisas da Amazônia, Caixa Postal 478, CEP 69011-970 Manaus, AM, Brazil

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ABSTRACT

This study examined the harvest of nuts from Brazil nut trees (*Bertholletia excelsa*) in the valley of the Trombetas River, a 760-km tributary on the northern bank of the Amazon River in Pará state, Brazil. The region is characterised by old-growth forests dominated by Brazil nut trees. Demographic data were obtained from twenty-five 50-m × 1000-m transects with different harvest intensities (total area = 125 ha) established approximately along the trails used by Brazil nut harvesters. For each transect, correlations were calculated between regeneration indicators (seedling, sapling, and juvenile densities) and potential ecological and demographic variables. The Brazil nut populations in the region were characterised by a low proportion of juveniles (7.8% of trees had a 10 cm < diameter at breast height – DBH < 40 cm), a dominance of large trees (DBH > 100 cm), and a tendency towards old growth (25.5% of trees had a DBH > 160 cm). There were no seedlings in 52% of the transects, and 80% of the transects had no saplings. The low regeneration levels observed were independent of both harvest intensity and the dispersive activity of agoutis. An analysis of the regeneration indicators and the possible explanatory variables showed that harvests were not responsible for the low regeneration levels observed in the region. Furthermore, in areas with shorter distances between the points of harvest and first transport, the densities of saplings and juveniles were greater. We conclude that the restrictions on Brazil nut harvesting that are intended to improve the regeneration of Brazil nut trees are of little or no value. We propose the implementation of compensatory measures involving local communities and the promotion of seedling enrichment in gaps, forest edges, and disturbed areas, with the goal of promoting the growth of new generations of Brazil nut trees in the region.

1. Introduction

The Brazil nut tree (*Bertholletia excelsa*, Lecythidaceae) is amply but irregularly distributed throughout the Amazon basin and the Guianas, extending west to Peru, Bolivia, and the upper Rio Negro in Venezuela (Prance and Mori, 1990). This tree generally grows in non-flooded (*terra firme*) forests on well-drained, low-fertility Oxisols and Ultisols (Peres and Baider, 1997). In Brazil, the Brazil nut tree is found principally in the states of Pará, Amazonas, Rondônia and Acre, as well as in the forested parts of the states of Amapá, Roraima, Maranhão and Mato Grosso (Müller, 1981). The Brazil nut tree is an emergent tree of great size, frequently reaching 40–50 m in height and 3 m or more in diameter at breast height (DBH; Zuidema and Boot, 2002; Salomão, 2009). The fruit is a lignified sphere with a diameter of 10–12 cm and a weight of 0.5–2.5 kg, and it contains 10–25 seeds. The seeds (the commercially available Brazil nuts) are edible, have an angular form, and are covered by a protective lignified shell (Mori and Prance, 1990).

Brazil nut trees can live for hundreds of years (Camargo et al., 1994). Most individuals of reproductive age have DBHs > 40 cm (Zuidema and Boot, 2002), whereas the most productive trees have DBHs between 80 and 160 cm (Viana et al., 1998; Wadt et al., 2005). Their long lives and high survival rates under natural conditions allow these trees to produce nuts for hundreds of years (Zuidema and Boot, 2002).

One characteristic of the population structure of the Brazil nut tree is that it forms stands of between 75 and 150 trees with DBHs > 10 cm (Peres and Baider, 1997) at high densities (5–20 trees ha^{-1}). These densities are higher than those of other tree species in the Amazon rainforest, with the exception of the oligarchic species identified by Peters et al. (1989). These stands are interspersed with areas of forest that contain densities of Brazil nut trees as low as 1 tree per 6 ha (Mori and Prance, 1990). Most demographic studies of Brazil nut populations have reported a low proportion of non-reproductive trees (DBH < 40 cm; Salomão, 1991; Nepstad et al., 1992; Peres et al., 2003) and a dominance of trees of

* Corresponding author. Tel.: +55 93 2101 49 37.
E-mail address: ricardscoles@yahoo.es (R. Scoles).
[1] Present address: Diretoria de Pesquisas, Instituto de Pesquisas do Jardim Botânico do Rio de Janeiro, Rua Pacheco Leão 915, Jardim Botânico, CEP 22460-030 Rio de Janeiro, RJ, Brazil.

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intermediate size (80 cm < DBH < 160 cm; Zuidema and Boot, 2002; Peres et al., 2003; Wadt et al., 2008; Salomão, 2009).

The patchy distribution of high-density stands of Brazil nut trees across the landscape and the dominance of intermediate diameter classes in the population structure of this species have been explained by three theories that are not mutually exclusive these high-density stands form because this species. The first is that grows best in large gaps during the initial stages of its life cycle (Mori and Prance, 1990; Salomão, 1991). The second is that the abandonment of fields used by indigenous peoples throughout history has permitted the development of approximately even-aged stands of Brazil nut trees and that therefore, these stands should be viewed as a type of anthropogenic forest (Ducke, 1946; Posey, 1985; Balée, 1989; Paiva et al., 2011; Scoles and Gribel, 2011). The third theory is that these stands can be explained by a pattern of short-range seed dispersal promoted by large caviomorph rodents called agoutis (*Dasyprocta punctata* and *Dasyprocta leporina*; Huber, 1910; Peres and Baider, 1997; Tuck Haugaasen et al., 2010).

The dispersal of the seeds of the Brazil nut tree begins with the fall of mature fruits during the rainy season. The second phase, the horizontal dissemination of seeds, can occur through the activity of agoutis. The storage and burial by agoutis of uneaten seeds in locations disparate from those of the fruit fall is called 'scatter-hoarding', and this is thought to be the principal mechanism of dispersal of Brazil nut seeds because a significant proportion of these seeds are subsequently not retrieved (Peres and Baider, 1997). Despite being primarily seed predators, agoutis are considered the principal dispersers of tropical tree seeds that produce lignified fruits (Peres et al., 1997). Under natural conditions, the majority of Brazil nut fruits are opened by these animals (Peres and Baider, 1997; Ortiz, 2002; Tuck Haugaasen et al., 2010).

Once germination has occurred, the survival of the seedling is supported by the large quantity of nutrient reserves in the seed. Seedling growth is promoted by favourable light conditions in large gaps or below canopy disturbances in the forest. The Brazil nut tree is a heliophytic species (Salomão, 1991) that behaves as a long-lived pioneer (Zuidema, 2003) of which the saplings are unable to develop in understory conditions (Myers et al., 2000; Peña-Claros et al., 2002).

Brazil nut seeds are an important non-timber forest product harvested by human populations that inhabit the Amazon rain forest. The intensive harvest of Brazil nuts can occur in productive stands, with seed harvest accounting for up to 93% of the removal of fruits from these stands (Zuidema and Boot, 2002). Harvest activities occur in areas both near and far from communities, and the choice of harvest location depends on the availability of time and resources as well as the seasonal productivity of Brazil nut stands. When more productive stands are located far from a community, the harvesters construct temporary shelters near these stands during the harvest. Concomitant with the intense removal of seeds from these stands, the harvesters also hunt animals, such as agoutis, during the harvest period, especially when harvest activity requires extended periods in the forest and away from the community (Ortiz, 1995; Zuidema, 2003; personal observation by the authors).

Although the intensive removal of Brazil nuts and the hunting of their principal dispersers (agoutis) might be expected to be detrimental to the natural regeneration of the species, the communities that practice Brazil nut extraction might, in fact, be promoting such regeneration. Brazil nut harvesters may serve as unintentional dispersers of Brazil nuts during harvest activities, including the opening of the fruits and the transport, washing, and storage of the nuts (Ortiz, 2002; Zuidema, 2003). Furthermore, in stands where harvests occur frequently, the increase in the small disturbances inherent to human activities in the forest could favour the establishment and growth of seedlings and saplings because of the increased penetration of light into clearings and around trails.

The relationship between the hunting of agoutis by Brazil nut harvesters and the natural regeneration of Brazil nut trees is neither direct nor simple to model. The reduction in agouti population size caused by hunting likely results in the opening of fewer fruits and a lower rate of nut storage and burial. Unopened fruits might hamper natural regeneration because most seeds do not germinate within unopened fruits, and seeds that do germinate in this condition likely have a poorer chance of surviving than those extracted by agoutis. However, an alternative view of the consequences of the relationship between agouti hunting and Brazil nut tree regeneration holds that as long as agoutis are not locally extinct (which is rare in exploited stands: Rumiz and Maglianesi, 2001; Ortiz, 2002; Rosas, 2006), the resulting lower levels of intraspecific competition will reduce the consumption of fruits by agoutis and promote a higher rate of nut storage and burial (Ortiz, 2002; Zuidema, 2003). Additionally, agoutis killed by hunters might leave behind large quantities of buried seeds that would not be subsequently found by other agoutis, and this may facilitate regeneration.

Currently, commerce in Brazil nuts is one of the principal sources of income for thousands of families in the Amazon region (Ortiz, 1995; Clay, 1997; Stoian, 2004). In fact, the Brazil nut seed is the only international commodity that is harvested exclusively in natural forests (Clay, 1997). According to the Brazilian Institute of Geography and Statistics (IBGE, 2010), in commercial terms, the Brazil nut is the second most heavily harvested non-timber forest product in northern Brazil after the assai fruit (*Euterpe* spp.).

The harvest of Brazil nuts is frequently used as an example of a human activity that can be compatible with both environmental conservation and socioeconomic development (Clay, 1997). The harvest of non-timber forest products, such as fruits and seeds, has generally been considered both an activity with a low environmental impact and an important source of income for the traditional communities that inhabit humid tropical forests (Fearnside, 1989; Allegretti, 1994; Anderson, 1994). However, extractive activities have also been criticised for their relatively high production costs, which are caused by the patchy distribution of the species in the forest, the minimal use of technology and a lack of consistency in product quality and uniformity, which are in high demand in modern trade (Homma, 1993, 2000; Amin, 1997; Clement, 2006).

Several studies evaluating the environmental impacts of extractive activities on forests have concluded that fruit and seed harvesting has limited short- and intermediate-term impacts; however, information on possible long-term impacts is currently lacking (Boot and Gullison, 1995; Ruiz-Pérez et al., 2004; Ticktin, 2004). The sustainability of Brazil nut harvests became a topic of controversy following the publication of a comparative meta-analysis of 23 natural populations of Brazil nut trees distributed throughout Amazonia (Peres et al., 2003). That study highlighted the relative scarcity of trees of non-reproductive age (juveniles) in intensely harvested stands and suggested that the history of extractive activities is the principal determinant of the current population structure in such stands. The conclusion of the study predicted that the demographic collapse of Brazil nut stands is likely under a regime of permanent exploitation and stressed the need to adopt regulations that neutralise the risks associated with an unsustainable activity, although such risks may not be apparent today due to the long life cycles of reproductive trees.

Several smaller-scale studies of demographics and regeneration in harvested stands of Brazil nut trees have contradicted the conclusions of the meta-analysis conducted by Peres et al. (2003). For example, several studies of forests with a history of harvesting activity in the state of Acre in southwestern Brazilian Amazonia have documented the regeneration of Brazil nut trees and have noted a tree population structure represented approximately by a