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# Brazil nut stock and harvesting at different spatial scales in southeastern Amazonia

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## Abstract

### Keywords:

*Bertholletia excelsa*

Kayapó

Landscape

Non-timber forest products

Satellite image

Evaluations of the effects of non-timber forest product (NTFP) extractive industries by traditional communities have focused on local effects, but effective conservation of species often requires evaluation at wider scales that can only be efficiently undertaken with the use of remote sensing. Brazil nut (*Bertholletia excelsa* seed) is one of the most important NTFP in the Amazon basin and has received considerable attention from researchers aiming to guarantee its sustainability. However, most studies evaluating the impacts of *B. excelsa* seed harvesting investigated only effects in harvested sites, and did not consider *B. excelsa* availability in the landscape, or patterns of harvesting at broader scales, which are critical to evaluate the viability of extraction and plan management practices. We used high-resolution satellite images associated with ground truthing, participative mapping with harvesters and harvest records, to evaluate abundance of *B. excelsa* in the territories of three Kayapó indigenous communities in southeastern Amazonia. This allowed us to obtain conservative estimates of the proportion of Brazil nut harvested by the Kayapó at scales appropriate to evaluate effects on stocks in the landscape and in harvested groves. *B. excelsa* groves are abundant in the Kayapó lands, but only about 30% of them are harvested. In recent years, the villagers have harvested from 7.2% to 43% of the seeds produced in harvested groves. These represent only 2.5–12.7% of total seeds estimated to have been produced within the Brazil nut-collection territories of those Kayapó villages. Our results show that the Kayapó have undertaken non-intensive Brazil nut harvesting at local and especially at landscape scales, which suggests that *B. excelsa* is currently not threatened by harvesting in the region and that there is still potential to expand commercial production in at least one of the sites. The application of similar multi-scale approaches in other sites and for other non-timber forest products would provide important information to evaluate their long term conservation, subsidize the development of management plans and help to guarantee the livelihoods of traditional communities.

## 1. Introduction

Non-timber forest products (NTFP)<sup>1</sup> have been considered one of the best alternatives for income generation by traditional people and for conservation of Amazonian forests (Anderson, 1990; Clay, 1997; Nepstad and Schwartzman, 1992; Richards, 1993). However, together

with the growing importance of NTFP as a conservation tool, concern over sustainability of their harvesting has increased, since overexploitation has been shown in many cases to cause ecological impacts for the harvested species (Gaoue and Ticktin, 2008, 2010; Nakazono et al., 2004; Peres et al., 2003; Scoles and Gribel, 2012; Ticktin, 2004; Ticktin et al., 2002). The availability of high-quality ecological information is critical to evaluate and plan sustainable harvesting of a NTFP, and estimates of resource distribution, abundance and productivity are considered to be the main inputs required for this evaluation (Peters, 1994). Information on spatial variation in environmental and harvesting conditions is also necessary to evaluate the impacts of harvesting (Gaoue and Ticktin, 2008; Ticktin, 2004).

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<sup>1</sup> NTFP is the abbreviation of non-timber forest product throughout the article.

Brazil nut, the seed of *Bertholletia excelsa* Bonpl. (Lecythidaceae), is one of the most important NTFP in the Amazon forest and is harvested almost exclusively from the wild (Clay, 1997; Mori, 1992; Ortiz, 2002). Brazil nuts have been harvested by indigenous people for thousands of years, and their commercialization is an important source of revenue for indigenous and riverine families in this region (Clement, 1999; Escobal and Aldana, 2003; Ortiz, 2002). Due to its importance for the Amazonian economy, *B. excelsa* has received considerable attention from scientists aiming to gather the ecological information necessary to increase commercial production and economic benefits for harvesters, as well as to guarantee its long-term use. Studies have been undertaken throughout the Amazon on the demography of *B. excelsa* (Peres and Baider, 1997; Scoles, 2010; Wadt et al., 2005; Zuidema and Boot, 2002), pollination (Maués, 2002), seed dispersal and predation (Baider, 2000; Jorge and Peres, 2005; Peres et al., 1997; Tuck Haugaasen et al., 2010), seed germination (Kainer et al., 1999), fruit production (Baider, 2000; Kainer et al., 2006, 2007) and seedling establishment (Cotta et al., 2008; Kainer et al., 1998; Myers et al., 2000; Paiva et al., 2011; Scoles, 2010), as well as the evaluation of impacts of harvesting (Peres et al., 2003; Scoles and Gribel, 2011; Wadt et al., 2008; Zuidema and Boot, 2002).

Although there is growing information about the ecology of *B. excelsa*, little is known about *B. excelsa* tree abundance and distribution, or harvesting patterns across the landscape. Except for the study of Scoles and Gribel (2011), evaluations of the effects of Brazil nut harvesting are usually based on one to three sites (Baider, 2000; Wadt et al., 2008; Zuidema and Boot, 2002). Even when those results are grouped for the whole Amazon (e.g., Peres et al., 2003), they still reflect the local effects of seed collection and do not consider impacts on the species throughout the landscapes around the studied localities. This is mainly due to the time-consuming and costly field work required to map *B. excelsa* trees in the forest and, consequently, reliable estimates of sizes of stocks of Brazil nut in larger landscapes are unavailable. Although these approaches are not necessarily incorrect, since they reflect the scale of interest of authors (Levin, 1992), inferences based on them about *B. excelsa* conservation status at wider scales may be unreliable. The lack of information about stocks across the landscape also limits the options for adaptive management in the case of overexploitation.

All ecological relationships depend on the scale evaluated (Peterson and Parker, 1998), and analysis of the effects of human harvesting on natural resources at scales different than those usually studied may provide valuable information to conserve and manage species where they are exploited (Levin, 1992). In this paper, we evaluate, through use of high-resolution satellite images, associated with ground truthing, participative mapping with harvesters and harvest records, how estimates of Brazil nut stocks and the proportion of seeds harvested vary depending on the scale evaluated, in three indigenous communities located in a reserve in southeastern Amazonia. Specifically, we asked the following questions: (1) What is the abundance of *B. excelsa* trees and seeds in the groves harvested by the Kayapó Indians and in the landscape (here considered the Brazil nut-collection territories of the villages)? (2) What is the proportion of *B. excelsa* groves in the landscape that is harvested by the Kayapó? (3) How does the proportion of Brazil nut harvested by the Kayapó vary at local (groves) and landscape scales?

## 2. Materials and methods

### 2.1. Study site and species

The study was undertaken in the territories of three Kayapó villages – A'Ukre (07°41'43"S, 51°52'53"W), Moikarakô (07°26'11"S,

51°48'57"W) and Kikretum (07°08'17"S, 51°39'26"W), located along the Riozinho and Fresco Rivers, which are second- and first-order tributaries of the Xingu River, respectively (Fig. 1). The three villages are located in the Kayapó Indigenous Land (hereafter Kayapó IL), a 3,284,005 ha reserve in southeastern Amazonia, in the transition zone between the Amazon forest and the savannas of central Brazil, where the dominant vegetation is seasonally-dry forest (Salm, 2004). The altitude of Kayapó IL varies between 200 and 500 m and the climate of the region is humid and hot, with a prominent dry season between May and August. The mean annual rainfall between 1996 and 2002 was 2100 mm and mean monthly maximum and minimum temperatures were 34.2 °C and 18.1 °C (Jerolimski, 2005).

At the time the study was conducted, A'Ukre, Moikarakô and Kikretum had approximately 380, 380 and 840 inhabitants respectively. The distance between the most southern (A'Ukre) and the most northern village (Kikretum) is 65 km. The size and the boundaries of the territories of each Kayapó village are not clearly defined, but there are political agreements about the use of natural resources by each village. In the case of Brazil nut, harvesting territories are contained within a radius of approximately 15–20 km around each village. The Kayapó people traditionally harvest Brazil nuts for subsistence (Robert, 2009), and most families of the studied villages have been involved in Brazil nut harvest for subsistence or trade in the last decades. A'Ukre produced Brazil nut oil for a British cosmetics firm between 1991 and 2003, and has sporadically traded nuts on the local market. Moikarakô has traded nuts on the local market only in the last few years. Kikretum has constantly traded Brazil nuts on the local market due to its proximity to cities, except during the logging period between the late 1980s and 2002. Since 2005, all three communities have been engaged in an initiative of Brazil nut certification and fair trading lead by the Associação Floresta Protegida (AFP), a local indigenous non-profit organization.

*B. excelsa* occurs in *terra firme* forests of Brazil, Bolivia, Peru, Colombia, Venezuela and the Guianas (Mori and Prance, 1990; Peres et al., 2003; Shepard and Ramirez, 2011), and is among the tallest and most long-lived species of the Amazon forest (Mori and Prance, 1990; Vieira et al., 2005). Brazil nut trees normally occur in groves (clumps) of few to more than 300 individuals (Mori, 1992; Peres and Baider, 1997; Ribeiro, 2011), although individuals may be randomly distributed at relatively low densities in some areas (Wadt et al., 2005), and density of reproductive trees in these sites usually varies between 1 and 10 individuals ha<sup>-1</sup> (Baider, 2000; DHV, 1993; Peres et al., 2003; Ribeiro, 2011; Scoles, 2010; Wadt et al., 2005). Fruit production usually varies from about 60–180 fruits per tree per year (Baider, 2000; Kainer et al., 2006, 2007; Zuidema and Boot, 2002). Fruits of *B. excelsa* are extremely hard, contain from 10 to 30 seeds and fall during the rainy season (Baider, 2000). Apart from humans, only a few species can open *B. excelsa* fruits, including agoutis, which are the main non-human Brazil nut predators and dispersers (Baider, 2000; Tuck Haugaasen et al., 2010). Recruitment of young *B. excelsa* trees in natural forest occurs mostly in gaps (Myers et al., 2000).

### 2.2. Data collection and analysis

#### 2.2.1. Abundance and location of *B. excelsa* groves

Information on the abundance and location of *B. excelsa* groves in the territory of each Kayapó village was obtained from Kayapó villagers during participative mapping and interviews. We conducted three participative-mapping sessions, one in each Kayapó village. During a community meeting, satellite images with geographic and cultural references were presented to the Kayapó, who indicated the location and names of *B. excelsa* groves in the villages. Additionally, 98 interviews were conducted with individual villagers, 37 in A'Ukre, 32 in Moikarakô and 29 in Kikretum.

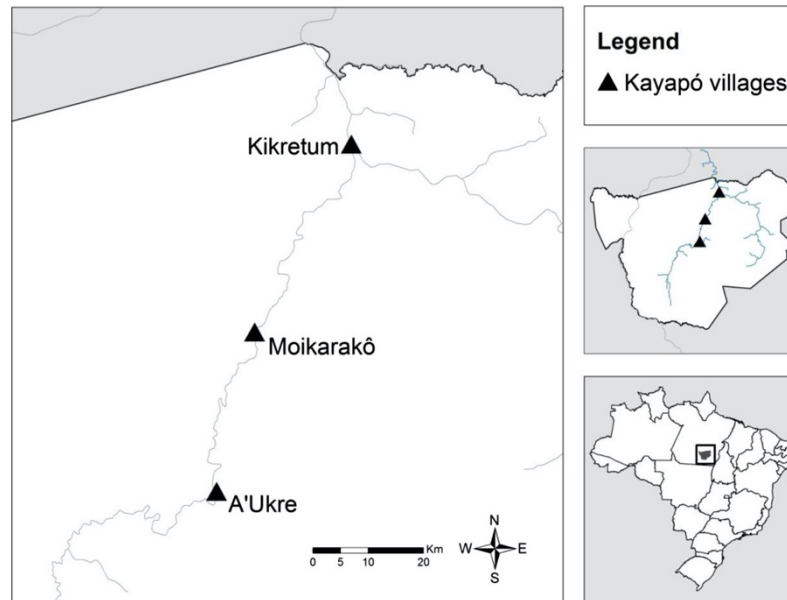


Fig. 1. Location of the study site and the Kayapó villages A'Ukre, Moikarakô and Kikretum, within Kayapó Indigenous Land, Southeastern Amazonia, Brazil.

During interviews, which were conducted in the Kayapó native language with the help of a Kayapó translator, each person was separately asked to cite the names of the *Brazil nut* groves in the territory of their respective village.

#### 2.2.2. Area of *B. excelsa* groves

The areas of *B. excelsa* groves, as well as information on unknown groves, were obtained through the analysis of high-resolution panchromatic (2.5 m) and multispectral (10 m) SPOT 5 HRG satellite images (obtained on 6 April 2006). We visited nine of the *B. excelsa* groves identified during participative mapping and interviews accompanied by experienced Kayapó harvesters, and registered the geographic coordinates of 1101 adult *B. excelsa* trees with diameter at breast height (DBH)  $\geq 60$  cm. By plotting the coordinates of recorded trees on the high-resolution SPOT images, it was possible to identify individual *B. excelsa* trees and groves (Fig. 2) due to the conspicuous pattern produced by *B. excelsa* tree canopies. This analysis provided detailed information about the area, distribution of groves and the identification of unknown groves in the Kayapó territories. Four new groves found through satellite images were verified in the field. The area of groves was calculated using the program ArcGIS (Johnston et al., 2001) and we considered that *B. excelsa* trees located more than 200 m from others were not part of the grove. We used the areas of 62 groves visible on the satellite image to calculate the mean area of groves for each Kayapó village.

#### 2.2.3. Density of *B. excelsa* trees in the groves

In April to June 2009 and April to June 2010, we estimated the density of adult *B. excelsa* trees (DBH  $\geq 60$  cm) in 21 *B. excelsa* groves (four in the territory of Kikretum village, 12 in the territory of A'Ukre and five in the territory of Moikarakô). The 21 Brazil-nut groves sampled were spatially distributed on both sides of the river and included small, large, harvested and unharvested groves, as well as groves unknown to the Kayapó. Density was estimated from line transects established from the border to the interior of each grove along its longest axis, usually crossing the entire grove. In very small groves, two perpendicular transects were established, discounting the overlap area where they crossed. Transect lengths varied from 600 to 1400 m, depending on the size of the grove. We

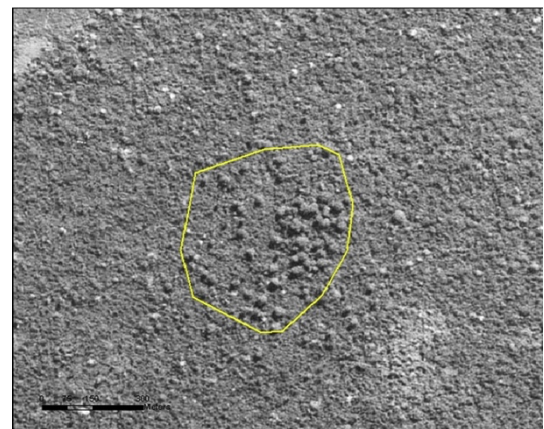


Fig. 2. *Bertholletia excelsa* grove identified in the Kayapó Indigenous Land, Southeastern Amazonia, from a SPOT 5 HRG panchromatic image obtained in 06/04/2006. Copyright CNES. Source: SEAS Guyane, project 0042-IRDUR169. Exclusive commercial distribution Spot image SA.

measured all adult trees seen and recorded their perpendicular distance from the transect. Densities were estimated with the program DISTANCE (Buckland et al., 2001), with truncated distances of 30 m on each side of the transect line. At this truncation distance, the probability of detection of individuals estimated by DISTANCE was 1 and the mean detection distances did not differ among groves (ANOVA:  $F_{20,342} = 0.05$ ,  $P = 0.58$ ). When the number of detected individuals in any one grove was below the limit to estimate densities using DISTANCE (usually less than 30 individuals), we corrected the density by a correction factor calculated with DISTANCE using transects of all groves pooled in a single analysis.

#### 2.2.4. Fruit and seed production by *B. excelsa* trees

The mean production of fruits by *B. excelsa* trees was obtained from Baider (2000), who counted fruits of 48 trees ( $>60$  cm DAP) in two groves located at Pinkaiti Research Station (12 km from A'Ukre village and inside our study site), for four consecutive years (1997–2000). That study estimated the mean number of *B. excelsa* fruits produced per tree annually ( $\pm$ SD) as  $184.3 \pm 72.2$ , ranging

from 103.2 fruits per tree in years with low productivity to 269.5 fruits per tree in years with very high productivity. To determine whether Baider's data, collected in different years from our study, reflects current seed production by *B. excelsa* trees in our study site, we compared her estimates with data on seed production obtained by us from 79 trees of seven Brazil-nut groves in 2010 (considered by the Kayapó a year of high fruit production). In each of those trees we counted all fruits in the ground under the canopy tree and 10 m from it. The mean number of seeds per fruit was estimated by counting seeds from a total of 329 fruits of 22 *B. excelsa* trees from the same seven groves in the three Kayapó villages in the years of 2009 and 2010. The mean weight of dry *B. excelsa* seeds was obtained from Baider (2000), and corresponds to 13 g/seed.

### 2.2.5. Brazil nut stocks in harvested groves and in the landscape

Information on the number and names of the *B. excelsa* groves harvested in the territory of each of the three Kayapó villages was obtained during participative mapping and interviews with villagers, as well as from AFP harvest records during the harvesting seasons of 2009 and 2010. We estimated stocks of Brazil nuts for the harvested groves and for the whole territory of each of the three Kayapó villages, and for the territories of the three villages combined. Seed stock in groves (in tons) was calculated as the product of the mean area of the groves in each village, mean density of *B. excelsa* trees in the groves, mean fruit production by adult trees, mean number of seeds per fruit, and mean mass of seeds.

### 2.2.6. Proportion of Brazil nut collected from harvested groves and from the landscape

The amount of Brazil nut in tons commercialized by each village was obtained from AFP harvest records during the harvesting seasons of 2009 and 2010. The amount of Brazil nut harvested for subsistence by the Kayapó was estimated from the number of sacks collected for home consumption, based on 98 interviews with villagers, 37 in A'Ukre, 32 in Moikarakô and 29 in Kikretum. We calculated the proportion of Brazil nut harvested (in tons) in the landscape and in harvested groves from the amount of seeds harvested by the Kayapó for commercial and subsistence purposes, and the estimates of Brazil nut seed stocks in the landscape and in harvested groves.

## 3. Results

### 3.1. Abundance, location and use of *B. excelsa* groves by the Kayapó

Based on participative mapping, interviews and harvest records, we identified 117 *B. excelsa* groves known to the Kayapó in the territories of the three villages, plus four groves in the A'Ukre territory unknown to the Kayapó that were found through analysis of satellite images. The Kikretum territory has 73 groves spread along both sides of the Fresco and Branco Rivers. A'Ukre has 35 groves, most of them on the right bank of Riozinho River, and many of them can be accessed only on foot. Moikarakô territory has 13 groves, spread along both sides of the Riozinho River. Only about 30% of the groves cited by the Kayapó are harvested. Only 25 of 73 groves in Kikretum territory are harvested, and those are the groves nearest to the village and closest to the river bank. In the A'Ukre territory, only nine of 35 groves are frequently harvested. In Moikarakô territory, only four of 13 groves are harvested, and those are the ones accessible from the river.

### 3.2. Area of the *B. excelsa* groves

More than 60 *B. excelsa* groves were detected in the vicinity of Kikretum by inspection of satellite images. However, not all of

them are clearly defined, and this restricted our estimates of grove areas in this village territory. Most groves in the Kikretum territory are large and their edges delimited by areas subject to flooding. In the territories of A'Ukre and Moikarakô, groves are smaller and well defined. Due to these differences, we calculated separate mean areas for the groves of each village. The mean area of the groves ( $\pm$ SD) was  $181.7 \pm 179.7$  ha ( $n = 24$ ) in Kikretum,  $69.9 \pm 65.5$  ha ( $n = 30$ ) in A'Ukre, and  $87.0 \pm 115.3$  ha ( $n = 8$ ) in Moikarakô territory. Grove area in the territories of the three villages ranged from 5.4 to 840 ha.

### 3.3. Density of *B. excelsa* trees in groves

Density of adult *B. excelsa* trees (DBH  $\geq 60$  cm) estimated from line transects varied greatly among Kayapó village territories (min. = 1.0, max. = 5.1 individuals  $\text{ha}^{-1}$ ). Although groves associated with Kikretum are larger, the density of *B. excelsa* trees in the territory of this village is lower than in the others (mean  $\pm$  SD;  $1.7 \pm 0.6$  trees  $\text{ha}^{-1}$ ,  $n = 4$ ). A'Ukre groves have the highest densities of adult *B. excelsa* trees ( $3.5 \pm 1.2$  trees  $\text{ha}^{-1}$ ,  $n = 12$ ), while groves in the Moikarakô territory were intermediate in density ( $2.4 \pm 1.1$  trees  $\text{ha}^{-1}$ ,  $n = 5$ ).

### 3.4. Fruit and seed production by *B. excelsa* trees

The mean fruit production per grove in 2010 was  $207 \pm 97.6$  fruits per tree, which was comparable to Baider's estimates (269.5 fruits/tree) for a year considered of high productivity. Therefore, we consider that Baider's estimates reflect current seed production, especially considering that our estimates did not include fruits dispersed to more than 10 m out of the mother tree, while hers include, since fruits were counted before they fell from the trees. Considering that the mean fruit production of 184.3 fruits/tree provided by Baider (2000), that the mean number of seeds per fruits was  $17.4 \pm 2.6$ , and that the mean mass of each seed was 13 g (Baider, 2000), the mean number of *B. excelsa* seeds produced per tree each year would be 3207, which corresponds to 41.7 kg of seeds. In years of low productivity, this production per tree falls to 1796 and 23.3 kg, but can reach 4689 seeds and 61.0 kg in years of high productivity.

### 3.5. Brazil nut stocks in the landscape and in harvested groves

According to our estimates, in years of low seed productivity, total Brazil nut stock in the three villages was approximately 791 tons, ranging from 64 to 519 tons in the territories of Moikarakô and Kikretum villages, respectively. In years of high productivity, total stocks reach around 2000 tons, with stocks in individual villages ranging from 168 to 1355 tons in Moikarakô and Kikretum territories, respectively. Considering only the harvested groves, total Brazil nut stock in years of low productivity is around 250 tons, with stocks in individual villages ranging from 20 to 178 tons in Moikarakô and Kikretum, respectively, whereas in years of high productivity harvested groves have total stocks of about 655 tons, and stocks in individual villages ranging from 52 to 464 tons in Moikarakô and Kikretum (Table 1).

### 3.6. Amount of Brazil nut harvested by the Kayapó

The total amount of Brazil nut harvested for commercial purposes by the Kayapó seems to be proportional to the amount of seed produced by trees in that year (Fig. 3). According to AFP records, seed harvesting for commercial purposes varies from zero, in years of extremely low production and in which harvesters do not consider it worthwhile to collect for the market (such as in 2008), to more than 110 tons in years when seed production is very

Table 1

*Bertholletia excelsa* seed stocks in the harvested groves and in the territories of the Kayapó villages Kikretum, A'Ukre and Moikarakô, Southeastern Amazonia, estimated for years of low, medium and high seed production by *B. excelsa* trees. KKT = Kikretum, AUK = A'Ukre, and MKK = Moikarakô.

	KKT	AUK	MKK	Total
<i>Harvested groves</i>				
Stock of <i>B. excelsa</i> seeds (ton) – low productivity	177.7	53.5	19.8	250.9
Stock of <i>B. excelsa</i> seeds (ton) – medium productivity	317.3	95.5	35.4	448.1
Stock of <i>B. excelsa</i> seeds (ton) – high productivity	463.9	139.6	51.7	655.3
<i>Landscape</i>				
Stock of <i>B. excelsa</i> seeds (ton) – low productivity	518.8	207.9	64.4	791.1
Stock of <i>B. excelsa</i> seeds (ton) – medium productivity	926.4	371.3	115.0	1412.7
Stock of <i>B. excelsa</i> seeds (ton) – high productivity	1354.6	542.9	168.2	2065.7

high. In 2009, considered by the Kayapó a year of low to medium seed production, the total amount of Brazil nut harvested by the three Kayapó villages together was 64.5 tons (40.5 Kikretum, 15.2 A'Ukre, 8.8 Moikarakô), according to AFP records. In 2010, considered a year of high productivity, villagers sold 114.5 tons of Brazil nut (88.6 tons by Kikretum, 16.9 tons by A'Ukre, and 9.0 tons by Moikarakô).

Brazil nuts are important in the diet of the Kayapó people and seed harvesting for subsistence is relatively constant and independent of seed production by *B. excelsa* trees than harvesting for commercial purposes (Fig. 3). The mean amount of Brazil nut consumed by each Kayapó family (household) annually ( $\pm$ SD) is  $2.3 \pm 2.2$  sacks of about 60 kg ( $n = 80$ ). Considering that the mean number of members of Kayapó households is 9 and that Kikretum, A'Ukre and Moikarakô have 839, 380 and 384 inhabitants (obtained from National Health Foundation of Brazil in March 2010), the total amount of Brazil nuts consumed each year for subsistence by the three Kayapó villages is approximately 25 tons (12.9 tons in Kikretum, 5.9 tons in A'Ukre and 5.8 tons in Moikarakô).

### 3.7. Percentage of Brazil nut harvested in the landscape and in harvested groves

The percentage of Brazil nut harvested by the Kayapó for commercial and subsistence purposes from the harvested groves ranged from 7.2% in Kikretum, in years of low harvesting intensity and seed production, to 41.3% in Moikarakô, in years of medium harvesting intensity and medium seed production by *B. excelsa* trees. In the year of high seed production (2010), the percentages of Brazil nuts collected were lower for Moikarakô and A'Ukre villages (16.4% and 28.6% respectively) than in the year of medium

harvesting and seed production (2009–22.1% and 41.3%). In Kikretum, almost twice as many seeds were harvested in 2010 than in 2009, but this represented only 21.9% of the local Brazil nut stock due to the large number of groves in the village territory. However, in years of low seed production, even a medium-intensity harvest may result in a high percentage of seeds harvested (almost 75%), especially in the territory of Moikarakô, which has the lowest number of groves. On average, the proportion of the Brazil nut stock removed from the landscape was at least three fold lower than the proportion removed from harvested groves. The proportion of Brazil nut removed from the landscape stock varies from about 2.5% in years of low harvesting and low seed production, to 12.7% in years of medium harvesting and seed production, and could reach a maximum of about 23% in the case of high harvesting intensity in a year of low seed production, a situation that has not been recorded (Table 2).

## 4. Discussion

Brazil nut is a major extractive product which is widespread in most Amazonian regions (Peres et al., 2003; Shepard and Ramirez, 2011) and is harvested from wild stands that generally occur in large areas of preserved forests (Clay, 1997; Ortiz, 2002; Scoles, 2010; Wadt et al., 2008). Although studies have evaluated the local impacts of Brazil nut harvesting on *B. excelsa* populations, the impacts of harvesting, the management and the conservation of this species in large forest areas will be affected by the abundance of individuals at wider scales. In this study, we show that changing the scale of analysis may provide different perspectives and important information to evaluate the sustainability of harvesting and subsidize development of management plans for Brazil nut harvesting. The use of high-resolution satellite images to identify *B. excelsa* groves across the landscape was critical to quantify the abundance of Brazil nut and the amount of seeds harvested at broader scales.

### 4.1. Methodological considerations about harvesting estimates

Data on fruit production used here to calculate the proportion of Brazil nut harvesting by the Kayapó (Baider, 2000) were based on *B. excelsa* trees from two groves located in our study site, which were also sampled by us. Fruit production by *B. excelsa* trees has been shown to be spatially correlated in Acre (Kainer et al., 2007), so it is possible that *B. excelsa* fruit production also varies between groves in Kayapó IL, which could add error to our estimates. Baider's data were also collected in different years from this study, although they included temporal variability in production over four consecutive years. The comparison with fruit production data collected by us in different groves in 2010, however, showed that Baider's data seem to reflect current seed production by *B. excelsa* trees in the study area. All other parameters were estimated for each village, so errors in estimates of mean production per tree

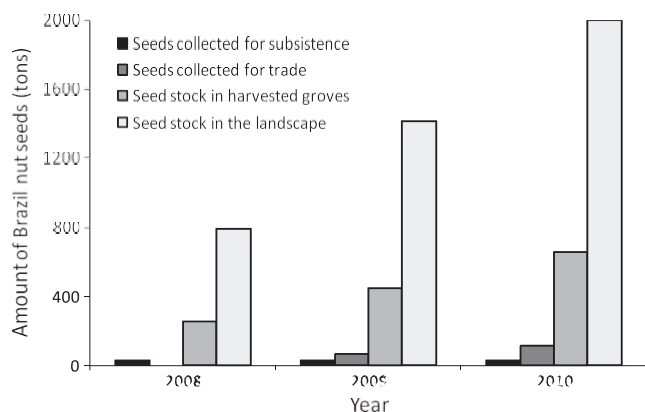


Fig. 3. Estimated amount in tons of Brazil nut harvested for subsistence and for commercial purposes by the Kayapó of A'Ukre, Kikretum and Moikarakô villages, Southeastern Amazonia, and estimated seed stocks in harvested groves and in all groves in the Brazil nut-harvesting territories of those villages, in the years of 2008, 2009 and 2010.

Table 2

Estimated percentages of *B. excelsa* seeds harvested from harvested groves and in the territories of the Kayapó villages Kikretum, A'Ukre and Moikarakô, Southeastern Amazonia, in years of low, medium and high seed production by *B. excelsa* trees, and under low, medium and high harvesting intensities. Values with asterisks are based on the percentages of seed harvested according to registers of commercial harvesting for 2008, 2009 and 2010, and information on subsistence harvesting from interviews with the Kayapó. KKT = Kikretum, AUK = A'Ukre, and MKK = Moikarakô. Values without asterisks are estimated values that would apply if the Kayapó did not adjust harvesting intensity to productivity.

	2008 – Low harvesting intensity				2009 – Medium harvesting intensity				2010 – High harvesting intensity			
	KKT	AUK	MKK	Total	KKT	AUK	MKK	Total	KKT	AUK	MKK	Total
<i>Harvested groves</i>												
% of harvesting – low-productivity year	7.2	11.0	29.4	9.8	30.0	39.4	73.8	35.5	57.1	42.7	74.7	55.4
% of harvesting – medium-productivity year	4.1	6.2	16.5	5.5	16.8	22.1	41.3	19.9	32.0	23.9	41.8	31.0
% of harvesting – high-productivity year	2.8	4.2	11.3	3.8	11.5	15.1	28.3	13.6	21.9	16.4	28.6	21.2
<i>Landscape</i>												
% of harvesting – low-productivity year	2.5	2.8	9.0	3.1	10.3	10.1	22.7	11.3	19.6	11.0	23.0	17.6
% of harvesting – medium-productivity year	1.4	1.6	5.1	1.7	5.8	5.7	12.7	6.3	11.0	6.2	12.9	9.8
% of harvesting – high-productivity year	0.9	1.1	3.5	1.2	3.9	3.9	8.7	4.3	7.5	4.2	8.8	6.7

would have little effect on our estimates of the proportion of seeds harvested from the landscape.

We did not include *B. excelsa* trees isolated from the groves in seed-production estimates for the landscape. This is especially relevant for the territory of Kikretum village, where we identified a considerable number of isolated trees outside groves. Furthermore, the areas of the *B. excelsa* groves estimated from satellite images are also underestimated, since only the larger trees are detected on the image. Therefore, our estimates of seed production are conservative and the estimated percentage of seeds harvested is probably higher than the amount actually harvested.

Future estimates should include spatial variability of fruit production from trees of different sub-regions studied, which would provide more accurate estimates of proportion of seeds harvested. Moreover, a spatial analysis of the SPOT-identified *B. excelsa* trees would help to quantify the spatial distribution or the degree of aggregation of the species in the different villages, as well as the relative importance of isolated trees to the total stock of seeds in the landscape. It is worthy to note that our study was conducted in a seasonally-dry forest, where *B. excelsa* is one of the few emergent species, which facilitated the identification of *B. excelsa* trees and groves. In forests with a higher and denser canopy, *B. excelsa* trees may not be as conspicuous (but see Carleer and Wolff, 2004).

#### 4.2. Patterns of Brazil nut harvesting by the Kayapó in local and landscape scales

Overall, our results indicate that Brazil nut harvesting by Kayapó Indigenous peoples of the studied villages has been of low-intensity at local and, especially, at landscape scales. Although there are dozens *B. excelsa* groves in the territories of Kayapó villages, only about 30% of them are harvested, usually the ones that are most accessible, those with the highest densities of trees, and those belonging to their families or chiefs. Besides the low proportion of groves harvested, the Kayapó harvested only part of the seeds produced in harvested groves (7.2–41.3%) and this proportion is much lower when we consider seeds produced in all the groves found within the village's territories (2.5–12.7%). The amount of Brazil nut harvested by the Kayapó usually is correlated with the productivity of groves in that year. However, even if the Kayapó harvested the maximum amount observed in the last few years in a year of very low seed production, it would still be within the limits suggested by Peters (1994) as acceptable and likely to not have negative effects on harvested populations. Zuidema and Boot (2002), based on matrix population models, concluded that harvesting of 93% of *B. excelsa* seeds was sustainable in a Bolivian locality. For palm species, studies have shown that a harvesting level of 80–95% of the seeds may be sustainable (Ticktin, 2004).

The amount of Brazil nut harvested by the Kayapó and, therefore, the impacts on *B. excelsa*, are influenced by the demand for seeds and by the effort of seed harvesters. Many factors influence the effort of harvesters, including seed production by trees, market prices, distance to markets and access to public policies which promote the commercialization of forest products. In the case of the villages of A'Ukre and Moikarakô, the amount of Brazil nut harvested is in part limited by the difficulty and cost of transportation. That is probably why the amount of Brazil nut harvested in those villages did not vary with seed production by trees in the years between 2009 and 2010, as occurred in Kikretum. It is likely that an increase in the market price of Brazil nut would be followed by an increase in effort by harvesters.

Furthermore, an increase in the Kayapó population density would probably result in a higher Brazil nut harvesting pressure. This could be a problem for sustainability of harvesting in the Moikarakô territory, where there are few groves and unharvested groves are distant from the village. In the case of Kikretum, which is the village closest to cities and with the highest dependence on income-generation activities, Brazil nut production could be enhanced without threatening *B. excelsa* populations. In this village, despite the large amount of Brazil nut harvested, the proportion of seeds harvested from the stock in the forest is still very low (max. 20%), and there are many unharvested groves.

#### 4.3. Implications for management of *B. excelsa*

Our results show that the indigenous people of the studied villages have conducted non-intensive Brazil nut harvesting, whether the analysis is conducted at the scale of the landscape or within harvested groves. As most of the *B. excelsa* groves in the area are not harvested, even if the harvest reduced recruitment of individuals in harvested groves, this would affect only a small proportion of groves in the area. Management practices, such the expansion of harvesting by the Kayapó to other groves associated with reduction of harvesting intensity within groves or the alternation of harvesting between groves, could be implemented if overexploitation leads to reductions in recruitment of *B. excelsa*. As current Brazil nut harvest levels probably do not represent a threat to *B. excelsa* in the region, there is still potential to expand commercial seed production to other unharvested groves in one of the villages. Besides the identification of unknown *B. excelsa* groves, the use of high-resolution satellite images makes it possible to plan the location of trails to facilitate access to those and other unharvested sites.

More than 36% of the Brazilian Legal Amazon is under some form of protection that allows extractive activities by traditional peoples (Verissimo et al., 2011) and most of these areas are within the geographic distribution of *B. excelsa*. Multi-scale approaches,



such as the one we have used here, could provide important information not only to evaluate the intensity of Brazil nut harvesting, but to plan management practices over larger areas to increase both sustainability and income generation for traditional harvesters.

#### 4.4. Conclusions

The use of high-resolution satellite images associated with ground truthing, participative mapping with harvesters and harvest records, allowed us to evaluate harvest pressure on *B. excelsa* at local and landscape scales and provided important information for the development of management plans for Brazil nut harvesting in the studied site. Conservative estimates of the proportion of Brazil nut stocks harvested from Kayapó collecting territories indicate that such harvesting is unlikely to be a threat to the species unless technology permits levels of extraction far above those currently practiced.

We suggest that, especially in sites where extractive industries appear to represent a threat to the harvested species, the application of similar multi-scale approaches for this and other non-timber forest products would provide important information to evaluate their long term conservation and devise effective management plans to protect the species and the resources on which the people depend.

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