Brazil nut conservation through shifting cultivation

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ARTICLE INFO

ABSTRACT

The regeneration of Brazil nut trees depends on tree-fall gaps in the forest. However, shifting cultivation fallows also create comparable biotic and abiotic opportunities for the dispersion and establishment of this gap-loving species. At the same time, the ability of Brazil nut trees to resprout enables fallow individuals to survive successive slash-and-burn cycles. Recognizing the importance of shifting cultivation for the food security of forest dwellers, we investigated whether the high level of Brazil nut regeneration found in cultivation fallows could be explained by the resprouting capability of Brazil nut trees, the number of cultivation cycles, past agricultural use and distance to the nearest conspecific productive adults. We found that the Brazil nut tree population density increased from 8.86 trees ha^{-1} to 13.69 trees ha^{-1} and 27.09 trees ha^{-1} at sites after one, two and three or more shifting cultivation cycles, respectively. As a consequence of resprouting, after a certain number of shifting cultivation cycles, the fallows become dominated by Brazil nut trees, and the landholders may decide to preserve them and to exclude enriched sites from future agricultural use. Protected for their extractive value, the secondary forests spontaneously enriched with Brazil nut trees are allowed to develop into nut-producing forests that have reduced chances of conversion into crops or pastures, thus reversing the classical process of Amazon forest degradation.

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1. Introduction

The Brazil nut (BN)[1] tree (*Bertholletia excelsa*, Bonpland, 1808) is currently classified as vulnerable to extinction (IUCN, 2010). Its conservation status is attributed to extensive seed gathering, which is said to compromise the regeneration of the over-exploited populations, and to deforestation, which reduces the species' biogeographical range. That harvest pressure may result in vulnerability is controversial. This issue continues to divide those who support (Wadt et al., 2008; Zuidema and Boot, 2002) the ecological sustainability of BN extraction from those who deny that such sustainability is possible (Peres et al., 2003). In contrast, BN vulnerability due to habitat loss is clearly a direct consequence of the conversion of Amazon forests into agricultural fields (Escobal and Aldana, 2003) and pastures (Clay, 1997).

Medium to large farms and cattle ranches are responsible for nearly 70% of total Amazon deforestation (Fearnside, 2005). Indigenous and extractive populations stand out as historical antagonists and as a force for political resistance against latifundium expansion (Allegretti, 1990; Campos and Nepstadt, 2006). However, the forest dwellers also depend on agriculture for their subsistence, and shifting cultivation (SC)[2] plays an important role that complements extractive seasonality (Escobal and Aldana, 2003). Conklin (1961) defined SC as any continuous agricultural system in which impermanent clearings are cultivated for shorter periods (in years) than they are left to lie fallow. In the Amazon, SC has been practiced by indigenous and traditional populations for centuries and has created a significant portion of the forests that many consider pristine (Balée, 1993; Denevan, 1992).

The effect of SC on BN regeneration is well known by extractivists, who consistently report greater BN regeneration levels in fallows than in nearby undisturbed forests (Wadt et al., 2005). The dispersal of this nut-producing tree depends on a highly specialized mutualism with scatter-hoarding agoutis (*Dasyprocta* sp.), for seeds that remain trapped inside unopened fruits suffer almost 100% mortality (Peres et al., 1997). Although they are prized as bush meat, agoutis are relatively resilient to hunting pressure and remain abundant even in areas having long histories of BN collection (Peres and Baider, 1997; Rumiz and Maglianesi, 2001). Agoutis frequently visit SC crops for food and may also bene-

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[1] BN is the abbreviation for *Brazil nut* throughout the article.

[2] SC is the abbreviation for *shifting cultivation* throughout the article.

fit from the entangled vegetation and hollow trunks in fallows. These resources may offer shelter (Silvius and Fragoso, 2003) or visual cues for finding buried seed stocks (Smith and Reichman, 1984). Moreover, scatter-hoarding animals often transport nuts from late-successional, closed-canopy forests to hide them in early successional habitats such as old fields and disturbed areas. The animals thereby avoid pilferage from other nut-eaters that forage primarily in the forest (Vander Wall, 2001).

If the nuts transported to fallows survive and germinate, they have a higher probability of success due to reduced competition and a more favorable light environment. The luminosity is important because BN trees are light-demanding and depend on gaps in the forest to attain their reproductive size (Mori and Prance, 1990). Cotta et al. (2008) were first to outline an experiment to compare and explain the difference in BN regeneration density between fallows and mature nut-producing forests. They concluded that the higher density observed in fallows results from higher light availability. This conclusion for the fallow environment agrees with that established for forest tree-fall gaps, on which BN regeneration depends under closed canopy (Myers et al., 2000).

However, SC fallows are not tree-fall gaps (Janzen, 1990). Because of cyclical disturbances, SC creates gaps at a much higher frequency than do natural tree falls in the forest. In addition, every slash-and-burn cycle is a drastic intervention that eliminates all above-ground biomass before recreating the favorable biotic and abiotic conditions for the reestablishment of vegetation. Sprouters are favored over seeders when disturbance regimes are frequent and severe (Bond and Midgley, 2003), as in the dynamic environment of SC. Thus, to obtain a clear understanding of the effect of SC on BN regeneration, it is essential to consider the species' resprouting capability (Kainer et al., 1998).

Given the importance of SC to the economy and food security of BN-extractive communities, as well as the species' light-gap dependence and its ability to resprout from consecutive slash-and-burn events, we evaluated whether the high BN regeneration density observed in fallows near nut-producing areas could be explained by the (i) number of SC cycles, (ii) past agricultural use, (iii) resprouting capability, and (iv) distance to parent trees. Finally, we asked if the spontaneous enrichment of fallows influences landholders' decisions to protect them from further conversion into crop or pasture sites.

2. Materials

2.1. Study area

The study took place in the Reserva Extrativista do Rio Cajari, Amapá, Eastern Amazon, Brazil. The region contains a dense and open submontane rainforest with an Am Köppen climate (Peel et al., 2007). The annual average temperature is 25 °C with 2300 mm of average rainfall concentrated between December and June (Souza and Cunha, 2010). The relief is very hilly, and the predominant soil type is deep oxisols of Tertiary origin (RADAMBRASIL, 1974).

Our fieldwork was conducted from June to December, 2008, in the vicinity of two communities, *Martins* (52°17′30″W; 0°34′36″S) and *Marinho* (52°13′25″W; 0°34′40″S), both with a long BN-extractive tradition. These settlements followed the 19th- and 20th-century rubber-tapper migrations (tappers of *Hevea brasiliensis*). Following the decline in latex prices, these communities have subsisted chiefly on BN extraction and small-scale agriculture. For local dwellers, SC is more than a complementary activity to the seasonality of BN production. In those years when the market prices offered for the nuts do not even pay the costs of harvesting, agriculture guarantees a minimum income and food security. Currently, the landscape surrounding the two villages is a mosaic of mature forest with or without BN trees, active crops, pastures, and secondary forests in multiple seral stages.

2.2. Data collection

For the purposes of our study, BN regeneration refers to the individuals (seeders and resprouts) that we found colonizing agricultural sites following disturbances by cultivations. We related the BN regeneration density to a series of seven biotic and abiotic environmental variables measured at 40 sites with known agricultural past use and established near parent BN trees. For each site, we interviewed the responsible landholder about (1) past agricultural use and (2) the number of cultivation cycles, which were later confirmed by remote sensing techniques. We also recorded (3) current agricultural use, (4) fallow age, (5) site area, (6) distance to the nearest parent trees, and (7) landholder's decisions to preserve BN enriched fallows.

2.2.1. BN density, number of cycles and past agricultural use

We calculated BN regeneration density by dividing the number of BN seedlings ($10 \leq$ height < 150 cm), saplings (height ≥ 150 cm and dbh < 10 cm) and juvenile (non-mature) trees found in the census of the site by its respective area. All sites chosen had vegetation coverage adequate to localize BN plants of all sizes, including seedlings. We avoided recently abandoned crops because of their excessively dense and entangled vegetation. However, we sampled fallows older than ten years because they already show some stratification and, like the active crops, make the census easier to conduct. We also included some sites currently used as pastures. Pastures, an integral part of the local landscape, often succeed crops. The pastures are planted not only for cattle, but also as a grazing area for horses, donkeys, and mules, animals that represent a useful work force during the BN harvest and other daily activities.

The information obtained from the interviews about the number of cultivation cycles was later confirmed using a temporal sequence of Landst5 satellite images that were available with minimum cloud coverage above the studied sites. We used the multi-spectral TM sensor, comprising bands 5R4G3B of the 226/060 scene from 1985, 1991, 1996, 1997, 1998, 1999/2000, 2003, 2004, 2007 and 2008 images. The 2008 image was georeferenced with ground truth points collected during fieldwork (GPS Garmin 60 CS×), and the previous images were georeferenced based on the current one and adjusted using natural and man-made landscape features until a root-mean-square error lower than one pixel size was attained.

Our informers reported accurately about the last, penultimate and ante-penultimate agricultural use cycles on their fields. However, information prior to the ante-penultimate cycle occasionally sounded vague or divergent. At the same time, the limited temporal sequence of available images could not confirm cultivation patterns with certainty beyond the ante-penultimate cultivation cycle. For that reason, we restricted the number of cultivation cycles to those events of one, two and three or more cultivation cycles we were able to distinguish. Fallow sites were also classified according to the number of previous slash-and-burn cycles. We added one more cycle to the total for the site in cases of fallows having signs of prior disturbance verified in the oldest available image (light-green pixel sensor response in the 1985 scene).

We used a different counting method for pasture cycles. Because active pastures are burned repeatedly every two or three years, they never develop the vegetation coverage needed to support the natural disperser activity (Silvius and Fragoso, 2003). As chronically disturbed sites (Uhl et al., 1988), pastures were counted as a single continuous cycle from their establishment in the forest or as a second or third cycle if located in sites previously used for SC. In view of that adjustment, we sampled nine sites in a first-use cycle (established directly after clearance of mature forest), nine sites in

a second-use cycle (one previous fallow), and 22 sites after three or more cultivation cycles (two or more previous fallows).

2.2.2. Resprouting capability

The BN tree characteristically exhibits a straight and single trunk that branches out only at canopy height (Zuidema, 2003). Conversely, resprouted individuals usually exhibit multiple stems growing from the stump of trees damaged during the prior slash-and-burn event. It is common to find sprouts growing among stump remains of different ages. This observation demonstrates that the BN tree can survive and resprout from successive SC cycles. We attempted to determine the minimum number of times that each resprouted individual was cut. To do so, we observed the sequence of previous growth cycles in the preserved stumps and added one more cycle in cases where the oldest visible stumps had already grown from a multiple-stem individual.

Indications from the living stems and from the soil around each tree's base also furnished information about the number of times the individuals were cut and resprouted. A single resprouted stem could be mistaken for an uncut tree that had grown directly from seed. However, even such individuals preserve evidence in the form of scars, calluses, and thickness typical of trees that suffered fire damage or clear-cutting and then resprouted. We also examined the soil under the base of the trees, where we searched for buried stumps, charcoal, dark-hued carbonized wood tissue, and depressions resulting from root-structure decomposition. Digging in the soil was the best way to distinguish tiny resprouts from recently emerged seedlings, which preserve their almonds for over a year (Cornejo, 2003).

2.2.3. Distance to parent trees

We calculated dispersal distance by georeferencing all BN plants found and all of the conspecific productive adults surrounding the 40 cultivation sites. Pair distances were measured with the near tool in ArcGIS v.9.1 (ESRI, 2005). To compare BN density with the chances for each site to receive dispersed seeds from the surrounding parental trees, we used the ArcGIS spatial analyst tool to obtain the minimum Euclidean distance from the nearest productive BN trees to each 5-m^2 raster cell inside the perimeter of the sites (Parrish et al., 2007). With this approach, the average cell distance calculated for the entire site not only accounted correctly for the distances to all surrounding parent trees but also remained proportional to the areal extent, allowing for direct comparisons among the different sites.

2.2.4. Landholders' decision to preserve fallows

The extractivists may choose to preserve their fallows once the sites reach a noticeable BN density, thereby excluding them from further cultivation cycles. To assess this decisive factor, we compared the BN regeneration density with the landholder's or community's decision to preserve (or not to preserve) the sites. Another protective practice is aimed not at the fallow site as a whole, but at stretches of it or even at individual BN plants. In this case, the secondary forest is cut and burned as usual, but some BN trees are deliberately spared and remain standing, typically on the perimeter of the future crop or pasture site. To assess this forest management practice we compared the average height and diameter of the individuals we located on the perimeter to those we found within the sites.

2.3. Statistical analysis

We used a principal components analysis (PCA) as a multivariate exploratory technique to detect the variables most significantly related to the BN regeneration density. The PCA included the density (1), number of cycles (2), site area (3), distance to the nearest

conspecific adults (4), and fallow age (5). The past agricultural use was included as a grouping variable (6). After the PCA ordination, we used a one-way analysis of variance (ANOVA) to relate the density separately to the number of cultivation cycles (1–3) and to past agricultural use. An ANOVA also served to relate the number of living sprouts to the minimum number of times that each BN plant survived slash-and-burn. When an ANOVA detected significant differences, we used Tukey's test for post-hoc mean comparisons. A linear regression analysis related the regeneration density to the variables fallow age (years) and site area (m^2). The extractivists' decisions to preserve fallows according to the observed BN regeneration density were analyzed using Student's t-test. The same test compared differences in height and diameter between BN individuals found within or on the perimeter of the sampled sites. In these cases, the variables were log_{10} transformed to improve the normality and homoscedasticity of the residuals.

3. Results

In the 40 sampled sites, we located 375 BN plants, including seedlings, saplings, and juvenile trees. The inventory of the nearest productive adult trees surrounding the sites included 74 possible seed sources. All of the sites had at least one productive BN tree closer than 100 m to their perimeters with the exception of two pasture sites that were separated from the nearest parent tree by another pasture stretch. The remote sensing analysis based on the available satellite images proved adequate to distinguish between sites of one, two and three or more cultivation cycles, thus enabling us to match these results with information obtained from interviews with landholders.

The PCA identified the number of cultivation cycles as the variable most related to the BN regeneration density according to both the first and the second PCA axes (Fig. 1). The average BN density varied significantly and positively with the number of cultivation cycles ($F = 12.04$; $p < 0.001$) (Fig. 2a). The density also varied signif-
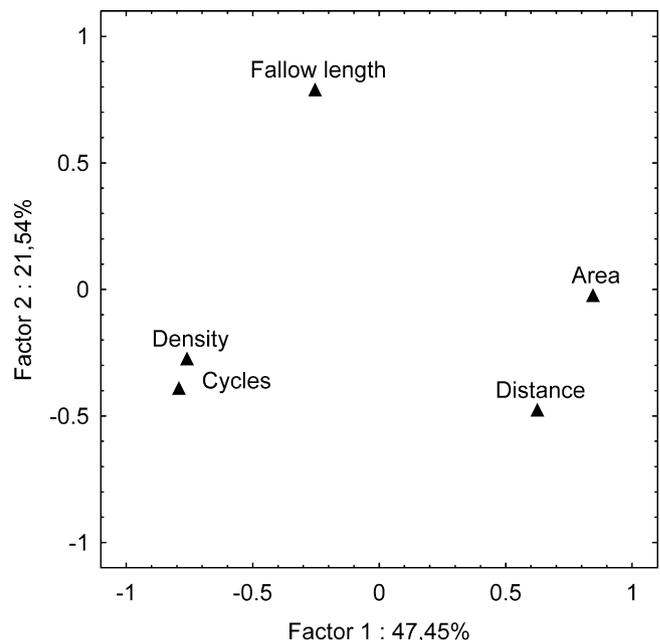

Fig. 1. First two axes of the principal component analysis (PCA) relating Brazil nut regeneration density (Density) to the number of cultivation cycles (Cycles), distance to the nearest conspecific adults (Distance), agricultural site area (Area), and fallow length since the last slash-and-burn event (Fallow length). These data were obtained from 40 agricultural sites near Brazil nut stands and with distinct past agricultural use (crops, pastures or both). Past agricultural use was included in the PCA as a grouping variable.
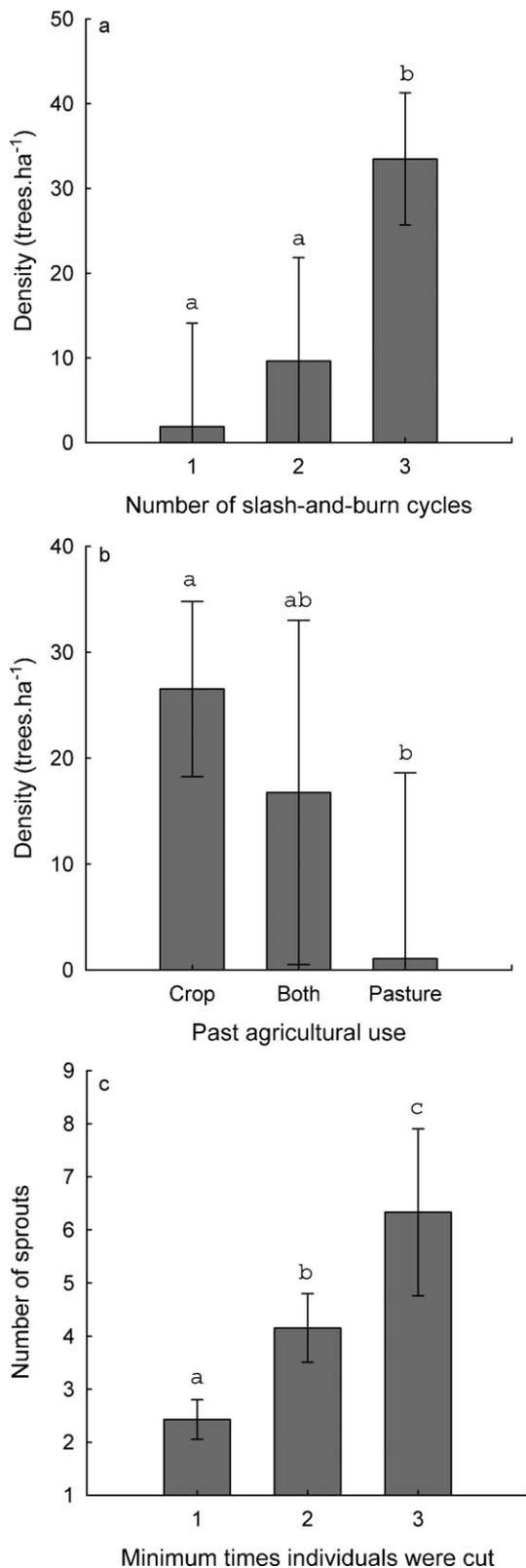
Fig. 2. Brazil nut regeneration densities in 40 agricultural sites plotted (a) against the number of prior slash-and-burn cycles and (b) against the past agricultural use. (c) Number of sprouts in Brazil nut stumps found in 40 agricultural sites plotted against the minimum number of times the trees suffered slash-and-burn and resprouted. Vertical bars denote 95% confidence intervals, and a difference between mean proportions in a post hoc comparison is indicated by a unique letter.
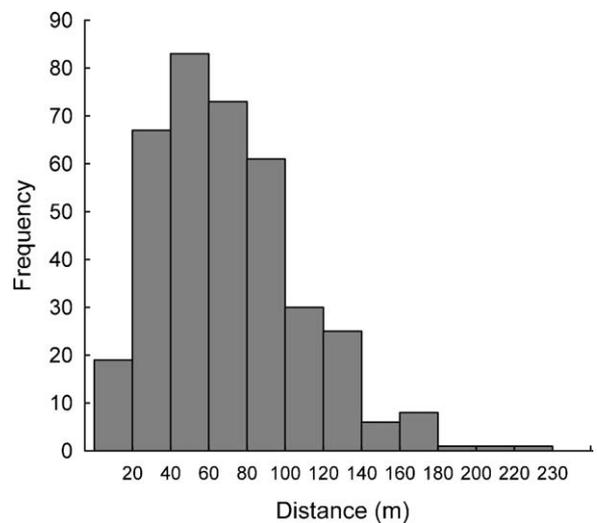

Fig. 3. Distribution of 375 Brazil nut plants in 20-m distance classes from the nearest conspecific productive adult tree for the 40 agricultural sites sampled.

icantly according to the past agricultural use ($F = 3.703$; $p = 0.034$). Sites used exclusively for SC presented an average density significantly greater ($p = 0.03$) than that of pastures established directly in the mature forest, but not significantly different ($p = 0.529$) from the average density of pastures established after SC use (Fig. 2b).

The BN tree exhibited strong resprouting capability. For sites after at least two slash-and-burn cycles, the ratios between resprouted and uncut trees (grown from seed) were 3.1:1 in areas currently occupied with crops, 2.2:1 for fallows and 15.1:1 for pastures. A damaged trunk usually resprouts with multiple shoots, many of which develop into stems during the consecutive fallow period. Once cut by the next slash-and-burn event, each of these resprouted stems may develop several shoots. The result is a progressive increase ($F = 19.365$; $p < 0.001$) in the number of stems each time the individual resprouts (Fig. 2c). However, the BN tree also exhibit self-thinning, as we inferred from the significant decrease ($T = 4.923$, $p < 0.001$) in the number of stems on resprouts growing at recently cultivated sites compared to those in fallows older than ten years.

Under the assumption that the nearest productive BN tree represented the putative seed source, we calculated the average distance between the established propagules and the nearest parent trees as 70 m, with the distances ranging from 6 to 277 m. Arranged by 20-m width frequency classes, 80% of the regeneration occurred within a radius of 100 m of the closest productive adult. The remaining 20% occurred at distances of up to 200 m. Only two individuals were found growing further apart (Fig. 3). The size of the sites can also influence the dispersal distance, and area was significantly related to regeneration density ($F = 9.045$, $p = 0.005$).

The regeneration density significantly influenced ($T = 4.375$, $p < 0.001$) the extractivists' decision to preserve fallows sites spontaneously enriched with BN trees from further conversion into crops or pastures (Fig. 4a). We investigated the protection of individual BN trees and confirmed the existence of an informal management practice directed at preserving at least some of the individuals encountered in fallows selected to be replanted. The differences between the $\log_{10}$ height ($T = 2.689$, $p = 0.007$) (Fig. 4b) and $\log_{10}$ diameter ($T = 3.965$, $p < 0.001$) (Fig. 4c) of regeneration found inside and on the perimeter of the agricultural sites were both significant.

Observed regeneration density did not vary significantly either with the current agricultural use ($F = 3.221$, $p = 0.051$) or with the fallow period since the last slash-and-burn event ($F = 0.442$, $p = 0.51$).
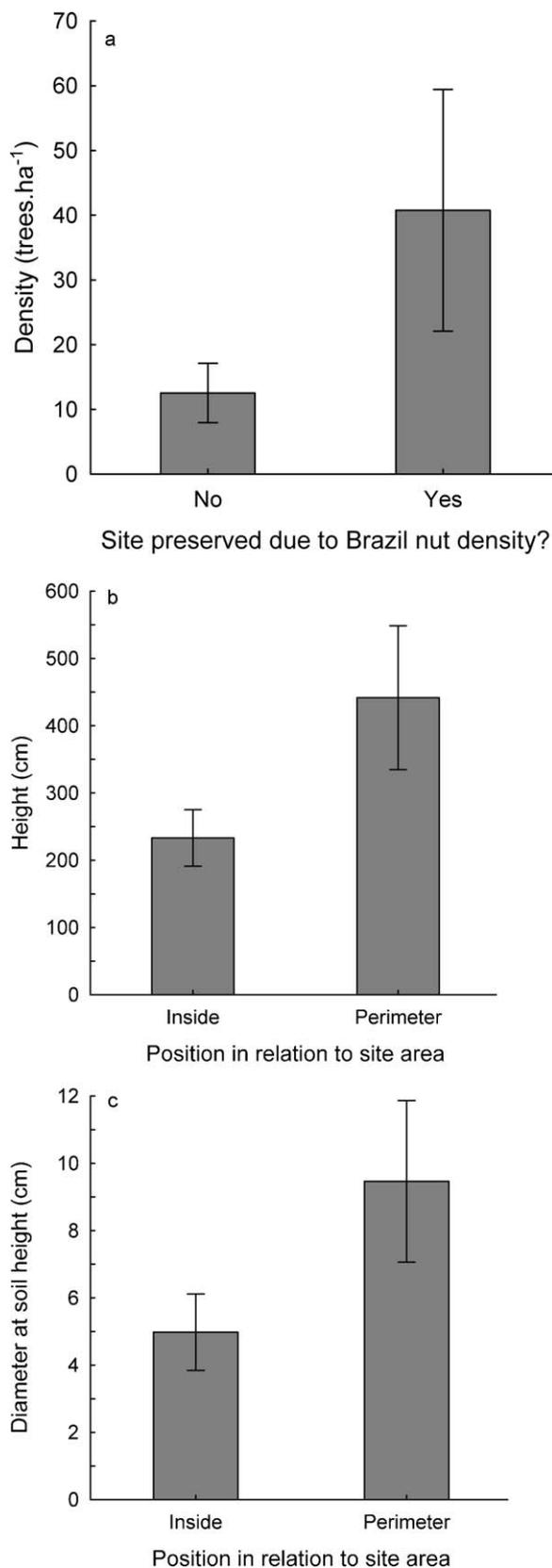
Fig. 4. (a) Landholder decisions to preserve enriched fallows according to the observed Brazil nut regeneration density. (b) Height and (c) Diameter of Brazil nut plants located inside and on the perimeter of 40 agricultural sites. Vertical bars denote means ± 1.96*SE.

4. Discussion

Of all of the variables related to regeneration density, the number of cultivation cycles was clearly the most influential (Fig. 1). This close relationship also characterized the finding of a previous sociological study that compared BN collecting and itinerant agriculture as economic choices of an indigenous population living by the Solimões River, Amazonas (Pereira and Lescure, 1994). The authors noticed a gradient in BN tree density that increased from the inner portion of the territory (1.79 trees ha^{-1}) to the river's margin (3.09 trees ha^{-1}), which was precisely the zone occupied by the mosaic of itinerant crops and fallows. Our results confirmed this impression because the BN density increased with the number of SC cycles (Fig. 2a). First-use sites, which opened directly in mature forest, showed a low BN regeneration density. This result supports the extractivists' statement that they avoid establishing crops or pastures in forests with BN trees or other valuable extractive resources. Second-cycle sites showed a higher average regeneration density, but it is usually after the third cultivation cycle that the BN tree density becomes substantial.

The impressive BN regeneration density at some of the sites with long histories of agricultural use (we registered up to 104 trees ha^{-1}) is perhaps better explained by a combination of factors. At the end of each SC cycle, the mature crop is an attractive source of food to the agoutis (Balée, 1994). This phase of the crop cycle coincides with site abandonment for forest succession. The dense and entangled colonizing vegetation shelters the natural disperser activity of the agoutis (Silvius and Fragoso, 2003) and is also a favorable microhabitat for seed and seedling establishment (Peña-Claros, 2001; Uhl, 1987). The BN seedling has a large nutrient reserve and may survive for several years under low-light conditions (Zuidema et al., 1999) but it depends on large forest gaps to thrive (Myers et al., 2000). This light-gap condition also occurs in fallows, as measured by Cotta et al. (2008). However, it is the frequency of SC disturbances in addition to the species' resprouting capability that ultimately results in the higher BN densities of fallows relative to BN densities in the nearby undisturbed forest.

Past agricultural use did not appear in the PCA because it was included as a grouping variable. However, this factor directly influenced the regeneration density observed (Fig. 2b). The higher light intensities offered by pastures may favor the growth of BN seedlings (Zuidema et al., 1999), but the frequency with which pastures are burned is incompatible with forest succession processes. Burning degrades the soil fertility and homogenizes the environment, eliminating seedling-establishment micro-sites and making seed dispersal from the surrounding forest improbable (Uhl, 1987; Uhl et al., 1988). The frequency of burning cycles, the absence of fallow intervals, and the presence of grazing animals tend to prevent vegetation regrowth. These properties of pastures probably discourage *Dasyprocta* dispersal activity because we rarely found gnawed-open fruits in the pastures, even though they were abundant in SC fallows and crops. This finding reinforces our assumption that the successful colonization of SC sites by BN trees depends as much on the disturbance events as on the consecutive fallow periods. The fact that pastures established in sites previously used for SC presented a regeneration density almost as high as those sites exclusively used for itinerant agriculture does not invalidate this conclusion. To show this argument correct, we must consider the characteristics of the regeneration that occurred in pastures established in areas previously used for plant crops. Most BN plants found in such post-crop pastures were resprouted individuals from the previous SC cycles, and the resprouted to uncut stem ratio was 16 times higher for such pastures.

Resprouts from slash-and-burn events enjoy several advantages when competing against most plants starting from seed (Kammesheidt, 1999). The BN resprouts possess a deep and well-

developed root system that favors water and nutrient intake (Kainer et al., 1998). Their above-ground growth in full-light conditions helps them cope with the dense and entangled understory of early forest succession. This ability to resprout renders the tree particularly resilient to SC disturbances. A good indication of the BN tree's resprouting capability was the ratio of individuals with resprouted versus uncut stems. This ratio was almost four times higher (3.7:1) in sites that had previously experienced two or more slash-and-burn cycles. Most resprouts exhibited multiple stems, and the number of living shoots increased with the number of times that the resprouts survived the SC events (Fig. 2c). Nevertheless, as observed by Kammesheidt (1998) for many species in fallows exposed to SC, the abundance of stems is later reduced by self-thinning.

The importance of resprouting as a demographic process depends on the frequency of severe disturbances, the probability that the species will resprout after them, and the rates of survival, growth and maturity of the resprouts (Paciorek et al., 2000). The only reference that we found regarding the maturity of resprouted BN trees reported anecdotal information from forest dwellers (Baider, 2000), who mentioned that resprouted trees die before they reach reproductive age. Our findings contradict this opinion because the majority of individuals present in fallows assigned to protection were resprouted trees. Although we did not collect data to address this question, the fact that resprouted multistem adults are owned and protected by extractivists is a good indication of their productivity.

Adult BN trees have very large crowns. Because many mature trees cannot coexist in the limited space available, the abundance of seedlings and saplings will ultimately be reduced in number through intraspecific competition. Considerations of this sort allow us to deduce a practical limit for the regeneration density increase and, consequently, a sufficient number of SC cycles after which the BN accumulation becomes redundant. In contrast, another landholder choice having decisive impact is the conversion of crops or fallows into pasture. Once this change has taken place, the development of previously established regeneration is no longer feasible, and that particular site will lose its potential to contribute a high-density BN stand.

Our results on dispersal distance suggest that SC sites established closer than 100 m to a productive adult have a higher potential for colonization, whereas sites located farther than 200 m apart contribute only in a limited manner to overall BN colonization (Fig. 3). Another implication of these same results is that the inner portion of extensive crops or pastures may also offer only a limited potential contribution to BN establishment. In this sense, the traditional SC crop, both because of its small area (±0.5 ha) and because of its adjustable form that fits into spaces amid mature BN trees, seems to be the most suitable regeneration site to promote the BN population increase. Admitting similarities between the shifting cultivation model of contemporary extractive communities and the itinerant agricultural practices of pre-columbian Amerindian societies, our results offer support for the anthropogenic origin hypothesis formulated to explain the highly clumped distribution of BN populations.

The landholder who preserves a secondary forest naturally enriched with BN trees, plans to use it as an extractive area. The result of this practice is a landscape management opportunity that is particular to extractive settlements near BN stands, where the deforested areas for crop use may eventually return to forest after a few SC cycles. This voluntary protection should not be perceived as a product of ecological conscience or fear of penalties associated with the removal of BN trees, though such removal is illegal in Brazil. The enriched fallows are primarily protected for an economic reason, when forest dwellers recognize their potential extractive

value. From that point, enriched fallows acquire a protected status equivalent to that of mature nut-producing forests and are watched over by the extractivist community. In addition to the 12 fallows declared as protected among our 40 sites (Fig. 4a), many other secondary forests having abundant BN trees were identified by local dwellers as sites under conservation. Even when BN density does not compensate for the loss of cultivation area, the landholder may limit the slash-and-burn extension to preserve at least some BN regeneration. The spared trees that typically surround the perimeter of the cultivated areas are significantly higher/larger than those within the sites (Fig. 4b and c).

BN are long-lived trees. In the forest they require 125 ± 50 years (Zuidema, 2003) to 208 years (Baider, 2000) to reach maturity. However, in fallows and in open sites, BN trees exhibit growth rates comparable to those of pioneer species. They have been considered a promising tree for timber plantations (Fernandes and Alencar, 1993) or for biological reconstruction of degraded areas (Salomão et al., 2006). In plantations, the species bears fruit at 12 years (Clay, 1997), 10 years (Mori and Prance, 1990), or even at 5 years (Shanley and Medina, 2005). The fact of such precocious maturity supports the protection of BN enriched fallows as a viable economical alternative.

From an economic perspective, the density increase of BN trees in fallows is a by-product of normal agricultural activities and thus demands neither extra effort nor any investment by the landholder or his family. Although proposals that recommend the planting of BN trees (Kainer et al., 1998; Peña-Claros et al., 2002; Zuidema et al., 1999) may earn the extractivists' acceptance, initial interest is soon replaced by the perception that nursery maintenance, seedling transplant, protection against livestock trampling, and cutting ants (Atta sp.) require resources, labor, and time that are rarely available. In the absence of continuous support, these unfamiliar tasks tend to be abandoned. However, an enrichment proposal that takes into account the spontaneous regeneration in SC areas may be a more practical and acceptable recommendation. Above all, this approach builds upon informal forest management practices already used by extractive communities, recognizing fallow selection criteria and other indicators acknowledged by forest-dwellers.

The IUCN Red List currently treats the BN as vulnerable to extinction because of deforestation occurring in the BN tree's biogeographical range. However, the BN tree population seems to be expanding rather than receding in our study sites. Our results thus point to shifting cultivation as a promising component in a strategy to promote the conservation of this valuable extractive resource. As controversial as it seems to conclude that shifting cultivation may actually promote the protection of forest acreage near extractive communities, it is important to note that secondary forests enriched with Brazil nut trees become valuable and consequently, gain protection from the extractive populations. In time, these areas also develop into mature forests and have a lower chance of being converted into commodity crops or pastures.

5. Conclusions

Bertholletia excelsa has great resprouting capability and, consequently, survives through repeated slash-and-burn cycles of shifting cultivation. Because each new cycle recreates the light-gap conditions favorable to the establishment of other individuals, the practice of shifting cultivation yields an increasing regeneration density that is directly proportional to the number of cultivation cycles. After a few cycles, as a function of parent-tree proximity, past agricultural use, and the size of the cultivated area, the site becomes densely colonized by Brazil nut regeneration. At this point, the extractivists may choose to protect and exclude enriched fallows from further agricultural use, and thereby plan an expansion of their nut-producing area.

Acknowledgements

References

Allegretti, M.H., 1990. Extractive reserves: an alternative for reconciliating development and environmental conservation in Amazonia. In: Anderson, A.B. (Ed.), Alternatives to Deforestation: Steps Toward Sustainable Use of the Amazon Rain Forest. Columbia University Press, New York, pp. 252–264.

Baider, C., 2000. Demografia e ecologia de dispersão de frutos de *Bertholletia excelsa* Humb & Bompl. (Lecytidaceae) em castanhais silvestres da Amazônia Oriental. In: Tese de doutorado. Departamento de Ecologia. Universidade de São Paulo, São Paulo.

Balée, W., 1993. Indigenous transformation of Amazonian forests: an example from Maranhão. Brazil. L'Homme 33, 231–254.

Balée, W., 1994. Footprints of the Forest. Columbia University Press, New York.

Bond, W.J., Midgley, J.J., 2003. The evolutionary ecology of sprouting in woody plants. Int. J. Plant Sci. 164, 103–114.

Bonpland, A., 1808. Plantes Áequinoxiales, Paris, 122–127.

Campos, M.T., Nepstadt, D.C., 2006. Smallholders, The Amazon's new conservationists. Conserv. Biol. 20, 1553–1556.

Clay, J.W. (Ed.), 1997. Brazil Nuts: The Use of a Keystone Species for Conservation and Development. The John Hopkins University Press, Baltimore.

Conklin, H.C., 1961. The study of shifting cultivation. Curr. Anthropol. 2, 27–58.

Cornejo, F., 2003. Historia Natural de la Castaña y Propuestas Para su Manejo. Asociación para la Conservación de la Cuenca Amazonica (ACCA), Puerto Maldonado, Peru.

Cotta, J.N., Kainer, K.A., Wadt, L.O., Staudhammer, C.L., 2008. Shifting cultivation effects on Brazil nut (*Bertholletia excelsa*) regeneration. For. Ecol. Manage. 256, 28–35.

Denevan, W.M., 1992. The pristine myth: the landscape of the Americas in 1492, in: Butzer, K.W., (Ed.), The Americas Before and After 1492: Current Geographical Research. Ann. Ass. Am. Geogr. 82, 369-385.

Escobal, J., Aldana, U., 2003. Are non-timber forest products the antidote to rainforest degradation? Brazil nut extraction in Madre de Dios. Peru. World Dev. 31, 1873–1887.

ESRI, 2005. Working with ArcGIS Spatial Analyst. ESRI Educational Services, Redlands.

Fearnside, P.M., 2005. Deforestation in Brazilian Amazonia: history, rates, and consequences. Conserv. Biol. 19, 680–688.

Fernandes, N.P., Alencar, J.d.C., 1993. Desenvolvimento de árvores nativas em ensaios de espécies. 4. Castanha-do-brasil (Bertholletia excelsa H. B. K.) dez anos após o plantio. Acta Amazon 23, 191–198.

IUCN 2010. Americas regional workshop (conservation & sustainable management of trees, Costa Rica) 1998. Bertholletia excelsa. In: IUCN 2010 Red list of threatened species. version 2010.1. <www.iucnredlist.org>. Downloaded on 25 May 2010.

Janzen, D.H., 1990. An abandoned field is not a tree fall gap. Vida Silv. Neotrop. 2, 64–67.

Kainer, K.A., Duryea, M.L., Macêdo, N.C., Williams, K., 1998. Brazil nut seedling establishment and autoecology in extractive reserves of Acre. Braz. Ecol. Appl. 8, 397–410.

Kammesheidt, L., 1998. The role of tree sprouts in the restoration of stand structure and species diversity in tropical moist forest after slash-and-burn agriculture in Eastern Paraguay. Plant Ecol. 139, 155–165.

Kammesheidt, L., 1999. Forest recovery by root suckers and above-ground sprouts after slash-and-burn agriculture, fire and logging in Paraguay and Venezuela. J. Trop. Ecol. 15, 143–157.

Mori, S.A., Prance, G.T., 1990. Taxonomy, ecology, and economic botany of the Brazil nut (*Bertholletia excelsa* Humb. & Bonpl.: Lecyhidaceae). Adv. Econ. Bot. 8, 130–150.

Myers, G.P., Newton, A.C., Melgarejo, O., 2000. The influence of canopy gap size on natural regeneration of Brazil nut (*Bertholletia excelsa*) in Bolivia. For. Ecol. Manage. 127, 119–128.

Paciorek, C.J., Condit, R., Hubbell, S.P., Foster, R.B., 2000. The demographics of resprouting in tree and shrub species of a moist tropical forest. J. Ecol. 88, 765–777.

Parrish, J., Parkinson, J., Ramseth, B., 2007. Advanced Analysis with ArcGIS. ESRI Educational Services. Redlands.

Peel, M.C., Finlayson, B.L., McMahon, T.A., 2007. Updated world map of the Köppen-Geiger climate classification. Hydrol. Earth Syst. Sci. 11, 1633–1644.

Peña-Claros, M., 2001. Secondary forest succession: process affecting the regeneration of Bolivian tree species. PROMAB Série científica n.3, Riberalta.

Peña-Claros, M., Boot, R.G.A., Dorado-Lora, J., Zonta, A., 2002. Enrichment planting of *Bertholletia excelsa* in secondary forest in the Bolivian Amazon: effect of cutting line width on survival, growth and crown traits. For. Ecol. Manage. 161, 159–168.

Pereira, H.d.S., Lescure, J.-P., 1994. Extrativismo e agricultura: as escolhas de uma população Kokama do médio Solimões. Universo do Amazon. 3, 1–9.

Peres, C.A., Baider, C., 1997. Seed dispersal, spatial distribution and population structure of Brazil nut trees (*Berthollethia excelsa*) in southern Amazonia. J. Trop. Ecol., 13.

Peres, C.A., Baider, C., Zuidema, P.A., Wadt, L.H.O., Kainer, K.A., Gomes-Silva, D.A.P., Salomão, R.P., Simões, L.L., Franciosi, E.R.N., Valverde, F.C., Gribel, R., Jr, G.H.S., Kanashiro, M., Coventry, P., Yu, D.W., Watkinson, A.R., Freckleton, R.P., 2003. Demographic threats to the sustainability of Brazil nut exploitation. Science 302, 2112–2114.

Peres, C.A., Schiesari, L.C., Dias-Leme, C.L., 1997. Vertebrate predation of Brazil-nuts (*Bertholletia excelsa*, Lecythidaceae), an agouti-dispersed Amazonian seed crop: a test of the escape hypothesis. J. Trop. Ecol. 13, 69–79.

RADAMBRASIL, 1974. Mapa exploratório de solos Folha SA-22/Belém, geologia, geomorfologia, solos, vegetação e uso potencial da terra, in: Levantamento de recursos naturais. IBGE, Rio de Janeiro.

Rumiz, D.I., Maglianesi, M.A., 2001. Hunting impacts associated with Brazil nut harvesting in the Bolivian Amazon. Vida Silv. Neotrop. 10, 19–29.

Salomão, R.P., Rosa, N.A., Castilho, A.F., Morais, K.A.C., 2006. Castanheira-do-Brasil recuperando áreas degradadas e provendo alimento e renda para as comunidades da Amazônia Setentrional. Bol. Mus. Para. Emilio Goeldi 1, 65–78.

Shanley, P., Medina, G. (Eds.), 2005. Frutíferas e plantas úteis da vida amazônica. CIFOR, Imazon, Belém.

Silvius, K.M., Fragoso, J.M.V., 2003. Red-rumped Agouti (*Dasyprocta leporina*) Home Range Use in an Amazonian forest: Implications for the aggregated distribution of forest trees. Biotropica 35, 74–83.

Souza, E. B., Cunha, A.C., 2010. Climatologia de precipitação no Amapá e mecanismos climáticos de grande escala, in: Tempo, clima e recursos hídricos–resultados do projeto REMETAP no Amapá, Cunha, A.C., Souza, E.B., Cunha, H.F.A., IEPA, Macapá.

Smith, C.C., Reichman, O.J., 1984. The evolution of food caching by birds and mammals. Annu. Rev. Ecol. Syst. 15, 329–351.

Uhl, C., 1987. Factors controlling sucession following slash-and-burn agriculture in Amazonia. J. Ecol. 75, 377–407.

Uhl, C., Buschbacher, R., Serrão, E.A.S., 1988. Abandoned pastures in Eastern Amazonia. I. Patterns of plant succession. J. Ecol. 76, 663–681.

Vander Wall, S.B., 2001. The evolutionary ecology of nut dispersal. Bot. Rev. 67, 74–117.

Wadt, L.H.O., Kainer, K.A., Gomes-Silva, D.A.P., 2005. Population structure and nut yield of a *Bertholletia excelsa* stand in Southwestern Amazonia. For. Ecol. Manage. 211, 371–384.

Wadt, L.H.O., Kainer, K.A., Staudhammer, C.L., Serrano, R., 2008. Sustainable forest use in Brazilian extractive reserves: natural regeneration of Brazil nut in exploited populations. Biol. Conserv. 141, 332–346.

Zuidema, P.A., 2003. Ecología y Manejo del árbol de Castaña (*Bertholletia excelsa*). Riberalta, Bolívia.

Zuidema, P.A., Boot, R.G.A., 2002. Demography of the Brazil nut tree (*Bertholletia excelsa*) in the Bolivian Amazon: impact of seed extraction on recruitment and population dynamics. Agriculture, fire and logging in Paraguay and Venezuela. J. Trop. Ecol., 18.

Zuidema, P.A., Dijkman, W., Rijsoort, J.V., 1999. Crecimiento de plantines de *Bertholletia excelsa* H.B.K. en función de su tamaño y la disponibilidad de luz. Ecol. Boliv. 33, 23–35.