Forest Ecology and Management xxx (2009) xxx–xxx

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Damage to Brazil nut trees (*Bertholletia excelsa*) during selective timber harvesting in Northern Bolivia

Manuel R. Guariguata[a,*], Juan Carlos Licona[b], Bonifacio Mostacedo[b], Peter Cronkleton[a]

[a] *Center for International Forestry Research (CIFOR), P.O. Box 0113 BOCBD, Bogor 16000, Indonesia*
[b] *Instituto Boliviano de Investigación Forestal (IBIF), Casilla no. 6204, Santa Cruz, Bolivia*

ARTICLE INFO

Article history:
Received 25 February 2009
Received in revised form 18 May 2009
Accepted 19 May 2009

Keywords:
Reduced impact logging
Multipurpose forest management
Logging damage
Non-timber forest products
Bolivia

ABSTRACT

The success of multiple forest management systems is contingent on a variety of social, economic, biophysical, and institutional factors, including the integration of timber and non-timber forest product (NTFP) extraction and management. Selective logging for timber is increasingly taking place in forests where the collection of Brazil nuts, a high-value Amazonian NTFP, also occurs. We report on logging damage to Brazil nut trees in three certified timber concessions in Northern Bolivia from which timber is harvested using reduced-impact logging (RIL) guidelines and nuts are gathered yearly from the ground by local people. Observed frequencies of logging damage to Brazil nut trees were low, likely mirroring the low intensity of timber harvesting ($\sim$0.5 trees/ha and $\sim$5 m^3/ha) being currently applied across the study area. Of the trees $\geq$10 cm in diameter at breast height about 0.1 Brazil nut trees and 0.4 timber species per hectare suffered some degree of logging damage. Crown loss was the predominant damage type for Brazil nut trees accounting for 50% of all damage. In spite of the observed low rates of tree damage, we further recommend that RIL guidelines be amended to include the pre-harvest marking of pre-reproductive Brazil nut trees along with the future crop trees of commercial timber species. Further refining directional felling to reduce crown damage to Brazil nut trees would also serve to help maintain nut yields in the long term.

1. Introduction

Given the many demands on and expectations from tropical forests, multipurpose management systems are essential but their success is contingent on a variety of social, economic, biophysical, and institutional factors (García-Fernández et al., 2008). In particular, successful integration of timber and non-timber forest product (NTFP) extraction and management is challenged by different factors and forest resource users with their own perceptions, needs, and objectives (e.g., Menton, 2003; Tieguhong and Ndoye, 2007). Other challenges include the lack of harmonization of timber and NTFP regulations and certification norms (Pierce et al., 2008), conflict of use for either timber or NTFP in multipurpose species (Herrero-Jáuregui et al., 2009), inadequate downscaling of timber management guidelines to (multi-use) small forests (Rockwell et al., 2007a), and a prevailing timber bias of many tropical foresters (Shanley and Stockdale, 2008; but see Pinto et al., 2008).

For multiple-use forestry to become a management paradigm for maintaining forest cover and achieving sustainability in the tropics, we need to move away from timber-oriented management models (see e.g., Sist et al., 2008 and accompanying papers). Also needed is research focused on the constraints and opportunities of integrated timber and NTFP extraction and management (e.g., Salick et al., 1995; Romero, 1999; Ribeiro do Valle et al., 2007). One forest use system that seems amenable to multiple-use management is where timber is selectively harvested from forests from which high-value Brazil nuts (*Bertholletia excelsa*, Lecythidaceae) are also collected. Brazil nuts are an economically important NTFP from the Amazon whose long-term productivity requires a forested matrix, and that supports the livelihood of hundreds of thousands of local extractivists annually (Ortiz, 2002; Peres et al., 2003). Enhancing this timber-NTFP compatibility is the fact that harvest of Brazil nut trees for timber is legally prohibited where the species is common (i.e., Brazil, Bolivia, and Peru). Furthermore, as a large canopy species, collateral damage to Brazil nut trees due to selective timber harvesting could be avoided by extending some of the norms commonly applied in reduced-impact logging (RIL) operations (reviewed in Putz et al., 2008). Moreover, at least in Western Amazonia, mechanized logging and Brazil nut harvest are, for the most part, temporally segregated (July–November and January–March, respectively). Despite the expectation of compatibility between timber and Brazil nut harvesting, there is still room for improvements in an integrated approach to management. Even

---

* Corresponding author. Tel.: +62 251 8622 622; fax: +62 251 8622 100.
E-mail address: m.guariguata@cgiar.org (M.R. Guariguata).

0378-1127/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2009.05.022

Please cite this article in press as: Guariguata, M.R., et al., Damage to Brazil nut trees (*Bertholletia excelsa*) during selective timber harvesting in Northern Bolivia. Forest Ecol. Manage. (2009), doi:10.1016/j.foreco.2009.05.022

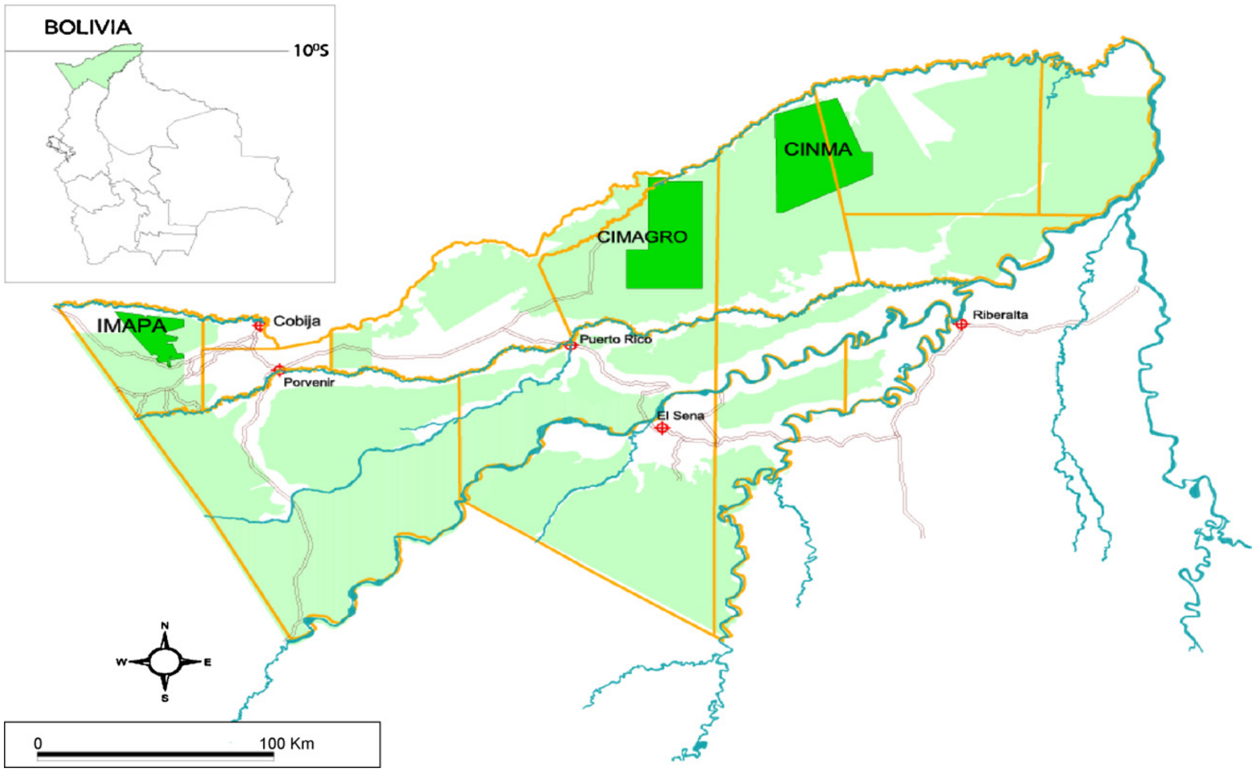

Fig. 1. The location of the three industrial timber concessions (IMAPA, CIMAGRO, CINMA) within the Department of Pando, northern Bolivia. Light shade indicates forest land currently allocated for permanent forest production.

when RIL guidelines are implemented, failure to map and mark Brazil nut trees is conducive to harvest-related damage, an issue of special concern in locally managed forests (e.g., Rockwell et al., 2007b).

Selective harvesting of timber is increasingly occurring in Western Amazonian forests that are also used for Brazil nut harvests (e.g., Rockwell et al., 2007b; Guariguata et al., 2008; Wadt et al., 2008); yet little quantitative evidence appears to exist on how timber extraction potentially affects Brazil nut tree populations. To fill this gap we report here on the frequency of collateral damage to Brazil nut trees in three certified (Forest Stewardship Council [FSC]-Smartwood) timber concessions across Northern Bolivia applying RIL guidelines and where nuts are gathered yearly by local people. Because the Brazil nut tree is catalogued as a “high conservation value” species in Bolivia (Rumiz et al., 2004), we expected to find minimal damage levels as required by FSC Principle 6 (FSC, 1996). We discuss our results in the context of how to integrate timber and Brazil nut extraction and management more effectively. Our overall objective is to further contribute to the integration of RIL guidelines into broader management objectives, an emerging forestry research and development topic in the Amazon (e.g., Ros-Tonen et al., 2008).

2. Methods

2.1. Study sites

The study was conducted from November 2007 to May 2008 in the Department of Pando, Northern Bolivia. The *terra firme* forests of Pando support an average density of trees ≥10 cm dbh (diameter at breast height) of 600 individuals/ha (Mostacedo et al., 2006a) with canopies dominated by the emergents *Apuleia leiocarpa*, *B. excelsa*, *Brosimum utile*, *Cariniana micrantha*, *Couratari macrosperma*, *Dipteryx odorata*, *Hymenaea parvifolia*, *H. courbaril*, *Parkia pendula*, and *Terminalia amazonica*. Across Pando, average annual precipitation and temperature range 1700–2000 mm and 25–26 °C, respectively (Mostacedo et al., 2006a).

We worked in three private timber concessions that cater to the export market: CINMA (East Pando, ~154,000 ha); CIMAGRO (Central Pando, ~131,000 ha); and, IMAPA (West Pando, ~40,000 ha; Fig. 1). As mandated by the 1996 Bolivian forestry legislation, tree harvesting adheres to reduced-impact logging (RIL) guidelines that include pre-harvest stand mapping of trees to be felled followed by layout of logging roads and skid trails and the application of directional felling. Brazil nuts are collected from the ground between December and March by families from different local communities outside the concessions. In both CINMA and IMAPA, intermediaries or “contratistas” decide which families collect nuts in a given year; in CIMAGRO, the concessionaire assigns families to pre-determined extraction areas.

Data collection took place in the 2007 logging areas in each of the three concessions. They ranged from ~1700 ha (CINMA) to ~ 2300 ha (CIMAGRO and IMAPA). The 2007 logging areas were identified from topographic maps provided by the concessionaires and later subdivided into contiguous, 110-ha “logging blocks”, two of which in each concession were randomly selected for vegetation sampling and assessments of logging damage (see below). We followed the methodology devised by Johns et al. (1996) and subsequently applied by Jackson et al. (2002) and Rockwell et al. (2007b) in other selectively logged forests in the region for determining both ground and tree damage.

2.2. Assessment of disturbed forest area

Within each of the two logging blocks sampled per concession, the area occupied by logging roads and skid trails was estimated by measuring and mapping road and skid trail lengths and widths at ~40 m intervals with a compass and a meter tape. The area of

Please cite this article in press as: Guariguata, M.R., et al., Damage to Brazil nut trees (*Bertholletia excelsa*) during selective timber harvesting in Northern Bolivia. Forest Ecol. Manage. (2009), doi:10.1016/j.foreco.2009.05.022

Table 1

Summary of tree (≥10 cm dbh) and stand level damage estimates due to selective logging of two 110-ha forest blocks within each of three timber concessions in Pando, northern Bolivia.

	Site					
	CIMAGRO		IMAPA		CINMA	
	Bertholletia	Timber species	*Bertholletia*	Timber species	*Bertholletia*	Timber species
Total no. of trees damaged	23	29	17	74	23	115
No. with severe damage	0	2	3	26	3	12
No. of trees damaged/tree extracted	0.21	0.26	0.13	0.55	0.16	0.79
Total no. of trees damaged/ha	0.10	0.13	0.08	0.34	0.10	0.52
No. with severe damage/ha	0	0.01	0.01	0.12	0.01	0.05
No. of trees harvested (#/ha)		111 (0.50)		134 (0.61)		145 (0.66)
No. of species harvested		8		10		6
Percent area disturbed (m^2/ha)						
Skid trails	2.1 (215)		1.9 (187)		2.0 (199)	
Felling gaps	1.4 (135)		1.9 (191)		2.5 (248)	
Logging roads	1.5 (145)		1.3 (116)		1.3 (122)	
Log yards	0.3 (29)		0.2 (15)		0.3 (30)	

Data corresponds to Brazil nut trees (*B. excelsa*) and species with current timber value in the area (23 total). Trees classified with “severe” damage were uprooted, snapped or crushed.

logging gaps and log landings was estimated through numerical integration by calculating perimeter through six distance and azimuth readings taken in the center and directly below visually undisturbed canopy (modified from Runkle, 1992).

2.3. Assessment of tree damage in logged forest

In each of the two logging blocks sampled per concession we determined the number of trees ≥10 cm dbh of Brazil nut trees and harvested timber species that showed signs of damage due to tree felling and road opening. We are confident that observed levels of tree damage correspond to the most recent (2007) harvest operation as all assessments were carried out within 5 months after logging and all the areas where we worked were reported as unlogged by the concessionaires. We classified the location of each damaged tree as in, or within 25 m of logging roads, skid trails, felling gaps, or log yards. Logging damage could have extended beyond 25 m thus our tree damage estimates are conservative. The following damage types were considered: (a) crown loss (visual estimation of <25% loss; 26–50% loss; 51–75% loss; >75% loss); (b) bole damage (including both damage to bark without exposed vascular tissue and with exposed vascular tissue); (c) root damage (i.e., exposed vascular tissue) and (d) uprooted, crushed, and/or snapped as indicators of “severe” (potentially fatal) damage.

2.4. Stand structure of Brazil nut trees and timber trees in unlogged forest

To gain an understanding of the population structure of Brazil nut trees (≥10 cm dbh) in unlogged forest, we assessed stand structure in areas at least 40 m away from skid trails, logging roads, felling gaps, or log landings. In areas that fit this description we established 20 m × 100 m (0.2 ha) plots at 100 m intervals within each of the two 100 ha logging blocks per concession (CINMA, $n = 31$ plots, 6.2 ha sampled; CIMAGRO, $n = 29$ plots, 5.8 ha sampled; IMAPA, $n = 27$ plots, 5.4 ha sampled).

3. Results

Logging was very selective in all three concessions. Of the 23 species with current timber value in Pando (Licona et al., 2007), only 12 “high value” species were harvested in 2007. From these, seven species comprised ~90% of the extracted commercial volume: *A. leiocarpa* (Fabaceae), *D. odorata* (Fabaceae), *Cedrela odorata* (Meliaceae), *Cedrelinga catenaeformis* (Meliaceae), *Clarisia racemosa* (Moraceae), *Couratari guianensis* (Lecythidaceae), and *H. parvifolia* (Fabaceae). The other species harvested were *Tabebuia* spp. (Bignoniaceae), *Amburana cearensis* (Fabaceae), *Manilkara bidentata* (Sapotaceae), *Mezilaurus itauba* (Lauraceae), and *Pithecellobium corymbosum* (Fabaceae). Minimum cutting diameters applied were either 50 or 70 cm dbh, depending on the species.

Harvest intensity was comparable across the three concessions and ranged from 0.5 (CIMAGRO) to 0.6 (CINMA and IMAPA) trees/ha with corresponding harvested volumes of 4 to 5 m^3/ha (Table 1). Accordingly, percentages (±SE) of ground area affected were similar in all habitat types (Kruskall–Wallis, $p \geq 0.16$ in all cases) and averaged 2.0% (0.1) for skid trails, 1.9% (0.2) for felling gaps, 1.3% (0.3) for logging roads, and 0.3% (0.1) for log yards (Table 1). A total of 63 Brazil nut trees and 218 timber trees (≥10 cm dbh) were found damaged during logging of the 660 ha surveyed. Both on a per area basis and per tree extracted, there were more timber trees damaged than Brazil nut trees across the three concessions (Table 1). The frequency of damaged trees was significantly higher for timber species than for Brazil nut trees (Chi-square = 17.5, d.f. = 2, $p < 0.001$) but it was also contingent on concession site (Heterogeneity Chi-square = 8.6, d.f. = 2, $p < 0.05$).

The frequency of damaged Brazil nut and timber trees across the three concessions was not independent of type of logged habitat (Chi-square = 11.5, d.f. = 2, $p < 0.005$ for all damage types combined excluding log yards due to absence of damaged Brazil nut trees); of all damaged trees, 43% and 41% were tallied along skid trails and felling gaps, respectively, while 13% occurred along logging roads (Table 2). For Brazil nut trees only, the trends were parallel as 31% and 61% of damaged trees were found along skid trails and felling gaps, respectively, while only 8% were tallied along logging roads. Frequency of severely damaged trees appeared independent of type of logged habitat for Brazil nut and timber trees (Chi-square = 0.12, d.f. = 2, $p = 0.94$). In felling gaps, crown damage accounted to 78% of all damaged Brazil nut trees and up to 60% for timber species across the three concessions. When all (damaged) Brazil nut trees are included, crown damage accounted for about half (51%) of all tree damage. For timber species, in contrast, about 23% of all damaged trees were recorded as having suffered crown damage. Thus compared to other types of damage combined, the frequency of trees with crown damage was contingent on whether they were timber or Brazil nut trees (Chi-square = 18.3, d.f. = 2, $p < 0.0001$). Extreme crown loss (>75%) did not exceed 7% and 16% of damaged Brazil nut and timber trees, respectively (data not shown). For timber trees, smaller trees were damaged more frequently than larger ones (which likely mirrors

Please cite this article in press as: Guariguata, M.R., et al., Damage to Brazil nut trees (*Bertholletia excelsa*) during selective timber harvesting in Northern Bolivia. Forest Ecol. Manage. (2009), doi:10.1016/j.foreco.2009.05.022

Table 2
Number of trees (≥10 cm dbh) that suffered logging damage as a function of both damage type and logged habitat.

Damage type	Skid trails		Felling gaps		Logging roads		Log yards	
	Bertholletia	Timber species	*Bertholletia*	Timber species	*Bertholletia*	Timber species	*Bertholletia*	Timber species
Crown only	2	2	30	46	0	1	0	1
Bole only	6	9	2	1	1	2	0	1
Root only	2	2	0	0	0	0	0	0
Bole and root	5	68	0	1	2	14	0	0
Bole and crown	3	6	1	6	0	5	0	0
Crown, bole and root	1	5	2	7	0	1	0	0
Severe	1	8	3	16	2	11	0	5
Total	20	100	38	77	5	34	0	7

Trees were sampled in two, 110-ha forest blocks within each of three timber concessions in Pando, northern Bolivia. Trees classified with "severe" damage were uprooted, snapped or crushed. Data corresponds to Brazil nut trees (*B. excelsa*; total no. of damaged trees = 63) and species with current timber value in the area (23; total no. of damaged timber trees = 218). See text for results of selected statistical comparisons.

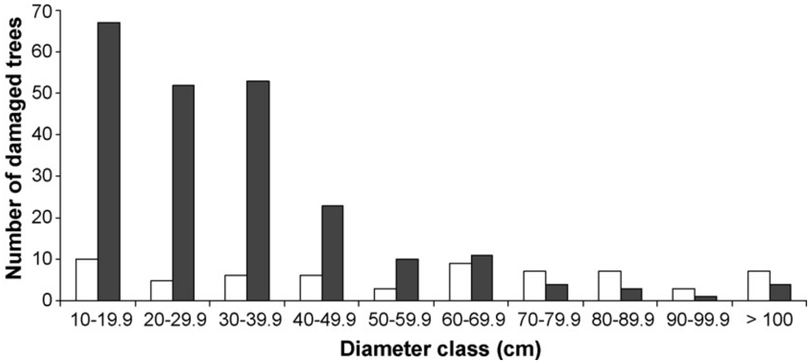

Fig. 2. Number of damaged trees due to logging as a function of diameter class and sampled in two 110-ha forest blocks within each of three timber concessions in Pando, northern Bolivia (i.e., 660 ha). Open bars correspond to Brazil nut trees (*B. excelsa*) and black bars for timber species with current timber value in the area (23 total).

their relative abundance and does not necessarily implies greater risk of being damaged) whereas for Brazil nut there was no discernible trend across size classes (Fig. 2) probably reflecting the overall low number of damaged trees. Estimated densities of Brazil nut trees (≥10 cm dbh) in unlogged forest, averaged 3 individuals/ha across the three concessions (range: 1–4.5/ha; Fig. 3).

4. Discussion

Our aim was to determine the frequency with which Brazil nut trees suffered damage during controlled, selective logging to gain further insights into the integration of management for timber and Brazil nuts in the Bolivian Amazon. On a per area basis, we found an average of one damaged Brazil nut tree (≥10 cm dbh) per 10 ha of logged forest. Based on the average density of Brazil nut trees (≥10 cm dbh) found in undisturbed forest across the three concessions we thus estimate a damage risk of ~3%. Considering only trees with severe damage, the estimated risk is lower (~0.7%). We believe that these values are representative as our density estimates for Brazil nut trees are similar to those reported from other primary forests across Pando (e.g., 3.1 trees/ha in Mostacedo et al., 2006a; 2.1 trees/ha in Licona et al., 2007).

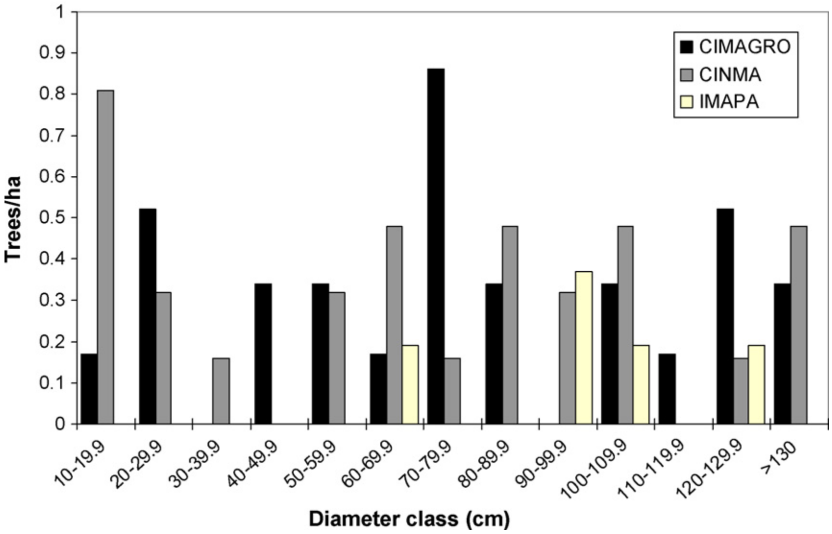

Fig. 3. Size class distribution of Brazil nut trees sampled in unlogged forest in two 110-ha forest blocks within each of three timber concessions (CIMAGRO, CINMA, IMAPA) located in Pando, northern Bolivia. See Methods for total sampled area.

Please cite this article in press as: Guariguata, M.R., et al., Damage to Brazil nut trees (*Bertholletia excelsa*) during selective timber harvesting in Northern Bolivia. Forest Ecol. Manage. (2009), doi:10.1016/j.foreco.2009.05.022

Timber harvest intensities across the three concessions studied were low (0.5 trees/ha, 4–5 m^3/ha) compared to other managed forests under RIL guidelines elsewhere in Bolivia (3–5 trees extracted/ha, 5–12 m^3/ha; Jackson et al., 2002, Mostacedo et al., 2006b, Peña-Claros et al., 2008) and Eastern Amazonia (3–6 trees extracted/ha; Sist and Ferreira, 2007). Reported levels of timber tree damage across the three concessions were correspondingly low (not exceeding one damaged tree per tree extracted) compared to the abovementioned studies (up to 13 timber trees damaged per tree extracted). The above estimates of damage risk for Brazil nut trees should, therefore, be interpreted in light of the harvesting intensities applied at our sites. Other private companies in the study area usually extract no more than 10 timber species in a given year (e.g., Licona et al., 2007) suggesting that, overall, logging impacts to Brazil nut trees may be currently low in Northern Bolivia. This may be largely inconsequential for nut collectors nowadays yet logging impacts are to increase at some point when more timber species enter the market and therefore more timber volume will be harvested (e.g., Sist and Ferreira, 2007 and references therein). Moreover, silvicultural intensification will be needed in Bolivian forests to maintain sustainable yields (Dauber et al., 2005) which also could enhance collateral damage rates (e.g., Mostacedo et al., 2006b).

Because Brazil nut trees do not start reproducing before they reach 30–40 cm dbh (Zuidema and Boot, 2002) and also because of inherently low juvenile population densities in closed-canopy forest (Myers et al., 2000; Zuidema and Boot, 2002; Wadt et al., 2008), care of pre-reproductive adults seems warranted in forests logged under RIL guidelines. There are at least two practical ways to minimize logging damage to Brazil nut trees in the context of selective timber extraction. One is by marking pre-reproductive individuals before timber harvesting when future crop (timber) trees are being flagged as part of RIL guidelines (Putz et al., 2008). However, and in spite of demonstrated short-term financial gains and long-term environmental benefits (Krueger, 2004), the practice of tallying future crop trees in Bolivian managed forests currently shows a very low level of adoption by timber concessionaires (Snook et al., 2006). Moreover, and although the timber certification status currently enjoyed by the concessions studied here includes minimizing damage to Brazil nut trees as a ‘‘high conservation value’’ species (Rumiz et al., 2004), the extent of field compliance with this requirement appears mixed. After reviewing the latest FSC-Smartwood certification assessments for each concession, we found no written evidence of explicit efforts to reduce collateral damage to Brazil nut trees in either CINMA (Smartwood, 2008a) and CIMAGRO (Smartwood, 2008b). Only IMAPA managers seem to have directly asked logging crews to flag Brazil nut trees during pre-harvest timber inventorying. Nevertheless the IMAPA certification assessment team noted lack of compliance of liana cutting and marking of future crop timber trees (Smartwood, 2008c), an oversight that could have easily extended to Brazil nut trees; coincidentally, IMAPA showed the highest percentage of ‘‘severe’’ damage in both Brazil nut trees (18%) and timber trees (35%) with respect to the other concessions (Table 2).

Another way to minimize damage of Brazil nut trees is for logging crews to refine directional felling as a high number of damaged Brazil nut trees were tallied in, or adjacent to, felling gaps (Table 2). High frequencies of tree damage in felling gaps are usually the norm in selectively logged tropical forests (Johns et al., 1996; Bertault and Sist, 1997; Jackson et al., 2002; Iskandar et al., 2006). However, the frequency of crown damage in Brazil nut trees was reportedly higher than for timber trees both across damage types and total number of trees damaged. A possible explanation is that, for a given diameter, Brazil nut trees may be more prone to crown damage as they are capable of emerging above the canopy (and releasing their crowns from lateral competition) at 30–40 cm dbh or even below (Zuidema and Boot, 2002; Wadt et al., 2005). To the extent that crown loss through logging damage generates irregular crown shapes (and therefore, smaller crown areas), deviations from an intact crown form may be conducive to smaller fruit crops (e.g., Kainer et al., 2007).

Although we focused this paper on the operational dimension of compatibility of timber and Brazil nut harvest, it is worth mentioning that CINMA currently enjoys organic certification status for the collection and handling of Brazil nuts (Smartwood, 2008b), independently from its FSC-Smartwood certification status. A price premium may be gained when organic certification is achieved yet we argue that having different standards both for timber and Brazil nuts may discourage integrated management approaches. For example, elsewhere in Pando, local cooperatives of Brazil nut collectors do not allow their members to harvest timber in organicallycertified Brazil nut stands; and to date, those forest concessions in Bolivia certified for timber under FSC standards have not attempted to seek the existing FSC-based certification scheme for Brazil nut (Pacheco and Cronkleton, 2008). Integration of NTFP and timber certification schemes emerges as an important research and development topic in tropical forest management (Shanley et al., 2008).

In conclusion, levels of logging damage to Brazil nut trees in our study sites were low, probably as a consequence of the equally low timber harvesting intensities currently applied in industrial concessions across Pando. Yet our impression is that if RIL guidelines can be more fully extended in industrial concessions to include Brazil nut trees, probably even lower damage figures can be achieved at relatively low financial costs (e.g., Krueger, 2004). Finally, it is important to point out that we are covering one side of the timber-Brazil nut harvest spectrum. Different challenges for integrated management may arise when one moves from extensive, certified forests under RIL guidelines to smaller, family-owned Brazil nut-rich forests in Northern Bolivia (e.g., Guariguata et al., 2008) where timber harvest is typically carried out by third parties and with little planning.

Acknowledgments

This work was produced with the financial assistance of the European Union and with the technical support of IFAD. We thank Marco Antonio Albornoz and René Anzaldo for field assistance and the three concessionaires for allowing us access to their forests. Thanks are also due to Marielos Peña-Claros, Amy Duchelle, Jack Putz, Plinio Sist, and Pieter Zuidema for comments on the original text. The observations of two anonymous reviewers greatly improved a previous version and are much appreciated. The views expressed here do not reflect the official opinion of IFAD or the European Union.

References

Bertault, J.G., Sist, P., 1997. An experimental comparison of different harvesting intensities with reduced-impact and conventional logging in East Kalimantan, Indonesia. Forest Ecology and Management 94, 209–218.

Dauber, E., Fredericksen, T.S., Peña-Claros, M., 2005. Sustainability of timber harvesting in Bolivian tropical forests. Forest Ecology and Management 214, 294–304.

FSC, 1996. FSC Principles and Criteria for Forest Stewardship. Document FSC-STD-01-001 (version 4-0). Bonn, Germany.

García-Fernández, C., Ruiz-Pérez, M., Wunder, S., 2008. Is multiple-use forest management widely implementable in the tropics? Forest Ecology and Management 256, 1468–1476.

Guariguata, M.R., Cronkleton, P., Shanley, P., Taylor, P., 2008. The compatibility of timber and non-timber forest product extraction and management. Forest Ecology and Management 256, 1477–1481.

Herrero-Jáuregui, C., García-Fernández, C., Sist, P.L.J., Casado, M.A., 2009. Conflict of use for multi-purpose tree species in the state of Pará, eastern Amazonia, Brazil. Biodiversity and Conservation 18, 1019–1044.

Please cite this article in press as: Guariguata, M.R., et al., Damage to Brazil nut trees (*Bertholletia excelsa*) during selective timber harvesting in Northern Bolivia. Forest Ecol. Manage. (2009), doi:10.1016/j.foreco.2009.05.022

Iskandar, H., Snook, L.K., Toma, T., MacDicken, K.G., Kanninen, M., 2006. A comparison of damage due to logging under different forms of resource access in East Kalimantan. Indonesia. Forest Ecology and Management 237, 83–93.

Jackson, S.M., Fredericksen, T.S., Malcolm, J.R., 2002. Area disturbed and residual stand damage following logging in a Bolivian tropical forest. Forest Ecology and Management 166, 271–283.

Johns, J.S., Barreto, P., Uhl, C., 1996. Logging damage during planned and unplanned logging operations in the eastern Amazon. Forest Ecology and Management 89, 59–77.

Kainer, K.A., Wadt, L.H.O., Staudhammer, C.L., 2007. Explaining variation in Brazil nut fruit production. Forest Ecology and Management 250, 244–255.

Krueger, W., 2004. Effects of future crop tree flagging and skid trail planning on conventional diameter-limit logging in a Bolivian tropical forest. Forest Ecology and Management 188, 381–393.

Licona, J.C., Peña Claros, M., Mostacedo, B., 2007. Composición florística, estructura y dinámica de un bosque amazónico aprovechado a diferentes intensidades en Pando, Bolivia. BOLFOR/Instituto Boliviano de Investigación Forestal (IBIF). Santa Cruz, Bolivia.

Menton, M.C., 2003. Effects of logging on non-timber forest products extraction in the Brazilian Amazon: community perceptions of change. International Forestry Review 5, 97–105.

Mostacedo, B., Balcazar, J., Montero, J.C., 2006a. Tipos de bosque, diversidad y composición florística en la Amazonia sudoeste de Bolivia. Ecología en Bolivia 41, 99–116.

Mostacedo, B., Peña-Claros, M., Alarcón, A., Licona, J.C., Ohlson-Kiehn, C., Jackson, S., Fredericksen, T.S., Putz, F.E., Blate, G., 2006b. Daños al bosque bajo diferentes sistemas silviculturales e intensidades de aprovechamiento forestal en dos bosques tropicales de Bolivia. Documento Técnico # 1. Instituto Boliviano de Investigación Forestal, Santa Cruz de la Sierra, Bolivia.

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. Forest Ecology and Management 127, 119–128.

Ortiz, E., 2002. Brazil Nut (*Bertholletia excelsa*). In: Shanley, P., Pierce, A.R., Laird, S.A., Guillén, A. (Eds.), Tapping the Green Market: Certification and Management of Non-Timber Forest Products. Earthscan, London, pp. 61–74.

Pacheco, P., Cronkleton, P., 2008. Developing standards for Brazil nuts in Bolivia. In: Shanley, P., Pierce, A., Laird, S., Robinson, D. (Eds.), Beyond Timber: Certification and Management of Non-Timber Forest Products. Center for International Forestry Research, Bogor, Indonesia, pp. 41–42.

Peña-Claros, M., Fredericksen, T.S., Alarcón, A., Blate, G.M., Choque, U., Leaño, C., Licona, J.C., Mostacedo, B., Pariona, W., Villegas, Z., Putz, F.E., 2008. Beyond reduced-impact logging: silvicultural treatments to increase growth rate of tropical trees. Forest Ecology and Management 256, 1458–1467.

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., Cornejo, F., Gribel, R., Shepard, G.H., 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.

Pierce, A.R., Shanley, P., Laird, S.A., 2008. Non-timber forest products and certification: strange bedfellows. Forests, Trees and Livelihoods 18, 23–35.

Pinto, L.F.G., Shanley, P., Gomes, A.P.C., Robinson, D., 2008. Experience with NTFP certification in Brazil. Forests, Trees and Livelihoods 18, 37–54.

Putz, F.E., Sist, P., Fredericksen, T., Dykstra, D., 2008. Reduced-impact logging: challenges and opportunities. Forest Ecology and Management 256, 1427–1433.

Ribeiro do Valle, D., Staudhammer, C.L., Cropper Jr., W.P., 2007. Simulating non-timber forest product management in tropical mixed forests. Journal of Forestry 105, 301–306.

Rockwell, C., Kainer, K.A., Marcondes, N., Baraloto, C., 2007a. Ecological limitations of reduced-impact logging at the smallholder scale. Forest Ecology and Management 238, 365–374.

Rockwell, C.A., Kainer, K.A., Staudhammer, C.L., Baraloto, C., 2007b. Future crop tree damage in a certified community forest in southwestern Amazonia. Forest Ecology and Management 242, 108–118.

Romero, C., 1999. Reduced impact logging effects on commercial non-vascular pendant epiphyte biomass in Costa Rica. Forest Ecology and Management 118, 117–125.

Ros-Tonen, M.A.F., van Andel, T., Morsello, C., Otsuki, K., Rosendo, S., Scholz, I., 2008. Forest-related partnerships in Brazilian Amazonia: there is more to sustainable forest management than reduced impact logging. Forest Ecology and Management 256, 1482–1497.

Rumiz, D.I., Mostacedo, B., Cochrane, B., Rozo, B., 2004. Guía de identificación de atributos para definir bosques de alto valor de conservación en Bolivia. Consejo Boliviano para la Certificación Forestal Voluntaria, Santa Cruz, Bolivia.

Runkle, J.R., 1992. Guidelines and sample protocol for sampling forest gaps. Pacific Northwest Research Station, General Technical Report PNW 283, Portland, USA.

Salick, J., Mejia, A., Anderson, T., 1995. Non-timber forest products integrated with natural forest management, Rio San Juan, Nicaragua. Ecological Applications 5, 878–895.

Shanley, P., Stockdale, M., 2008. Traditional knowledge, forest management, and certification: a reality check. Forests, Trees and Livelihoods 18, 55–67.

Shanley, P., Pierce, A., Laird, S., Robinson, D., 2008. Beyond timber: certification and management of non-timber forest products. Center for International Forestry Research, Bogor, Indonesia.

Sist, P., Ferreira, F.N., 2007. Sustainability of reduced impact logging in the Eastern Amazon. Forest Ecology and Management 243, 199–209.

Sist, P., García-Fernández, C., Fredericksen, T., 2008. Moving beyond reduced-impact logging towards a more holistic management of tropical forests. Forest Ecology and Management 256 p. vii-ix.

Smartwood, 2008a. Informe auditoría anual 2007 para Aserradero San Martín, Concesión Cinma Pando. Certificate code SW-FM/COC-123. Richmond, Vermont, USA.

Smartwood, 2008b. Informe auditoría anual 2007 para Grupo Industrial Maderero Cimagro Pando. Certificate code SW-FM/COC-1456. Richmond, Vermont, USA.

Smartwood, 2008c. Evaluación para certificación del manejo forestal de Industria Maderera Pando S. A. Certificate code SW-FM/COC-000202. Richmond, Vermont, USA.

Snook, L., Quevedo, L., Boscolo, M., Sabogal, C., Medina, R., 2006. Avances y limitaciones en la adopción del manejo forestal sostenible en Bolivia. Recursos Naturales y Ambiente 49/50, 68–80.

Tieguhong, J.C., Ndoye, O., 2007. The impact of timber harvesting on the availability of non-wood forest products in the Congo Basin. Forest Harvesting Case Study 23. Food and Agricultural Organization of the United Nations, Rome.

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. Forest Ecology and Management 211, 371–384.

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

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. Journal of Tropical Ecology 18, 1–31.

Please cite this article in press as: Guariguata, M.R., et al., Damage to Brazil nut trees (*Bertholletia excelsa*) during selective timber harvesting in Northern Bolivia. Forest Ecol. Manage. (2009), doi:10.1016/j.foreco.2009.05.022