Advances in Forestry Science
Original Article

Forest management in a secondary Atlantic Rainforest: assessing the harvest damage

Daniel Augusto da Silva[1]* Geferson Piazza[2] Alfredo Celso Fantini[2] Alexander Christian Vibrans[1]

[1] Forestry Engineering Graduate Program, Regional University of Blumenau, São Paulo St., Blumenau, 89030-080.
[2] Agroecosystems Graduate Program, Federal University of Santa Catarina, Admar Gonzaga Hwy., Florianópolis, 88040-900.

*Author for correspondence: daniel.florestal@live.com
Received: 08 June 2017 / Accepted: 29 September 2017 / Published: 31 December 2017

Abstract
Minimizing the impacts to the residual stand is one of the goals of sustainable forest management. To achieve this goal it's essential to know the dynamics of these impacts, its frequency, cause and severity. Various studies in this topic were carried out in primary tropical forest, but little is known in secondary forests, which have smaller and denser tree community. We evaluate the bole and crown damage and the incidence of leaning trees in the residual stand right after the timber harvesting in a secondary Atlantic Rainforest in southern Brazil. On average, 26% of the residual trees suffered some kind of damage, with 12.1% suffering moderate or severe damage. Bole damage was the most frequent, followed by the crown damage and leaning tree. The frequency of damages showed no statistic relation with the harvest intensity in all cases but crown damage, whilst the number of damaged trees per harvested tree showed strong negative relation with the harvest intensity. The skidding was the major cause of damage and had no relation with harvest intensity. Although it affected less than 1/3 of the residual stand, it is important to monitor the injured trees to clarify the long-term consequences of the damages.
Keywords: Selective logging; Tropical forest; Logging impacts; Residual stand

Introduction

Managed forests can maintain most of environmental services (Miller et al. 2011; Putz et al. 2012) and biodiversity (Gibson et al. 2011; Bicknell et al. 2014) provided by a mature forest; they also have greater ecosystem value than other land uses, such as agriculture and forest plantations (Edwards et al. 2014). Conversely, the pressure to replace forestland with other land uses is high in the tropics (FAO 2012), mostly because of the low value awarded to the native forest (Siminski and Fantini 2010). Thus, adding value to the forest through its management and involving the rural population in the conservation processes is an important strategy to reduce deforestation (Shanley and Gaia 2002).

This is also relevant when referring to secondary forests. Even though these forests have lower levels of biodiversity than mature forests (Gibson et al. 2011), they play a relevant role in the environment and biodiversity conservation efforts (Dent and Wright 2009), mainly when compared with other land uses (Mukul and Herbohn 2016), which have gained increasing recognition in recent years (Chazdon 2014). Secondary forests regenerate after the abandonment of areas where anthropic or natural disturbance decharacterize its original forest cover (Chokkalingam and Jong 2001) and occur, in most cases, on private land (Kammesheidt 2002). In the State of Santa Catarina, we see a similar scenario, with a great portion of the natural forests being secondary vegetation scattered as small fragments of less than 50 ha (Sevegnani et al. 2013; Vibrans et al. 2013). Thus, secondary forests represent an important component for environmental conservation in the region.

For its representativeness in the Atlantic Forest region, secondary forests have a great potential for sustainable management aiming not just for timber products, but for the provision and regulation of ecosystem services. The principle of the sustainable forest management is to harvest forest resources, including non-wood products, without compromising the ecological and social value of the forest (Sist et al. 1998). In a secondary forest, the maintenance of the ecological value implies, at some level, maintaining the successional processes. The forest management could maintain this processes by favoring the establishment of late successional species with plantation of saplings and/or releasing those from competition with others species, with control of the harvest intensity or also with the delimitation of preservation areas within the management area.

The harvest inevitably causes damages to the residual stand; the extend and frequency of these damages will depend upon the intensity and technique of the harvest applied (Putz and Brokaw 1989; Webb 1997, 1998; Sist et al. 2003a; Rockwell et al. 2007; Martin et al. 2015). The consequences of those damages range from reduced growth in the following years (Vidal et al. 2002; Tavankar et al. 2015) and wood defect, in cases of light and moderate damages (Jackson et al. 2002), to the death, right after or in the following years, of the trees damaged with more severity (Van Der Hout 1999; Sist and Nguyen-Thé 2002; Forshed et al. 2008; Picard et al. 2012). Thus, reducing the damages to the residual stand increases the wood stock, increases the wood quality and speeds up its recovery, potentially reducing the harvest cycle and/or increasing the harvestable timber volume with better quality (Putz 1994; Dykstra and Heinrich 1996).

It's considered acceptable and sustainable for up to 30% of the residual stand to be damaged by the harvest in tropical forest management (Huth and Ditzer 2001; Sist et al. 2003b; Sist et al. 2003c). Nevertheless, studies in tropical forests show that the damages range from approximately 20% (Sist and Ferreira 2007) to more than 50% of the original stand (Bischoff et al. 2005; Sist and Ferreira 2007). In a pan tropical meta-analysis, Picard et al. (2012) concluded that for a harvest intensity of 1 to 2 $tree.ha^{-1}$ (DBH > 60 cm), it's expected that 6% to 11% of the stand will be damaged. However, to the best of our knowledge, in the Subtropical Atlantic Rainforest there are fewer studies on harvest damage, and surely there are no studies on this theme on secondary forests.

The utilization of more efficient logging techniques, as the Reduced Impact Logging (RIL), tends to decrease the frequency of the harvest damages, as shown by Forshed et al. (2006). Combined with the RIL technique, the intensity of the harvest represents a determinant factor in the frequency of damage. Generally, with the increase of the harvest intensity there is also an increase in the absolute frequency of damage (Sist and Nguyen-Thé 2002; Picard et al. 2012; Martin et al. 2015). On the other hand, this relation is weaker or inexistent in areas where there is no harvest planning or utilization of RIL techniques, due to high damage rates even in low-harvest-intensities areas (Van Der Hout 1999).

Based on the assumption that logging damages the residual stand and that the frequency and intensity of theses damages are related to the intensity of the harvest, this study conducted at a managed subtropical rainforest in the northwest of the State of Santa Catarina has the following objectives: a) quantifying the residual stand damage due to the harvest (felling and skidding) and; b) analyzing the relation between the frequency of damage and the intensity of harvest.

Methods

The study was conducted in a secondary subtropical rain forest (Oliveira-Filho 2009) within a 42-ha farm in the northwest of the Estate of Santa Catarina (26º32´10´´S e 49º02´38´´O, Figure 1), with an altitude ranging from 160 to 500 m.a.s.l. According to the Köppen classification, the climate in the region is Cfa – mesothermic subtropical humid with a hot summer and without a dry season (Alvares et al. 2013). The study site is in a hilly terrain with slopes ranging from 10% to 40%. The soils in the region are predominantly cambisol (EMBRAPA 2004).

The study forest was originated by an enrichment plantation in an intensively exploited area made in 1978, in which saplings of *Miconia cinnamomifolia*, *Hieronyma alchorneoides* and *Nectandra* spp. were planted. At that time, the area was composed by pasture with some patches of forest in the initial phases of development. In the first five years after the plantation, the owner mowed the herbaceous vegetation at the site, and that was the only silvicultural treatment made to the forest (Schuch 2010). Since then, the area developed without intervention except for the eventual cutting of some *Euterpe edulis* for heart-of-palm production and woody species for timber uses.

We measured nine square experimental plots (EP) with 3600 sq.m. including a border with a measured area of 1600 sq.m. divided into 16 subunits of 100 sq.m. The experimental treatments were applied to the total area of the EP and consisted of different intensities of harvest (as shown in the *Harvest* section and Figure 2b). Three subunits were discarded from the data collect due to a tree felled before the measures, totaling 141 evaluated subunits.

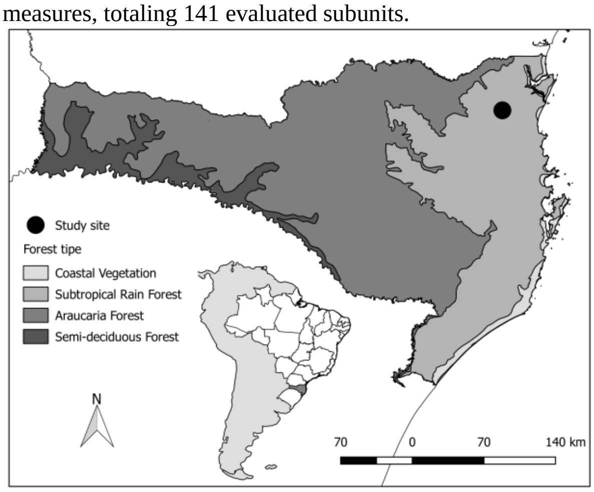

Figure 1. Study location in Santa Catarina State

The inventory before harvest was carried out in the first trimester of 2014, approximately six months before the operation. In this inventory, we measure the diameter at breast height (DBH), total height of all individuals with DBH > 5 cm and the botanical identification was made to the level of specie, whenever possible (Piazza 2014). All trees were located in the EP with x – y coordinates and were identified with numeric plates. Immediately after the harvest, we returned to the EPs to determine the effective intensity of the harvest and the damages in the residual stand. The classification of the damages was made visually and followed the criteria presented in Table 1.

The damage distribution in the diameter classes was compared to the residual stand diameter distribution using the Kolmogorov-Smirnov test. To determine the relation between the harvest intensity and the frequency of damage, we adjust a linear regression between the percentage of basal area harvested and the percentage of residual trees damaged. To determine the specific damage, that is, the damage caused by each harvested tree, we divided the total number of damaged trees by the total number of harvested trees. The relation between the specific damage and the harvest intensity also was analyzed using linear regression.

Table 1 - Classification criteria for the harvest damage on the residual stand in a secondary forest in the northwest of Santa Catarina.

Class of damage	Intensity of damage		
	Light	Moderate	Severe
Crown damage	<1/3 of crown	1/3 > 2/3 of crown	>2/3 of crown
Bole damage	Bark damage	Superficial wood damage (cambial tissue)	Deep wood damage (sub cambial tissue)
Tree leaning	Slight leaning	Partially uprooted	Totally uprooted

It is important to note that the harvest was done only inside the experimental plots and that all experimental plots are installed next to extraction roads. Thus, the damage assessed in this study refers only to the damage due to the felling and skidding of the trees inside the experimental plot. The extraction roads existed in the area since before the abandonment of the pasture and implantation of the forest (~1978) and were maintained without forest cover by the owner, so we cannot assess the damages of its opening.

All analyses were made accounting for the total number of trees damaged and also accounting for each damage class separately. The calculation was made in R (R Development Core Team, 2008), with significance of $p = 0.05$.

Harvest

The trees were pre-selected according to the pre-harvest inventory information. The selection took into account the timber potential, ecological group, minimum cutting diameter (MCD) and abundance of the species (Table 2). We also selected trees with timber potential under the MCD when those trees were mature, senile, dominated or when there was severe damage to the bole or crown. Climax species with local low density were preserved from harvesting.

We tried to keep the harvest intensity between 20% and 60% of the EP's total basal area. The felling was made with a chainsaw and the extraction with a tractor equipped with a winch. The trees were extracted with the tree-length system, with the debranching done inside the forest.

Table 2 - Selection criteria for the harvest in a secondary forest in the northwest of Santa Catarina.

Class	MCD
Tree species with no timber potential	> 5 cm
Pioneers and early secondary tree species with timber potential	> 25 cm
Late secondary tree species with timber potential	> 35 cm
Climax species with timber potential	> 40 cm

After the harvest of the pre-selected trees and the computation of the corresponding basal area removed, we return to the EP to complement the harvest according to the planed intensity. Trees that had broken boles or irreversible damages, had lost the entire crown or were smashed were then felled and extracted from the forest. In this way, the final harvest intensity resulted from the sum of the initial pre-selected trees plus the trees harvested because of their severe irreversible damage. At this time the branches with diameters below sawmill limit were extracted to be commercialized as firewood.

The distribution of the harvested individuals in the diameter classes followed the same distribution of the original stand (Figure 2a). The effective harvest intensity in the EP ranged from 18.2% to 56% of reduction in the basal area and from 11.7% to 41.8% of reduction in the number of trees (Figure 2b).

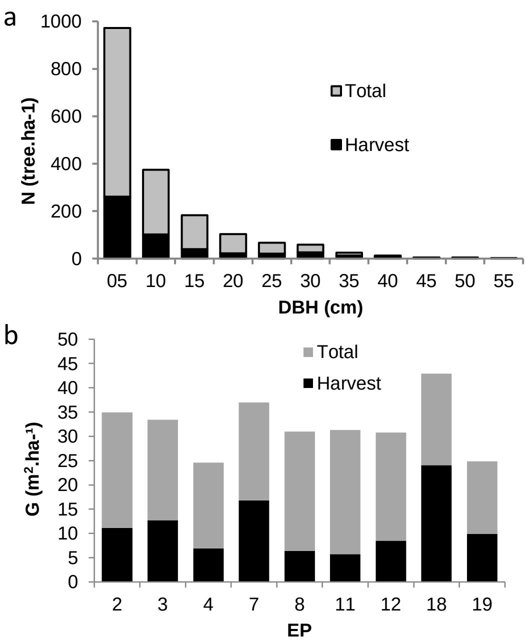

Figure 1. a) Diameter distribution of the original stand and harvested trees; b) original and harvested basal area in each experimental plot in a secondary forest in the northwest of Santa Catarina

Results

The harvest damaged 26% of the residual stand, which represents 22.7% of the basal area. The most frequent damage class was the bole damage, affecting 13.3% of the trees; followed by the crown damage, affecting 12.3% of the trees; and tree leaning, affecting 6.6% of the trees (Figure 3). In the three classes, the light damage was the most frequent, whereas only 0.9% of the trees have severe damage to the bole, 3.2% to the crown and 2.7% were totally uprooted.

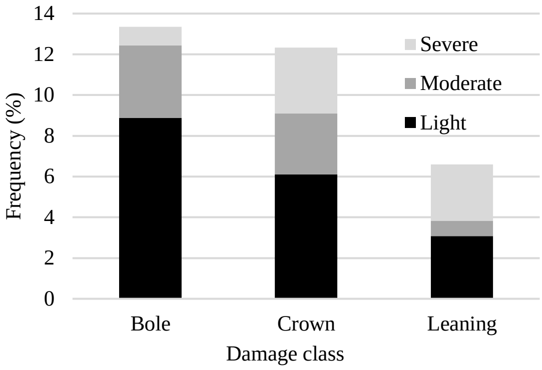

Figure 3. Frequency of the damage classes and intensity to the residual stand after harvest in a secondary forest in the northwest of Santa Catarina

Bole damage and leaning were due to both felling and skidding; meanwhile, the crown damage was due mainly to the felling operation. However, the leaning was observed only in the lower DBH classes, while the bole and crown damage occurred more evenly between classes (Figure 4). Nevertheless, the harvest damaged mostly trees in the 5 to 10 cm DBH class, showing a negative exponential distribution among classes. The damage distribution was statistically similar to the tree distribution after the harvest (KS = 0.364; n = 11; p = 0.374), showing that the damages were homogeneous among the DBH classes.

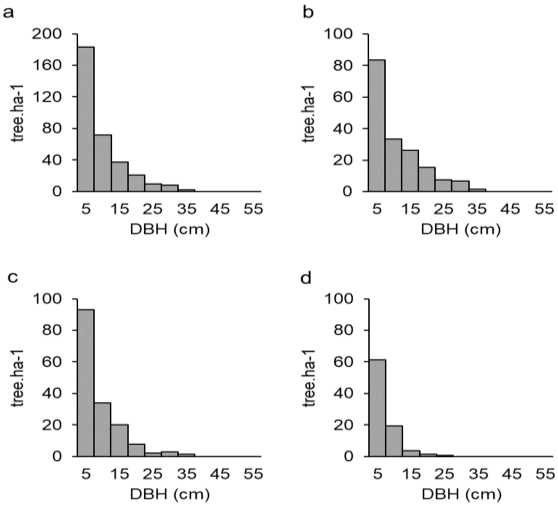

Figure 4. Number of damaged trees per DBH class after the harvest in a secondary forest in the northwest of Santa Catarina. a) total of damaged trees; b) bole damage; c) crown damage; d) leaning tree

The frequency of damaged trees does not have statistical relation to the intensity of harvest (% of the basal area) applied (Figure 5). The analysis by damage class reveals that only the crown damage had relation to the harvest intensity. The bole damage showed no relation to the harvest intensity at all, and the leaning, although not statistically significant, showed a tendency to increase with more basal area harvested. The relation between the damage frequency and the harvest intensity was negatively influenced by the independent distribution of the bole damage, which, because it is the majority of the damages observed, had a strong weight in the regression.

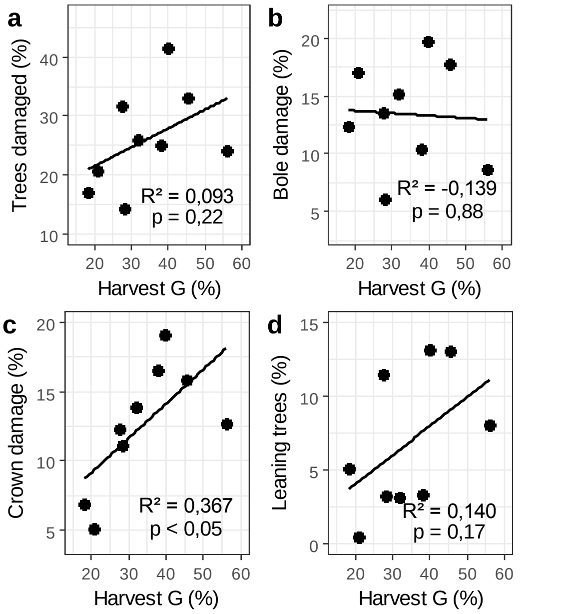

Figure 5. Relation between harvest intensity and the residual stand damage in a secondary forest in the northwest of Santa Catarina. a) total of trees damaged; b) bole damage; c) crown damage; d) leaning trees

On average, each harvested tree damaged, to some degree, 0.87 residual trees. Considering each damage class separately, each harvested tree damaged 0.47 boles, 0.39 crowns and caused leaning in 0.24 trees. The values showed considerable variation between the EP in all damage classes. The regression analysis showed a strong tendency of decrease in the number of damaged trees per harvested tree with the increase in the harvest intensity (Figure 6).

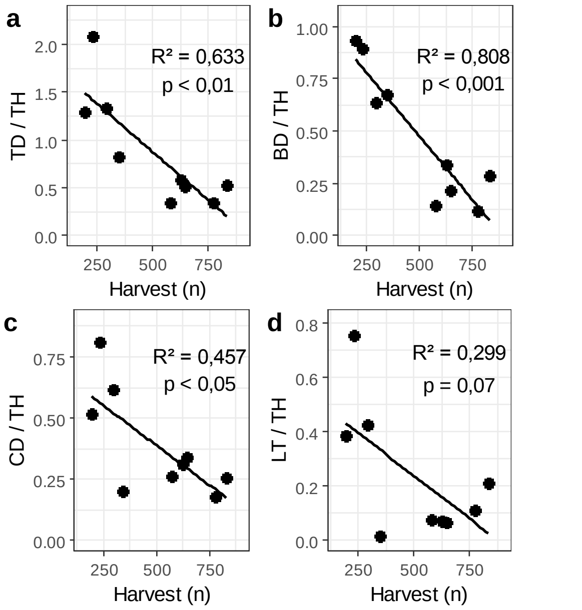

Figure 6. Relation between harvest intensity and damaged trees per harvested trees in a secondary forest in the northwest of Santa Catarina; a) total of damaged trees; b) bole damage; c crown damage; d) leaning trees. TH: trees harvested; TD: total damage; BD: bole damage; CD: crown damage; LT: leaning trees.

The bole damage had an elevated determination coefficient, indicating that in lower harvest intensities each harvested tree damages a considerably higher number of residual trees. The crown damage had a lower determination coefficient in relation to the former, corroborating with the previous results that shows its frequency to be dependent on the harvest intensity. The leaning trees had only a marginal probability in the level tested ($p = 0.07$).

Discussion

There are few studies analyzing damage caused by the selective timber harvest in the Brazilian Subtropical Atlantic Rainforest. Despite the inherent differences between the harvest intensity and the size of the trees felled, the frequency of damage in our study is in between 25% and 30%, which are considered to be acceptable by various authors in mature tropical forests (Huth and Ditzer 2001; Sist et al. 2003b; Sist et al. 2003c), despite being higher than the 15% suggested by Sist and Nguyen-Thé (2002). This similarity was possible because, beyond the harvest intensity, the size of the trees and the harvest method interfere with the frequency and intensity of the damages (Medjibe et al. 2011; Picard et al. 2012).

Our results lay in between the results found in areas with conventional logging and RIL. Studies in conventional logging areas in Asia and South America have, predominantly, damage frequencies above the ones observed in our study, ranging from 25.2% to 38% for intensities between 8 and 16 $tree.ha^{-1}$ (Bertault and Sist 1997; Van Der Hout 1999; Sist et al. 2003a; Forshed et al. 2006). Among the studies conducted with RIL techniques, also in Asia and South America, the frequency of damage ranged between 13.4% and 32.4% for harvest intensities between 4 and 16 $tree.ha^{-1}$ (Bertault and Sist 1997; Van Der Hout 1999; Sist et al. 2003a; Forshed et al. 2006; Rockwell et. al. 2007).

Most of the damaged trees suffered light injuries (9,57%), while moderate (4,26%) and severe (7,68%) damages were less frequent. This result could be partially attributed to the small size of the harvested trees. Moreover, some of the severe damaged trees in the pre-selected trees were also harvested and tapped as firewood, so these trees were not counted as damaged trees, but harvested trees. In the study area, 12.12% of the remaining stand suffered moderate or severe injuries. The mortality rate of these moderate/severe damaged trees could be up to twice the mortality rate of healthy trees in the first two years after the harvest (Sist and Nguyen-The 2002) and remain higher for periods of up to 5 to 10 years after the intervention (Van Der Hout 1999; Picard et al. 2012). Besides that, the growth rate of damaged trees (light, moderate or severe) could be up to 1.6 times smaller than the growth rate of healthy trees in the first years after the harvest (Vidal et al. 2002). Thus, keeping the damage frequency low helps with the forest recovery after the harvest and prevents an excessive lengthening in the harvest cycle due to a lower growth rate or a higher mortality rate.

In our study, the most frequent damage class was the light bole damage, which can be due to the felling and/or skidding of the trees. Bertault and Sist (1997) notes that the crown damage is the most frequent in areas with RIL techniques, while Van Der Hout (1999) shows that the frequencies of the damage classes depend on the applied harvest technique. The author noted that the felling damage (crown, bole or leaning) was predominant in the RIL area; meanwhile, the skidding damage was predominant in the conventional logging area. This is because, markedly in RIL areas, the number of skidding trails does not increase linearly with the harvest intensity (Sist and Ferreira 2007). As the same trail can be used to extract multiple logs, the number of trees damaged by the skidding operation is reduced.

By the other side, the high frequency of bole damage seen in our study can be attributed to the low efficiency of the skidding. The hilly terrain complicates the directional felling of the trees, the skidding maneuvering and, by consequence, the skidding trail reuse. This condition required more trails to be created and also required more bole maneuvering to extract trees from the forest. The restriction to the directional felling, imposed by the terrain, also complicated the protection of commercially or ecologically relevant species near the felled tree. The bole damage to commercial trees not only may cause reduction in its growth, which reduces the wood volume for the next harvest cycle, but also may cause wood stain and defects, which decrease its value (Vidal et al. 2002; Jackson et al. 2002; Tavankar et al. 2015).

The observed damage had little relation to the harvest intensity, opposing numerous studies conducted in tropical forests (Bertault and Sist 1997; Webb 1997; Van Der Hout 1999; Sist and Nguyen-The 2002; Sist et al. 2003a; Picard et al. 2012; Martin et al. 2015). Still, some results show that the damages are less related to the harvest intensity in conventional logging areas (Bicknell et al. 2014) and, specially, the relation between the skidding damage and the harvest intensity can be very weak in these areas (Van Der Hout 1999; Sist et al. 2003a). In this way, our results indicate that the lack of statistical relation between the damage frequency and the harvest intensity is also due to the low efficiency of the skidding operation. The same conclusion is reinforced when we analyze the specific damage, which shows a strong negative relation with the harvest intensity, suggesting that the damage to the residual stand can be minimized in the low intensities of harvest.

The small size of the trees and the high harvest intensity, inherent of the management of a young secondary forest, contributed to keeping the specific damage low, with 0.87 damaged trees for each harvested tree. Two effects of the harvest's high intensity contribute to this; first, there are fewer residual trees to be damaged, and secondly, there is a greater chance of a felled tree falling in a location where others trees already were felled. The specific damage can reach 44 trees per felled tree in mature forests with low harvest intensity (Jackson et al. 2002). In most studies of conventional logging areas in Asia and South America, these values range from 7 to 18.1 tree/harvested tree (Van Der Hout 1999; Forshed et al. 2006; Iskandar et al. 2006; Macpherson et al. 2010). In RIL logging, similarly the values range from 8.2 to 17.7 tree/harvested tree (Van Der Hout 1999; Forshed et al. 2006; Rockwell et. al. 2007; Macpherson et al. 2010; Medjibe et al. 2011). Nonetheless, for similar harvest intensities the use of RIL techniques tends to reduce the specific damage (Van Der Hout 1999; Macpherson et al. 2010), suggesting that the application of these techniques can reduce even more the damage in our study area.

Conclusions

The selective timber harvest damaged 26% of the residual stand, affecting mainly small trees and causing light damage. The frequency of these damages has no statistical relation with the harvest intensity; meanwhile, the specific damage strongly decreased with the increase in harvest intensity. We believe that the poor planning of the skidding trails, the hilly terrain and the high understory density had great influence on this result.

The results suggest that damages to the residual stand are not a key factor to determine the ideal harvest intensity for a secondary forest. Other factors, such as remaining stock, canopy opening and the favoring of species with economic interest had a greater influence on the decision-making. Despite this, it's necessary to monitor the injured trees to determine if there is change in growth and morality rates and then be able to infer the consequences of the injuries in the recovery and development of the forest, especially of the species with economic interest.

The utilization of RIL techniques, mainly the directional felling and planning of the skidding trails, can be important tools to reduce the impact of harvesting. Ultimately, these techniques still need to have their applicability and efficiency tested in secondary forests, with smaller trees and higher harvest intensity than mature forests and mostly hilly terrain.

Acknowledgment

The authors thank the Bisewski Family for the access to the study site and for the support in the harvest, FATMA for the management authorization, the Forest Engineers Geferson Piazza Heitor Felipe Ulller and Aline Klitzke for the help in the data collection. The Madeira Nativa project was funding by FAPESC (Award 18689/2009-9) from 2009 to 2014. The third author received productivity grant from CNPq. The first author thanks FAPESC and CNPq for the master grant, the others authors thanks CNPq for the research grant.

References

Alvares CA, Stape JL, Sentelhas PC, de Moraes Gonçalves JL, Sparovek G (2013) Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*; 22(6): 711–728. http://doi.org/10.1127/0941-2948/2013/0507

Bertault J, 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.

Bicknell JE, Struebig MJ, Edwards DP, Davies ZG (2014) Improved timber harvest techniques maintain biodiversity in tropical forests. *Current Biology*; 24(23): 1119–1120. http://doi.org/10.1016/j.cub.2014.10.067

Bischoff W, Newbery DM, Lingenfelder M, Schnaeckel R, Petol GH, Madani L, Ridsdale CE (2005) Secondary succession and dipterocarp recruitment in Bornean rain forest after logging. *Forest Ecology and Management*; 218(1-3): 174–192. http://doi.org/10.1016/j.foreco.2005.07.009

Chazdon RL (2014) *Second growth: the promise of tropical forest regeneration in an age of deforestation*. Chicago Press, Chicago.

Chokkalingam U, Jong W De (2001) Secondary forest : a working definition and typology. *International Forestry Review*; 3(1): 19–25.

Dykstra D, Heinrich R (1996) *FAO Model Code of Forest Harvesting Practice*. FAO. Rome.

Edwards DP, Gilroy JJ, Woodcock P, Edwards FA, Larsen TH, Andrews DJR, et al. (2014) Land-sharing versus land-sparing logging: reconciling timber extraction with biodiversity conservation. *Global Change Biology*; 20(1): 183–91. http://doi.org/10.1111/gcb.12353

EMBRAPA (2004) *Solos do Estado de Santa Catarina*. Embrapa solos, Rio de Janeiro.

FAO (2012) *State of the World ' s Forests*. FAO, Rome.

Forshed O, Karlsson A, Falck J, Cedergren J (2008) Stand development after two modes of selective logging and pre-felling climber cutting in a dipterocarp rainforest in

Sabah, Malaysia. *Forest Ecology and Management*; 255(3-4): 993–1001. http://doi.org/10.1016/j.foreco.2007.10.006

Forshed O, Udarbe T, Karlsson A, Falck J (2006) Initial impact of supervised logging and pre-logging climber cutting compared with conventional logging in a dipterocarp rainforest in Sabah, Malaysia. *Forest Ecology and Management*; 221(1-3): 233–240. http://doi.org/10.1016/j.foreco.2005.10.007

Gibson L, Lee TM, Koh LP, Brook BW, Gardner TA, Barlow J, et al. (2011) Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature*; 478(7369): 378–381. http://doi.org/10.1038/nature10425

Huth A, Ditzer T (2001) Long-term impacts of logging in a tropical rain forest - a simulation study. *Forest Ecology and Management*; 142: 33–51.

Iskandar H, Snook LK, Toma T, MacDicken KG, 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(1-3): 83–93. http://doi.org/10.1016/j.foreco.2006.09.079

Jackson SM, Fredericksen TS, Malcolm JR (2002) Area disturbed and residual stand damage following logging in a Bolivian tropical forest. *Forest Ecology and Management*; 166: 271–283.

Kammesheidt L (2002) Perspectives on Secondary Forest Management in Tropical Humid Lowland America. *AMBIO: A Journal of the Human Environment*; 31(3): 243–250. http://doi.org/10.1579/0044-7447-31.3.243

Macpherson AJ, Schulze MD, Carter DR, Vidal E (2010) A Model for comparing reduced impact logging with conventional logging for an Eastern Amazonian Forest. *Forest Ecology and Management*; 260(11): 2002–2011. http://doi.org/10.1016/j.foreco.2010.08.050

Martin PA, Newton AC, Pfeifer M, Khoo M, Bullock JM (2015) Impacts of tropical selective logging on carbon storage and tree species richness: A meta-analysis. *Forest Ecology and Management*; 356: 224–233. http://doi.org/10.1016/j.foreco.2015.07.010

Medjibe VP, Putz FE, Starkey MP, Ndouna, AA, Memiaghe HR (2011) Impacts of selective logging on above-ground forest biomass in the Monts de Cristal in Gabon. *Forest Ecology and Management*; 262(9): 1799–1806. http://doi.org/10.1016/j.foreco.2011.07.014

Miller SD, Goulden ML, Hutyra LR, Keller M, Saleska SR, Wofsy SC, et a. (2011) Reduced impact logging minimally alters tropical rainforest carbon and energy exchange. *Proceedings of the National Academy of Sciences of the United States of America*; 108(48): 19431–5. http://doi.org/10.1073/pnas.1105068108

Mukul SA, Herbohn J (2016) The impacts of shifting cultivation on secondary forests dynamics in tropics: A synthesis of the key findings and spatio temporal distribution of research. *Environmental Science and Policy*; 55: 167–177. http://doi.org/10.1016/j.envsci.2015.10.005

Oliveira Filho AT (2009) Classificação das fitofisionomias da América do Sul. *Rodriguésia*; 60: 237–258.

Piazza G E (2014) *Regeneraçao de Espécies Madeireiras na Floresta Secundária da Mata Atlântica*. Dissertation, Universidade Federal de Santa Catarina.

Picard N, Gourlet-Fleury S, Forni É (2012) Estimating damage from selective logging and implications for tropical forest management. *Canadian Journal of Forest Research*; 613: 605–613. http://doi.org/10.1139/X2012-018

Putz FE (1994) *Approaches to Sustainable Forest Management. Rainforest are our Business*. Retrieved from http://dlc.dlib.indiana.edu/dlc/handle/10535/3695

Putz FE, Brokaw NVL (1989) Sprouting of Broken Trees on Barro Colorado Island, Panama. *Ecology*; 70(2): 508–512.

Putz FE, Zuidema PA, Synnott T, Peña-Claros M, Pinard MA, Sheil D, et al. (2012) Sustaining conservation values in selectively logged tropical forests: the attained and the attainable. *Conservation Letters*; 5: 296–303. http://doi.org/10.1111/j.1755-263X.2012.00242.x

Rockwell CA, Kainer KA, Staudhammer CL, Baraloto C (2007) Future crop tree damage in a certified community forest in southwestern Amazonia. *Forest Ecology and Management*; 242(2-3):108–118. http://doi.org/10.1016/j.foreco.2006.12.028

Schuch C (2010) *Potencialidades da produçao de madeira serrada a partir de três espécies da floresta secundaria litorânea catarinense em condiçoes de plantio e em áreas de floresta regenerada naturalmente*. Dissertation, Universidade Federal de Santa Catarina.

Sevegnani L, Uhlmann A, Gasper AL, Vibrans AC, Santos AS, Verdi M, et al. (2010) Estádios sucessionais na Floresta Ombrófila Densa em Santa Catarina. In: Vibrans AC, Sevegnani L, Gasper AL, Lingner DV (editors) *IFFSC Vol. IV: Floresta Ombrófila Densa.* Edifurb, Blumenau.

Shanley P, Gaia GR (2002) Equitable ecology: collaborative learning for local benefit in Amazonia. *Agricultural Systems*; 73(1): 83–97. http://doi.org/10.1016/S0308-521X(01)00101-9

Siminski A, Fantini AC (2010) A Mata Atlântica cede lugar a outros usos da terra em Santa Catarina, Brasil. *Biotemas*; 23(2): 51–59.

Sist P, Nolan T, Bertault JG, Dykstra D (1998) Harvesting intensity versus sustainability in Indonesia. *Forest Ecology and Management*; 108(3): 251–260. http://doi.org/10.1016/S0378-1127(98)00228-X

Sist P, Nguyen-Thé N (2002) Logging damage and the subsequent dynamics of a dipterocarp forest in East Kalimantan (1990–1996). *Forest Ecology and Management*; 165(1-3): 85–103. http://doi.org/10.1016/S0378-1127(01)00649-1

Sist P, Sheil D, Kartawinata K, Priyadi H (2003a) Reduced-impact logging in Indonesian Borneo: some results confirming the need for new silvicultural prescriptions. *Forest Ecology and Management*; 179(1-3): 415–427. http://doi.org/10.1016/S0378-1127(02)00533-9

Sist P, Fimbel R, Sheil D, Nasi R, Chevallier MH (2003b) Towards sustainable management of mixed dipterocarp forests of South-east Asia: moving beyond minimum diameter cutting limits. *Environmental Conservation*; 30(4): 364–374. http://doi.org/10.1017/S0376892903000389

Sist P, Picard N, Gourlet-Fleury S (2003c) Sustainable cutting cycle and yields in a lowland mixed dipterocarp forest of Borneo. *Annals of Forest Science*; 8(60): 803–814. http://doi.org/10.1051/forest

Sist P, Ferreira FN (2007) Sustainability of reduced-impact logging in the Eastern Amazon. *Forest Ecology and Management*; 243(2-3): 199–209. http://doi.org/10.1016/j.foreco.2007.02.014

Tavankar F, Bonyad A, Marchi E, Venanzi R, Picchio R (2015) Effect of logging wounds on diameter growth of beech (Fagus orientalis Lipsky) trees following selection cutting in Caspian forests of Iran. *New Zealand Journal of Forestry Science*; 45(19): 1–7. http://doi.org/10.1186/s40490-015-0052-9

Van der Hout P. *Reduced Impact Logging in the Tropical Rain Forest of Guyana* (1999) Tropenbos-Guyana Programme, Georgetown.

Vibrans AC, McRoberts RE, Moser P, Nicoletti AL (2013) Using satellite image-based maps and ground inventory data to estimate the area of the remaining Atlantic forest in the Brazilian state of Santa Catarina. *Remote Sensing of Environment*; 130: 87–95. http://doi.org/10.1016/j.rse.2012.10.023

Vidal E, Viana VM, Batista JLF(2002) Crescimento de floresta tropical três anos após colheita de madeira com e sem manejo florestal na Amazônia oriental. *Scientia Forestalis*; 61: 133–143.

Webb EL (1997) Canopy removal and residual stand damage during controlled selective logging in lowland swamp forest of northeast Costa Rica. *Forest Ecology and Management*; 95: 117–129.

Webb EL (1998) Gap-phase regeneration in selectively logged lowland swamp forest, northeastern Costa Rica. *Journal of Tropical Ecology*; 14(2): 247–260. http://doi.org/10.1017/S0266467498000194.