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A 30-year study of the effects of selective logging on a stem-less palm (*Astrocaryum sociale*) in a central-Amazon forest

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ABSTRACT

We studied the long-term effects of different selective-logging intensities on the stem-less palm *Astrocaryum sociale* in a central Amazonian forest 90 km north of Manaus. The experiment consisted of three blocks of 24 ha, each divided into six 4 ha plots in which the treatments were allocated randomly. Each block had a control plot. Within each block, commercial timber was logged with intensities of 44%, 50% and 67% of basal area in 1987, 1988 and 1993 respectively. Stem-less palms in each plot were measured in 1996 and 2016. The number of individuals decreased slightly from 3229 in 1996 to 2997 in 2016, and there was an increase in the proportion of large palms. The degree of change in size structure was related to time since logging ($p = 0.012$), which also affected the total number of leaves ($p = 0.0001$), the sum of all leaf lengths ($p = 0.01$) and the number of adults ($p = 0.056$). The volume of timber extracted and in standing dead trees was not related to size-structure change. In the control block, the number of individuals changed slightly during the study period. As the different cutting intensities had little, if any, effect of the size-structure of this understory palm up to 30 years after logging, management concessions can contribute to the conservation of some elements of palm biodiversity.

1. Introduction

Well-planned forest management can contribute to global biodiversity conservation (Chaudhary et al., 2016). Reduced-impact logging (RIL) techniques are considered useful tools for decreasing the rate of tropical-forest deforestation (Darrigo et al., 2016; Putz et al., 2012; Schwartz et al, 2012), can produce more profit than conventional logging (Barreto et al., 1998; Boltz et al., 2001; Holmes et al., 2002, Johns et al., 1996) and purportedly guarantee wood for the next logging cycle (Holmes et al., 2002; Johns et al., 1996; Verissimo et al., 1992). There are many studies concerning the effects of RIL on regeneration of commercial trees (Darrigo et al., 2016; de Carvalho et al., 2017; Doucet et al., 2009; Karsten et al., 2013; Rivett et al., 2016; Schwartz et al., 2012, 2013; 2017; Soriano et al., 2011), but few studies of regeneration of species with little commercial value in selectively logged areas (Clark et al., 2001; Costa et al., 2002; Dekker and De Graaf, 2003; Magnusson et al., 1999) and fewer studies evaluating the effects of logging techniques on palms (Arevalo et al., 2016).

Palms are an abundant and distinctive element in the central Amazon, found from sub-canopy to canopy, in all types of soil and topography and they exhibit a large range of growth forms (Kahn and Castro, 1985). The stem-less palm, *Astrocaryum sociale*, is endemic to the central Amazon region. It occurs on well drained, flat to slightly sloping areas (Kahn and Castro, 1985); the types of areas that are usually selected for logging. In these areas, stem-less palms are often the dominant component of the forest sub-canopy (Guillaumet, 1987; Kahn, 1986).

Several studies have evaluated the effects of selective logging on commercial and non-commercial species in the Manaus region (Costa and Magnusson, 2003; Limaet al., 2002; Magnusson et al., 1999). However, there are no studies of the effects of selective logging on *A. sociale*. The aim of this study was evaluate the effects of different logging intensities on *A. sociale* in an area that was selectively logged in 1987, 1988 and 1993 (Higuchi et al., 1985).

2. Material and methods

2.1. Study site

The study was carried out in the ZF2 Forest-Management Station (2°37′S latitude, 60°11′W longitude) of the Instituto Nacional de Pesquisas da Amazônia, 90 km north of Manaus, Brazil. The site is covered by *terra firme* dense tropical rainforest (Braga, 1979), with an average altitude of 124 m above sea level and undulating topography. The Bionte project was initiated in 1985 to evaluate the effects of different intensities of basal-area reduction due to selective logging. The

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experiment was carried out in three blocks of 24 ha, each with 6 plots of 4 ha, where treatments were allocated randomly. Each block had one control plot.

The projected logging intensities were 44% (1987), 50% (1988) and 67% (1993) of the basal area of commercial timber. Chainsaws, a bulldozer with a front blade and a tree-pusher, a winch and a truck with a crane were used for logging. The bulldozer was used for extracting the logged timber, because the truck did not function, resulting in more damage to the remaining forest. In this paper, we used the reduction in volume of all tree species with dbh ≥ 10 cm as our index of logging disturbance (Magnusson et al., 1999) and not the predicted logging intensities.

2.2. Data collection

The data were collected from each 4-ha plot by walking along 8 straight parallel 200-m walking trails spaced 25 m apart that are used for ongoing tree inventories (Higuchi et al., 1985). On each trail, 4 sub-plots (5 × 25 m) spaced 25 m apart were selected for collecting data on the number of individuals, total number of leaves, longest leaf length, individual position in the plot and the presence of reproductive parts. The collected data is from the same plots, but not necessarily the same individuals measured in 1996. Data were collected in 1996 by Maria Marcela Ortiz Brasil (Brasil, 1997). Data collection in 2006 was carried out by EMH. Individuals with longest leaf length of less than 3.5 m were

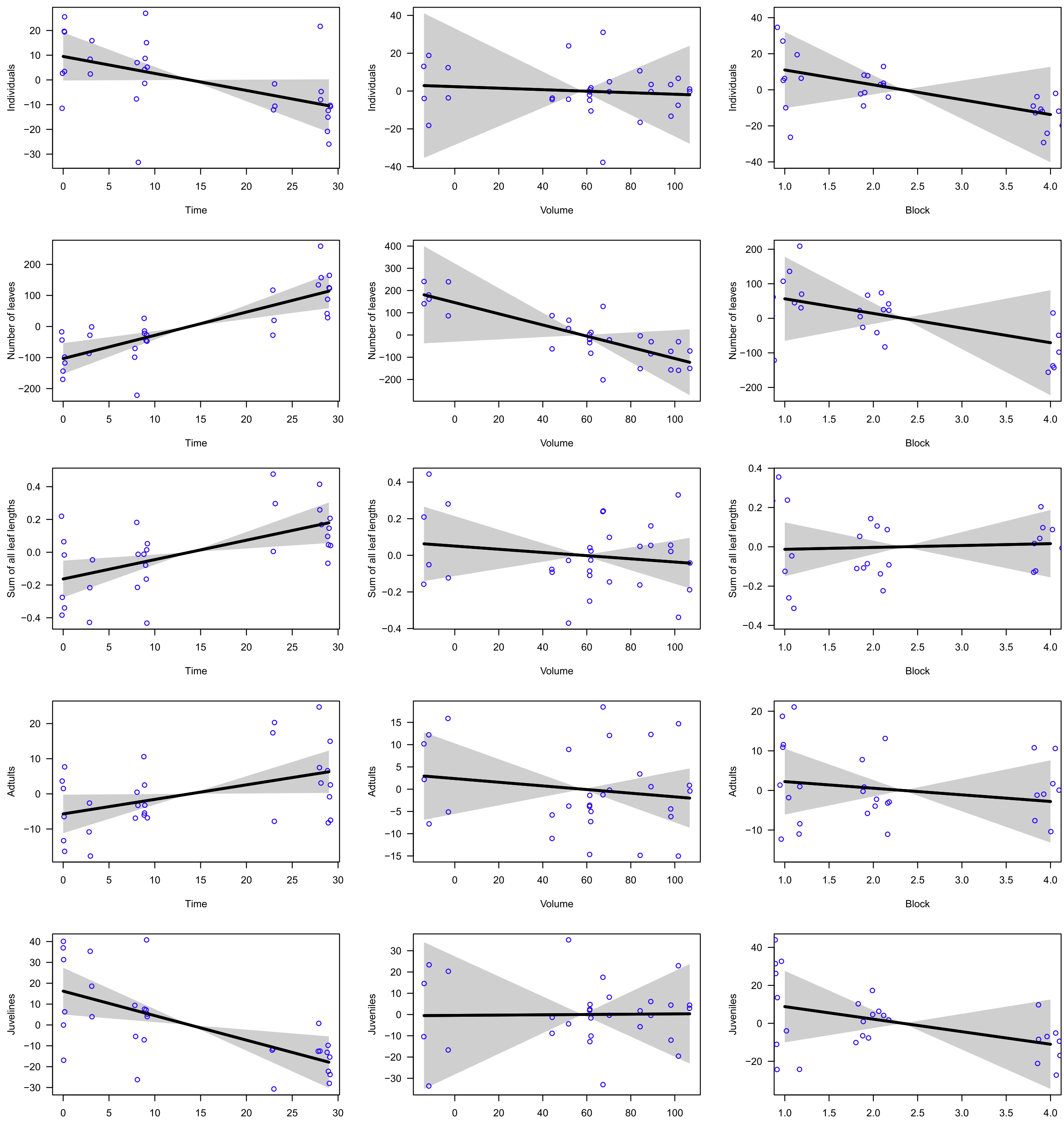

Fig. 1. Partial graphs from the fitted model presenting the effects of Time after logging, damaged Volume and Block on each characteristic analyzed.

treated as juveniles because no individuals with smaller leaves were found to be reproducing.

2.3. Data analysis

Linear mixed regressions were carried out in the program R (R Core Team, 2015) and the *lme4* (Bates et al., 2015), *lmerTest* (Kuznetsova et al., 2017) and *sjstats* (Lüdecke, 2018) packages. Time after logging (Time), reduction in wood-volume (Volume) and Block were considered as fixed effects and the plots as random effects, nested in the blocks. We used the likelihood ratio test to select the best model (Bolker et al., 2009) from the full model:

$$Y_{ijk} = Time_{ijk} + Volume_{ijk} + Block_{ik} + (1|Block_{ik}/plot)$$

Y: Dependent variable
Time: time since logging
Volume: reduction in wood volume due to logging
Block: experimental blocks.
plot: 4 ha plot where treatments were allocated

3. Results

In 1996, there were 3229 individuals in the plots, none of which had flowers or fruits. In 2016, 2997 individuals were found of which 7 had produced fruit. The number of individuals decreased over the years since logging (Fig. 1).

Part of this is explained by the time elapsed since logging ($p = 0.075$), but there was no evidence that reduction in wood volume affected the number of individuals ($p = 0.884$) (Table 1).

Although the number of individuals changed only slightly during the study, the number of adults increased, and this was related to the

Table 1
Summary of multiple mixed regression analyses evaluating the effects of time since logging and volume of trees killed due to logging operations on the total number of individuals, number of juveniles, number of adults, sum of leaf lengths and total number of leaves.

Number of individuals

Fixed Parts	Estimate	Standard Error	*p*
Intercept	238. 589	24.543	4.22E−07
Time	−0.688	0.359	0.0752
Volume	−0.040	0.271	0.8848
Block	−8.248	8.110	0.3291
Random Parts	Variance		
Residual	316.2		
Plot:Block	1332.7		
Block	0		
$N_{Plot:Block}$	15		
N_{Block}	3		
$Icc_{Plot:Block}$	0.808229		
Icc_{Block}	0		
Observations	30		

Number of juveniles

Fixed Parts	Estimate	Standard Error	*p*
Intercept	198.587	21.873	8.1E−07
Time	−1.175	0.415	0.0126
Volume	0.007	0.245	0.9775
Block	−6.607	7.208	0.3773
Random Parts	Variance		
Residual	428.9		
Plot:Block	962.3		
Block	0		
$N_{Plot:Block}$	15		
N_{Block}	3		
$Icc_{Plot:Block}$	0.691		
Icc_{Block}	0		
Observations	30		

Number of adults

Fixed Parts	Estimate	Standard Error	p
Intercept	40.733	8.931	0.0950
Time	0.414	0.202	0.056
Volume	−0.041	0.070	0.565
Block	−1.672	3.181	0.691
Random Parts	Variance		
Residual	112.41		
Plot:Block	24.27		
Block	30.55		
$N_{Plot:Block}$	15		
N_{Block}	3		
$Icc_{Plot:Block}$	0.145		
Icc_{Block}	0.182		
Observations	30		

Sum of leaf lengths

Fixed Parts	Estimate	Standard Error	p
Intercept	1.995	0.152	0.0168
Time	0.012	0.004	0.0109
Volume	−0.001	0.001	0.5538
Block	0.010	0.053	0.8842
Random Parts	Variance		
Residual	0.04719		
Plot:Block	0.01099		
Block	0.00571		
$N_{Plot:Block}$	15		
N_{Block}	3		
$Icc_{Plot:Block}$	0.172		
Icc_{Block}	0.089		
Observations	30		

Total Number of leaves

Fixed Parts	Estimate	Standard Error	*p*
Intercept	1292.856	140.793	8.28E−07
Time	7.484	1.835	0.00106
Volume	−2.514	1.549	0.12895
Block	−42.370	46.556	0.38072
Random Parts	Variance		
Residual	8221		
Plot:Block	45,037		
Block	0		
$N_{Plot:Block}$	15		
N_{Block}	3		
$Icc_{Plot:Block}$	0.845		
Icc_{Block}	0		
Observations	30		

time elapsed since logging (p = 0.056). However, change in size structure was not related to decrease in wood-volume (p = 0.565). The number of juveniles decreased because of the development of seedlings to adulthood and consequently the number of leaves increased from 16,204 in 1996 to 18,342 leaves in 2016. The change in the total number of leaves was related to time (p = 0.001), with little evidence for an effect of reduction in wood volume (p = 0.129). The decrease in the number of juveniles was associated with an increase in the number of adults from 517 ind. (1996) to 688 ind. (2016) which was related to time (p = 0.013), but not to reduction in wood volume (p = 0.978). The sum of all leaf lengths increased slightly and was related to time (p = 0.011), but not to reduction in wood volume (p = 0.554).

The number of individuals of *A. sociale* in logged plots decreased slightly throughout the study, but this also occurred in the control areas (Fig. 1).

4. Discussion

The Bionte Project used a wide range of levels of selective logging and tree mortality was even greater than that estimated from the volume of wood removed (Magnusson et al., 1999). Nevertheless, effects of the intervention on the density and sizes of *Astrocaryum sociale* were small or nonexistent, and could not be distinguished from changes that occurred in the control blocks. Arevalo et al. (2016) evaluated the effect of reduced-impact logging (2.7 ind. ha^{-1}) on five species of palms and they also detected no effect of the extraction except in logging patios, but they only evaluated the effects over a period of one year post-logging. Our study covered a period of 30 years and is probably indicative of long-term effects.

Logging affects the regeneration of many tree species in the understory (Darrigo et al., 2016), probably because of falling branches (Clark et al., 2001), reduction in humidity (Martínez-Ramos et al., 2009) and soil compaction (Clarke and Walsh, 2006; Hattori et al., 2013), but appears to have little effect on *A. sociale*. Nonetheless, the size structure of the individuals in the area appears to be changing, both in logged and control areas. Possible causes of structural changes in the forest unrelated to direct human interventions include recuperation from severe storm events in the past (Marra et al., 2014; Nelson, 1994), droughts induced by El Ninõ and North Atlantic atmospheric-pressure oscillations, changes in rainfall regimes and increase in atmospheric CO_2 concentrations (Laurence et al., 1997). It is not possible to evaluate these factors with data from a single site over a 30-year period.

Dominance of large stem-less palms is a characteristic of central-Amazonian forests (Laurance et al., 2009; Ribeiro et al., 1999), and *A. acaule* is the most common species with this life-form in areas suitable for sustainable logging. Therefore, logging will probably not cause large changes in the structure of the understory in this region. Studies of other taxa in the area have also not detected large changes due to logging (Costa et al., 2002; Costa and Magnusson, 2003; Lima et al., 2002; Magnusson et al., 1999), which indicates that logging concessions could contribute significantly to conservation of biodiversity.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foreco.2018.10.003.

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