Ciência Florestal

ISSN 1980-5098
Open access

Ci. Fl., Santa Maria, v. 32, n. 1, p. 333-350, Jan./Mar. 2022 • https://doi.org/10.5902/1980509855265
Submitted: 21st/09/2020 • Approved: 17th/06/2021 • Published: 25th/03/2022

**Artigos**

# Recruitment exceeds mortality in subtropical secondary forest after conventional selective logging

## Recrutamento supera a mortalidade em floresta subtropical secundária após colheita de madeira convencional

**Janine Kervald Likoski**[I]
**Alexander Christian Vibrans**[I]
**Daniel Augusto da Silva**[I]

[I]Universidade Regional de Blumenau, Blumenau, SC, Brazil

## ABSTRACT

Studies on the dynamics of managed forests are essential for planning and executing management strategies. Timber harvesting can modify recruitment rates, mortality, gain and loss of basal area of the remaining stand. In secondary forests, especially in the Atlantic Forest, these studies are still scarce. Our study hypothesis is that the management intervention stimulates the growth of the remaining trees, overcoming the reduction of the growth of the damaged trees and the harvest mortality. We investigated the dynamics of the remaining trees and recruits (in number of individuals and basal area), with DBH ≥ 5 cm, by ecological group of the species, and the damage to the remaining adult individuals. We measured eleven permanent plots with 1.600m² each, before and four years after being harvested in a secondary forest in southern Brazil. We found that the different harvesting intensities significantly influence the forest dynamics, special the annual recruitment rates, while basal area gain/loss showed a weaker relationship to logging intensity. However, the mortality rates are similar in control plots and managed plots. We also observed that in the managed plots, the recruitment rate (5.3 ± 1.9% year-¹) exceeded mortality (2.3 ± 1.2% year-¹). Among ecological groups, we found less recruitment of climax species than of secondary species. In general, the proportion of damage of remaining trees decreased over time. We conclude that the management has modified the forest dynamics, indicating that planning, including adequate cutting limits and low impact harvesting methods are essential for achieving the sustainability of forest management.

**Keywords:** Forest dynamics; Logging damages; Harvest intensity; Conventional logging

## RESUMO

Estudos de dinâmica de florestas manejadas são fundamentais para planejamento e execução de estratégias de condução das florestas. As intervenções de colheita madeireira podem modificar taxas de recrutamento, mortalidade, ganho e perda de área basal da floresta remanescente. Em florestas secundárias, especialmente na Mata Atlântica, estes estudos ainda são escassos. Nossa hipótese de pesquisa é que a intervenção de manejo estimule o crescimento das árvores remanescentes, superando a redução do crescimento das árvores danificadas e mortalidade da colheita. Foi investigado a dinâmica das árvores remanescentes e dos recrutas (em número de indivíduos e área basal), com DAP ≥ 5 cm, por grupo ecológico da espécie, e os danos nos indivíduos adultos remanescentes. Medimos onze parcelas permanentes, com área de 1600 m², antes e quatro anos após a colheita de madeira em uma floresta secundária no sul do Brasil. Verificamos que as diferentes intensidades de colheita influenciam significativamente a dinâmica da floresta, especialmente as taxas de recrutamento anual, enquanto perda e ganho de área basal apresentaram uma relação mais fraca com a intensidade de corte; as taxas de mortalidade, no entanto, são semelhantes em parcelas de controle e parcelas manejadas. Também observamos que nas parcelas manejadas a taxa de recrutamento (5.3 ± 1.9 % /ano) superou a mortalidade (2.3 ± 1.2 % / ano). Entre os grupos ecológicos, encontramos menos recrutamento de espécies clímax do que de espécies secundárias. Em geral, a proporção de danos às árvores remanescentes diminuiu com o tempo. Concluímos que o manejo modificou a dinâmica florestal, indicando que o planejamento, incluindo limites de corte adequados e métodos de colheita de baixo impacto são essenciais para o alcance de um manejo florestal sustentável.


**Palavras-chave:** Dinâmica florestal; Danos de colheita; Intensidade de colheita; Colheita convencional

# 1 INTRODUCTION

Good forest management practices are essential to conserve or improve important ecosystem services while promoting the continuous production of quality timber and income generation (DUNCKER *et al*., 2012). For this, forest managers should consider studies that aim to determine minimum cutting diameters and specific cutting cycles for each target species of the harvest (DAVID *et al*., 2019). Therefore, it is necessary to implement a management regime with adequate cutting intensity and exploration techniques to minimize the negative effects of wood harvesting. Otherwise, both factors can result in increased damage and mortality of remaining trees, which can compromise future forest productivity (SILVA *et al*., 2017; LOCONTE, 2018). Canopy opening can also benefit the growth and the entry of species that demand full light, but that produce little valuable timber, to the detriment of species that produce marketable wood, but are tolerant to shade (SILVA, 2016; GRANSTROM, 2019). This can, in the long term, cause an unwanted change in the composition of forest species (DARRIGO; VENTICINQUE; SANTOS, 2016; AVILA *et al*., 2017).

Both the cutting intensity and the selection of trees to be explored can lead the management area to variable rates of forest recovery (DING e*t al.*, 2017). The community structure and species composition can be recovered relatively quickly when, at least, part of the forest structure is maintained (SOUZA *et al*., 2017). However, the recovery process can be difficult when intensive and frequent cuts are applied (HILTNER *et al*., 2018). In the latter case, residual damage, such as soil degradation, fragmentation of the forest and the uprooting or destruction of saplings, may, in future cycles, inhibit the establishment of species of greater commercial value and with larger dimensions, causing subsequent harvests to include less valuable trees.

The direct effects of the harvest on the remaining trees are related to the cutting intensity (SILVA *et al*., 2017), harvesting methods, and log extraction (BRITTO *et al*., 2019). These impacts caused by tree harvesting can damage crowns and trunks of the remnant trees and, indirectly, affect mortality and recruitment rates of the stand (MARTIN *et al*., 2015). For these reasons, the study of forest resilience, especially in biological aspects, which include the growth of remaining trees and ingrowing trees, is relevant for a greater understanding of the forest, since these variables will determine the dynamics of forest development (SANTOS *et al*., 2018). However, little is known about the changing parameters (mortality, recruitment, loss and gain of basal area) of the medium-term forest in managed areas.

In Brazil, almost all studies involving the management of forests for timber purposes are being carried out in the Amazon. In other regions, like the Atlantic Forests, mature forests with significant timber stocks, as well as secondary forests, cannot be managed due to legal restrictions. However, an increasing number of authors advocate the possibility of careful and thoroughly planned timber harvest, especially in secondary forests (FANTINI; SIMINSKI; GAIO, 2016; FANTINI *et al*., 2017, 2019; FANTINI; SIMINSKI, 2017; SILVA *et al*. 2017; BRITTO *et al*., 2019). Due to their representativeness in the Atlantic Forest region, secondary forests have a great potential for sustainable management, combining timber production and provision of ecosystem services (SILVA *et al*., 2017). Furthermore, secondary forest management is believed to assure the survival of the native forest cover and to restrain the continuous (and illegal) land use change to other land uses.

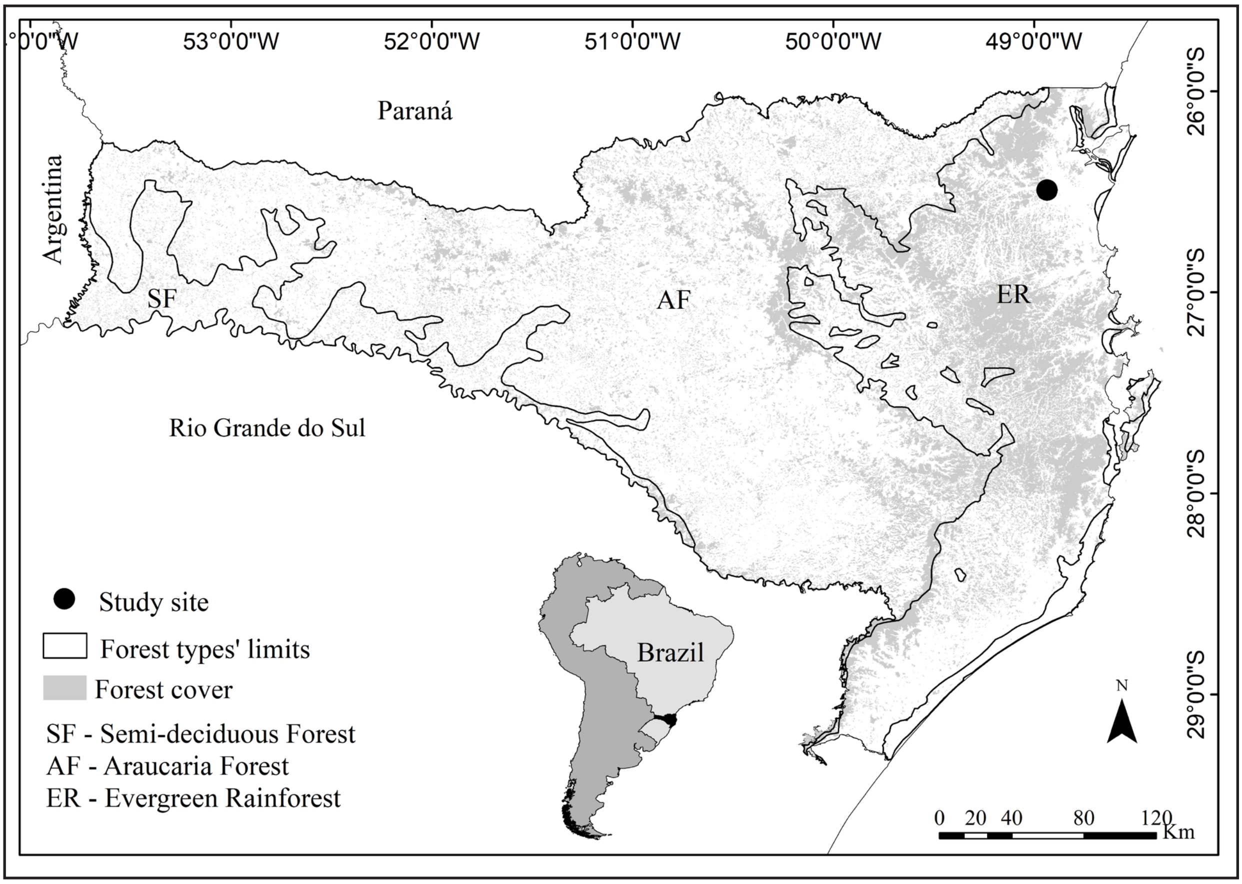
Given the fact that timber harvesting can trigger several processes that influence the recovery of the forest, our hypothesis is that the management intervention stimulates the growth of the remaining trees, overcoming the reduction of the growth of the damaged trees and the harvest mortality. Our objectives are twofold:: i) to quantify the growth and mortality of the remaining and ingrowing trees (in number of individuals and basal area), by ecological group four years after timber harvesting; ii) to quantify the effects of tree damage during harvesting on tree growth and mortality rates of the remaining trees.

## 2 MATERIAL AND METHOD

### 2.1 Characterizing the local

This study was conducted in a secondary forest located in the northeast of Santa Catarina state, southern Brazil, with a total area of 41.9 hectares (26º31’57”S and 49°02’32”W, approximately, Figure 1). The local climate, according to Köppen, is classified as Cfa - humid mesothermal without dry season (WREGE *et al*., 2012), with annual rainfall ranging from 1.700 mm to 1.900 mm and average temperature of 19 to 20ºC (ALVARES *et al*., 2013). The study area has altitudes between 160 and 500 m.a.s.l., slopes between 30% and 40%, and southern-southeastern exposure.

Figure 1 – Location of the study site in Santa Catarina state, southern Brazil




Source: Authors (2020)

The forest in the study area was heavily logged until the 1970s to produce sawn wood of the most valuable species. At that time, some forest patches were left amidst of pastures and initial forest regrowth and some remaining trees. An enrichment planting with seedlings of native tree species, especially *Miconia cinammomifolia* (DC.) Naudin, *H. alchorneoides* Allemão and *Nectandra* spp., was performed in 1978. Irregular spacing was applied and some silvicultural treatments were applied (cleaning and mowing) during the first five years after the plantation.

## 2.2 Experimental design

We measured nine permanent plots with 1.600 m² each, before and four years after being harvested, and two control plots in non-harvested stand. Within the plots DBH and total height of all trees with DBH ≥ 5 cm were measured six months before harvesting. Trees were identified at species level, whenever possible; botanical material was collected and identified at Dr. Roberto Miguel Klein Herbarium (FURB) of Regional University of Blumenau. Species were classified according to its ecological group (pioneer, secondary and climax) following the methodology of the Forest and Floristic Inventory of Santa Catarina (IFFSC) (VIBRANS *et al*., 2013). All trees were located in the plot with x – y coordinates and were identified with numeric tags. The harvest criteria included mainly the tree timber quality, ecological group and abundance of the species at plot level (SILVA *et al*., 2017). The treatments applied in the second half of 2015, consisted of different harvest intensities, from 21.8 to 51.1% of the total basal area in the plots 2, 3, 4, 7, 8, 11, 12, 18 and 19 (Table 1). Because of operational constraints, it was not possible to hit exactly the initially intended intensities of 20, 40 and 60%. A locally common conventional timber harvesting method was carried out. The felling was made with chainsaw (model Stihl 251) and the extraction by a Valmet tractor model 85 (2x4, 63 kW), equipped with a winch TMO model Caçador 33T (BRITTO *et al*., 2019). The trees were extracted without directional cut, using the tree-length system, and with the debranching done inside the forest (SILVA *et al*., 2017). A total of 695 trees, mainly *H. alchorneoides*, *M. cinammomifolia* and *Nectrandra* spp. were harvested. Minimum felling diameter was 25 cm for sawn wood and 5 cm for fuelwood production. In addition, two control plots were left without treatments (plots 6 and 20).

Table 1 – Basal area and number of initial and harvested individuals per plot

| Plot | G initial ($m^2.ha^{-1}$) | Harvested G ($m^2.ha^{-1}$) | Harvested G (%) | Initial density (ind. $ha^{-1}$) | Nº ind. harvested (ind. $ha^{-1}$) | Nº ind. harvested (%) |
|---|---|---|---|---|---|---|
| 6 | 29,2 | 0 | 0 | 1825 | 0,0,0 | 0 |
| 20 | 30,6 | 0 | 0 | 1575 | 0 | 0 |
| 2 | 34,9 | 11,4 | 32,6 | 2018,8 | 569,3 | 28,2 |
| 3 | 33,4 | 12,5 | 37,4 | 1962,5 | 600,5 | 30,6 |
| 4 | 24,5 | 6,8 | 27,8 | 1918,8 | 568 | 29,6 |
| 7 | 37 | 16,4 | 44,3 | 2168,8 | 780,8 | 36 |
| 8 | 31 | 6,9 | 22,4 | 1706,3 | 356,6 | 20,9 |
| 11 | 31,3 | 6,8 | 21,8 | 1643,8 | 212 | 12,9 |
| 12 | 30,8 | 8,6 | 28 | 1750 | 238 | 13,6 |
| 18 | 43,1 | 22 | 51,1 | 1856,3 | 694,2 | 37,4 |
| 19 | 25,3 | 10,3 | 40,7 | 1256,3 | 325,4 | 25,9 |
| Mean | 32,1 | 9,3 | 27,8 | 1789,2 | 395 | 21,4 |

Source: Authors (2020)

In where: G = basal area; ind. = individuals.

Immediately after the tree harvesting, we returned to the plots to determine the effective harvest intensity and the damages in the residual stand (see SILVA *et al*., 2017). Four years after the harvest, all individuals with DBH ≥ 5 cm were re-measured, including recruits, that is, those who had reached the inclusion criteria. Individuals measured on other occasions and not found alive in 2019 were considered dead. The damage classification on both occasions was made visually and followed the criteria presented in Table 2.

Table 2 – Classification criteria for the harvest damage on the residual stand

| 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 |
| Stem damage | Bark damage | Superficial wood damage (cambial tissue) | Deep wood damage (sub cambial tissue) |
| Tree leaning | Slight leaning | Partially uprooted | Totally uprooted |

Source: Silva *et al*. (2017)

## 2.3 Data analysis

We tested the normality of the data applying the Shapiro-Wilk test. This demonstrated that most of the data did not present a normal distribution. Therefore, in cases of non-normality, non-parametric methods were used in the analyzes. We verified whether there was a difference between the initial (2015) and the final (2019) basal area stock, using the paired sample T-test. The forest change parameters: annual rates of mortality, recruitment, loss and gain of basal area, were calculated, according to Sheil, Burslem and Alder (1995) and Sheil and May (1996), for a five-year period as by, Equations (1), (2), (3) e (4):

$$\text{annual mortality rate} = \{1 - [(N_0 - m) / N_0]^{1/t}\} \times 100 \quad (1)$$

$$\text{annual recruitment rate} = [1 - (1 - r/N_t)^{1/t}] \times 100 \quad (2)$$

$$\text{annual loss rate} = \{1 - [(AB_0 - (AB_m + AB_d)) / AB_0]^{1/t}\} \times 100 \quad (3)$$

$$\text{annual gain rate} = \{1 - [1 - (AB_r + AB_g) / AB_t]^{1/t}\} \times 100 \quad (4)$$

In where: G =; $t$ = time interval between surveys; $N_0$ = initial number of trees; $N_t$ = final number of trees after time $t$; m = number of dead trees; r = number of recruited trees; $BA_0$ = initial tree basal area; $BA_t$ = final tree basal area after time $t$; $BA_m$ = basal area lost by tree death; $BA_d$ = basal area lost by decrement (tree decay and partial stem loss); $BA_r$ = basal area gained by recruited trees; $BA_g$ = basal area gained by increment (tree growth).

The difference inforest change parameters between the control and harvested plots were compared using the Mann-Whitney test. These variables per ecological group were also compared using analysis of variance (ANOVA), with Tukey's HSD post-hoc test, or by Kruskal-Wallis test, at the level of 5% of significance. The annual rates of mortality, recruitment, loss and gain of total stand basal area and the averages of the variables by ecological group were correlated with the values of i) number of harvested trees, ii) basal area of harvested trees, using Spearman's linear correlation coefficient. Subsequently, for these statistically significant relationships, a simple linear regression was performed. The relative number of remaining individuals damaged by the harvest in the periods 2015 and 2019 was verified through graphic distribution analysis. The remaining damages were correlated with the applied harvest intensities, also through Spearman's linear correlation test. All analyzes were performed using Past 3.25 software (HAMMER, 2019).

## 3 RESULTS AND DISCUSSION

In 2015, right after harvest, there were 3.325 individuals on the logged plots, which had a total basal area of 32.38 $m^2\ ha^{-1}$ (with sd: ±0.91 and 0.95% CI: ±0.60); in 2019, a total of 3.848 trees were found, with a total basal area of 29.33 $m^2\ ha^{-1}$ (with sd: ±0.86 and 95% CI: ±0.56). We did not find significant difference between the pre-harvest mean basal area and four years after harvesting ($n = 11$; $p = 0.50$). The means of the annual rates of mortality, recruitment, loss and gain of basal area, were higher in the harvested plots ($p < 0.05$); however, the mortality rates were similar in control plots and managed plots ($p = 0.64$) (Table 3).

We did not find significant differences in rates of mortality and net basal area change between ecological groups ($p > 0.05$). However, climax species annual recruitment rate was lower than that of pioneers and secondary species ($F = 7.415$; $p < 0.05$), in the same way that it was observed five years after the reduced impact logging in a forest in the Eastern Amazon (DIONISIO *et al*., 2018). This occurs because the process of recovering climax species is, in general, slow, with lower entry and growth rates compared to pioneer species, requiring a longer period for the recovery of the removed stock (GARCIA-FLOREZ *et al*., 2017). Thus, it is necessary to continue this study in order to verify the possible regeneration and growth of these species.

In managed plots, we can highlight a great recruitment rate; we found the greatest gain in basal area of pioneer species, species characterized by rapid growth and occupation of disturbed environments, favored by increased sun exposure due to the opening in the forest canopy. This intense colonization is also described in other areas of forest management in the tropics (MEDJIBE *et al*., 2014; DIONISIO *et al*., 2018; AMARAL *et al*., 2019). On the other hand, in the control plots, the mortality of pioneers indicates that, as predicted, throughout the succession process and canopy closure, there is a higher mortality of pioneer individuals, while the recruitment should decline (AVILA *et al*., 2017).

Table 3 – Means and standard deviation of annual forest change rates during four years after timber harvest in a subtropical secondary forest in Santa Catarina state

| Parameters / EG | | Mortality | Recruitment | G gain | G loss |
|---|---|---|---|---|---|
| | | % year-¹ | | | |
| Total | Control plots | 1.8 ± 0.5 A | 2.8 ± 1.3 A | 4.5 ± 1.3 A | 0.4 ± 0.3 A |
| Pioneer | | 3.7 ± 3.3 | 3.2 ± 2.0 | 4.8 ± 2.7 | 0.2 ± 0.0 |
| Secondary | | 1.5 ± 0.4 | 3.0 ± 1.2 | 4.9 ± 1.3 | 0.3 ± 0.1 |
| Climax | | 1.7 ± 0.7 | 0.9 ± 0.4 | 3.4 ± 0.2 | 0.3 ± 0.0 |
| Total | Managed plots | 2.3 ± 1.2 A | 5.3 ± 1.9 B | 8.6 ± 3.5 B | 0.5 ± 0.5 B |
| Pioneer | | 2.4 ± 1.4 a | 6.1 ± 3.0 a | 31.4 ± 48.3 a | 1.2 ± 1.6 a |
| Secondary | | 2.3 ± 1.4 a | 5.2 ± 1.4 a | 8.0 ± 3.1 a | 0.3 ± 0.3 a |
| Climax | | 1.9 ± 1.6 a | 2.4 ± 1.0 b | 5.7 ± 2.6 a | 0.2 ± 0.5 a |

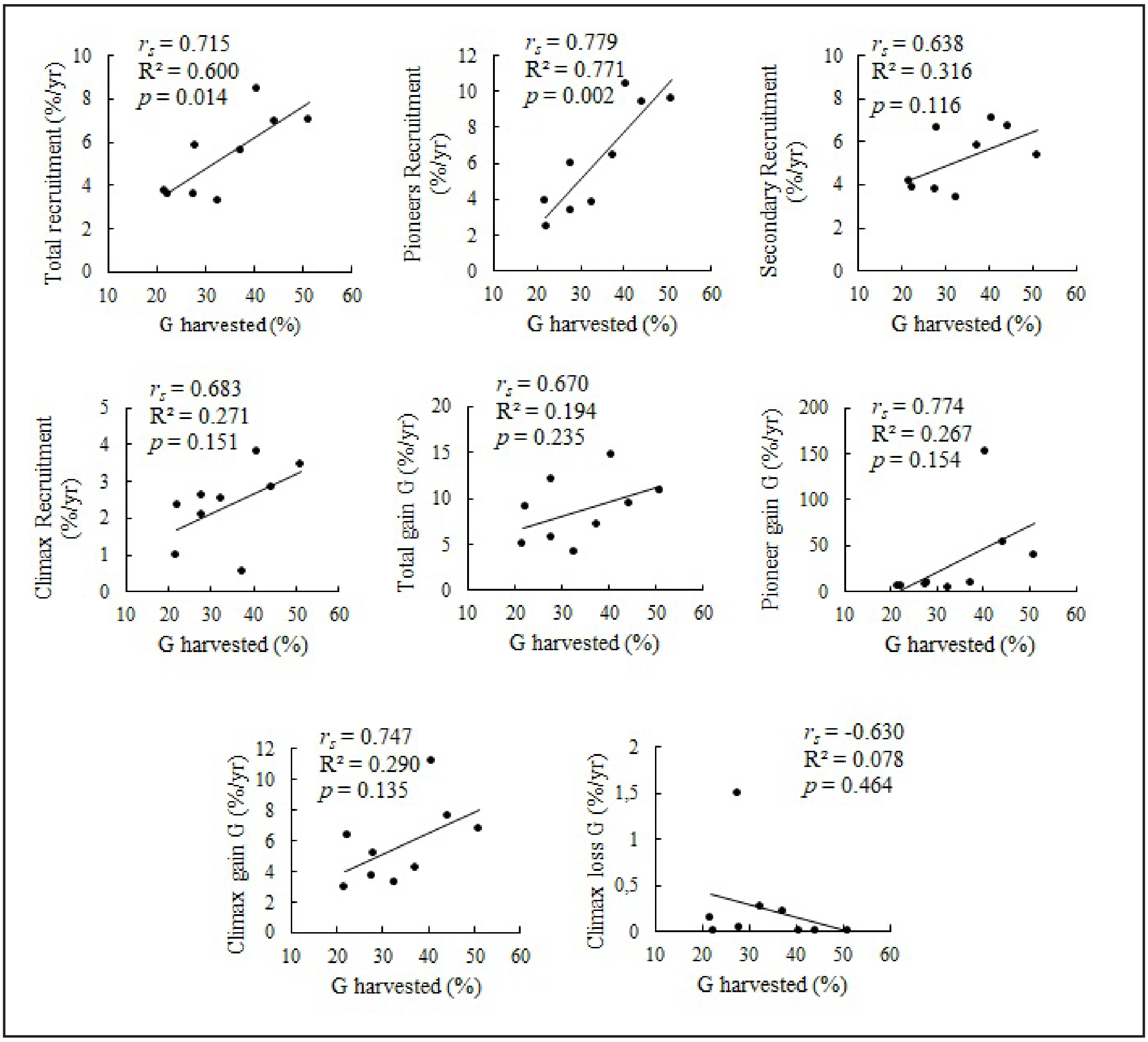
Source: Authors (2020)

In where: G = basal area and EG = ecological group; Different capital letters indicate a significant difference between control and managed plots by the Mann-Whitney test; Different lowercase letters indicate a significant difference between ecological groups by the Tukey test or by Kruskal-Wallis test, at 5% probability.

Analyzing the variables with potential influence on forest change rates (Figure 2), we found that the relationship between the harvested basal area and the recruitment rate was significant and positive (total and in the case of pioneer species), while secondary and climax species recruitment presented no significant relationship with harvested basal area (with Spearman's correlation significant, or close to significant, and linear regression not). Hence, we can infer that the different logging intensities (% of the basal area harvested) influence the succession after management, regarding ingrowing trees (recruits), validating our research hypothesis.

The canopy openings promote decreased competition for nutrients and water, allowing remaining trees to invest in growth (AMARAL *et al*., 2019), which explains, in general, the significant correlation between gain in basal area of climax species after logging and the harvested basal area. Also, there was significant and negative correlation between the basal area harvested and the loss of basal area for this group. In turn, the decrease of basal area loss of remaining climax species suggests that logging removed senescent trees from the forest and, that lower cutting intensities may have caused more damage to the remaining trees, causing reduced growth or even the death of these individuals; on the other hand, greater harvesting intensity caused less damages on the (fewer) remaining trees. In Paragominas (Eastern Amazon), in the first years after logging, the overall mortality of large trees injured by timber harvesting contributed significantly to the annual AGB losses (up to 40%) (SIST *et al*., 2014).

Figure 2 – Relationships between the harvested basal area and change rates of forest variables (alfa = 0.05)




Source: Authors (2020)

In where: G = basal area.

The analysis of the results allows us to infer that higher annual recruitment rates are verified in plots with greater logging intensity (Table 4); with the exception of plot 12, where we observed a higher mortality rate. Thus, we found that although there was mortality, the opening of the clearings allowed the growth of new trees. In turn, the largest losses of basal area were seen in plots 3 and 4, indicating a greater standing dead tree basal area, with a decay and partial stem loss during the four years after harvest, possibly due to greater damage caused by management or even by the existence of older trees in those plots.

Table 4 – Mortality, recruitment, gain and loss of basal area (G) (%/year) per plot during four years after timber harvest at different intensities (means with sd)

| Plot | G harvested | Nº ind. harvested | Mortality | Recruitment | Gain (G) | Loss G |
|---|---|---|---|---|---|---|
| | (%) | | (% / year) | | | |
| 6 | 0.0 | 0.0 | 2.15 | 3.8 | 5.4 | 0.7 |
| 20 | 0.0 | 0.0 | 1.48 | 1.9 | 3.6 | 0.2 |
| 11 | 21.8 | 12.9 | 1.8 | 3.7 | 5.0 | 0.2 |
| 8 | 22.4 | 20.9 | 1.16 | 3.6 | 9.1 | 0.1 |
| 4 | 27.8 | 29.6 | 2.32 | 3.6 | 5.6 | 1.5 |
| 12 | 28.0 | 13.6 | 3.59 | 5.8 | 12.0 | 0.1 |
| 2 | 32.6 | 28.2 | 1.95 | 3.2 | 4.2 | 0.4 |
| 3 | 37.4 | 30.6 | 1.93 | 5.6 | 7.1 | 1.2 |
| 19 | 40.7 | 25.9 | 4.74 | 8.4 | 14.7 | 0.3 |
| 7 | 44.3 | 36.0 | 2.32 | 6.9 | 9.4 | 0.6 |
| 18 | 51.1 | 37.4 | 0.89 | 7.0 | 10.8 | 0.3 |
| Mean | 27.8 | 21.4 | 2.2 ± 1.1 | 4.9 ± 2.0 | 7.9 ± 3.6 | 0.5 ± 0.5 |

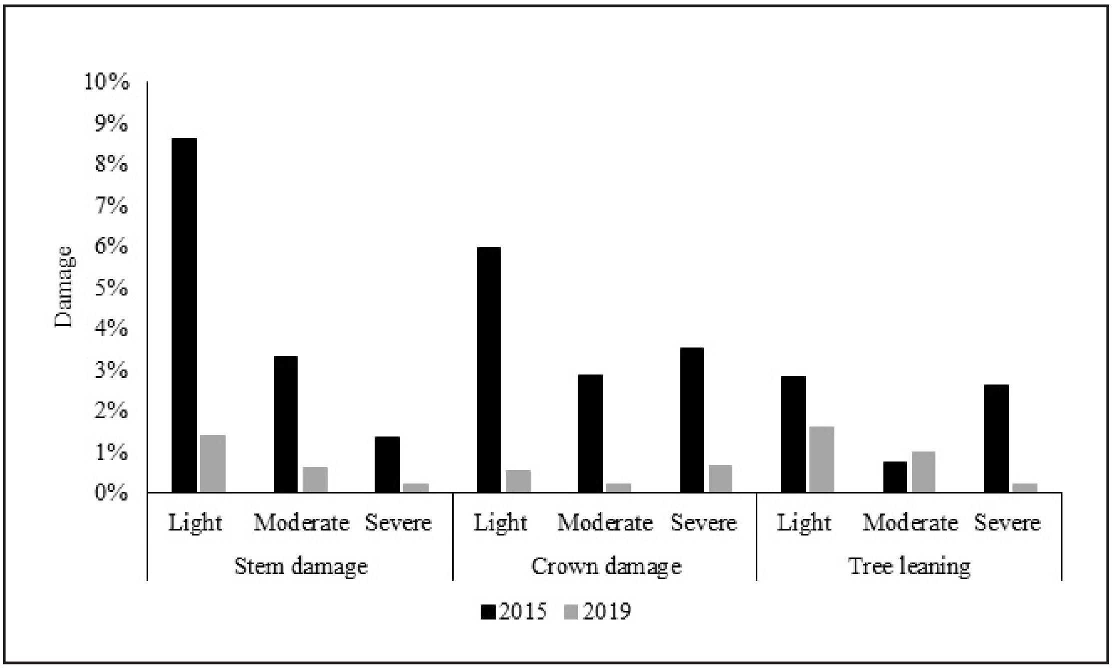
Source: Authors (2020)

In where: G = basal area; Nº ind. = number of individuals.

In relation to post-logging damages, we found 477 individuals damaged by harvest operations shortly after the intervention, which represented 25% of the remaining trees and a total of 331 trees $ha^{-1}$ (SILVA *et al*., 2017). Four years after, 386 individuals still showed some form of damage. Right after harvesting, damaged trees amounted to 6.99 $m^2$ of basal area (23% of the remaining basal area). However, four years after damaged trees were only 8% of the basal area, or 2.32 m², that means a 70% reduction of total damages. Stem and crown damages decreased, from the first to the fourth year after harvesting, under all harvest intensities (Figure 3), while the intensity of moderate damage for tree leaning increased – probably due to the greater exposure of trees to winds (ARAUJO; OLIVEIRA; MIRANDA, 2017). This last one, resulting both from the felling of trees and the dragging of the logs, indicates that greater care should be taken regarding the directional tree felling. In the present case, the steep slopes made it difficult to direct the fall, reuse the drag trails and handle the logs. In general, reduced impact logging (RIL) would be an important tool to reduce damages to remaining trees (KHAI *et al*., 2016).

Damaged trees can suffer high mortality rates for decades after management, and survivors generally grow slowly, develop cavities in the stem, or recover largely (BUCHMANN, 2016). However, it is important to note that in our case we did not observe a significant correlation between cutting intensity and logging damages ($p > 0.05$).

Figure 3 – Percentage of logging damages to different tree compartments in a subtropical secondary forest in Santa Catarina state, four years after tree harvest




Source: Authors (2020)

Defining the optimum harvesting intensity, that is economically viable, without inducing damage to the remaining forest stand and its future productivity, is one of the greatest difficulties of sustainable management. Although we recognize the limitation of the sampled area in this study, we highlight the importance of indicating a harvesting intensity limit in the future. Our timeframe of post-harvest observations is still small; therefore, we recommend performing more in-depth studies in the coming years, focused on analyses of the forest change parameters in relation to the logging intensity applied by diameter class.

## 4 CONCLUSION

This study demonstrated that the annual rates of mortality, recruitment, loss and gain of basal area are influenced by the different harvest intensities four years after logging. The management altered the dynamics of the forest, mainly through the increase of recruitment rates and basal area gain. The greater cutting intensities generated greater colonization of pioneer species, which can delay the regeneration of species from more advanced stages, in general with greater wood density. The mortality rate was similar in managed and control plots, indicating that the natural succession of the forest persists. In turn, the greater loss of the basal area in managed plots, leads us to assume that the residual damage persists for several years. This underlines the importance of reducing the logging damages. Nevertheless, we observed a steady increase of basal area after logging, showing the forest resilience or recovery capacity. Although the proportion of damage to the remaining individuals has been generally reduced over time, the increase in the damage of the moderate tree leaning class shows that future trees may be lost in the coming years.

## ACKNOWLEDGMENTS

The authors thank the owners of the study area, Mr. Clemente Bisewski and Mr. Cristiano Bisewski. We also thank FAPESC for the funding of the Madeira Nativa Project (Award 18689/2009-9), Alfredo Celso Fantini for the research site coordination, IMA for the management licence, CNPq for the master's degree scholarship to the first author (134009/2019-3), CNPq for research grant of the second author (309764/2019-0) and Capes for the Doctoral fellowship of the third author - Finance Code 001.

## REFERENCES

ALVARES, C. A. *et al*. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**, Berlin, v. 22, n. 6, p. 711-728, dec. 2013. Available in: https://www.schweizerbart.de/papers/metz/detail/22/82078/Koppen_s_climate_classification_map_for_Brazil. Access in: 18 apr. 2020.

AMARAL, M. *et al*. Dynamics of tropical forest twenty-five years after experimental logging in Central Amazon Mature Forest. **Forests**, [*s. l.*], v. 89, n. 10, p. 1-17, jan. 2019. Available in: https://www.mdpi.com/1999-4907/10/2/89/htm. Access in: 17 dec. 2019.

ARAUJO, H. J. B.; OLIVEIRA, M. V. N.; MIRANDA, E. M. **Manejo florestal madeireiro para pequenas áreas**. Rio Branco: Embrapa Acre, 2017. 16 p. Available in: https://www.infoteca.cnptia.embrapa.br/infoteca/bitstream/doc/1076118/1/26383.pdf. Access in: 27 ago. 2020.

AVILA, A. L. de *et al*. Recruitment, growth and recovery of commercial tree species over 30 years following logging and thinning in a tropical rain forest. **Forest Ecology and Management**, Amsterdam, v. 385, p. 225-235, feb. 2017. Available in: https://www.sciencedirect.com/science/article/pii/S0378112716304935#b0305. Access in: 08 nov. 2019.

BRITTO, P. C. *et al*. Impact Assessment of Timber Harvesting Operations for Enhancing Sustainable Management in a Secondary Atlantic Forest. **Sustainability**, [*s. l.*], v. 11, p. 6272-6292, 2019.

BUCHMANN, H. M. **Exploração florestal e seus impactos em áreas de primeiro e segundo ciclo de corte do manejo florestal na Amazônia Oriental, Brasil**. 2016. Dissertação (Mestrado em Ciências Florestais) – Universidade de Brasília, Brasília, DF, 2016.

DAVID, H. C. *et al*. A 20-year tree liberation experiment in the Amazon: highlights for diameter growth rates and species-specific management. **Forest Ecology and Management**, Amsterdam, v. 453, p. 117584, dec. 2019.

DARRIGO, M. R.; VENTICINQUE, E. M.; SANTOS, F. A. M. Effects of reduced impact logging on the forest regeneration in the central Amazonia. **Forest Ecology and Management**, Amsterdam, v. 360, p. 52-59, jan. 2016.

DING, Y. *et al*. The impacts of selective logging and clear-cutting on woody plant diversity after 40 years of natural recovery in a tropical montane rain forest, south China. **Science of the Total Environment**, Amsterdam, v. 579, p. 1683-1691, feb. 2017. Available in: https://www.sciencedirect.com/science/article/pii/S0048969716326511. Access in: 22 oct. 2019.

DIONISIO L. F. S. *et al*. Growth, mortality, and recruitment of tree species in an Amazonian rainforest over 13 years of reduced impact logging. **Forest Ecology and Management**, Amsterdam, v. 430, p. 150-156, dec. 2018.

DUNCKER, P. S. *et al*. How forest management affects ecosystem services, including timber production and economic return: synergies and trade-offs. **Ecology and Society**, [*s. l.*], v. 17, n. 4, p. 1-17, 2012. Available in: https://www.jstor.org/stable/pdf/26269223.pdf. Access in: 15 sep. 2020. DOI: http://dx.doi.org/10.5751/es-05066-170450.

FANTINI, A. C. *et al*. The demise of swidden-fallow agriculture in an Atlantic Rainforest region: Implications for farmers' livelihood and conservation. **Land Use Policy**, Guildford, v. 69, p. 417-426, dec. 2017.

FANTINI, A. C. *et al*. Small-scale Management of Secondary Forests in the Brazilian Atlantic Forest. **Floresta e Ambiente**, Seropédica, v. 26, n. 4, p. 1-11, 2019.

FANTINI, A. C.; SIMINSKI, A. Manejo de florestas secundárias da Mata Atlântica para produção de madeira: possível e desejável. **Revista Brasileira de Pós-Graduação**, [*s. l.*], v. 13, n. 32, p. 673-698, mar. 2017.

FANTINI, A. C.; SIMINSKI, A.; GAIO, M. F. Madeira de florestas secundárias em SC: nova fonte de renda para os agricultores. **Agropecuária Catarinense**, Florianópolis, v. 29, p. 15-18, may 2016.

GARCIA-FLOREZ, L. *et al*. Understanding 48 years of changes in tree diversity, dynamics and species responses since logging disturbance in a subtropical rainforest. **Forest Ecology and Management**, Amsterdam, v. 393, p. 29-39, jun. 2017. Available in: https://www.sciencedirect.com/science/article/abs/pii/S037811271631129X. Access in: 27 feb. 2021.

GRANSTROM, M. **Northern Conifer Forest Management**: silvicultural, economic, and ecological outcomes from 65 years of study. 2019. Dissertação (Mestrado em Recursos Florestais) - The University of Maine, Maine, 2019.

HAMMER, Øyvind. **PAST**: Paleontological Statistics. Oslo: Natural History Museum, University of Oslo, 2019. 275 p. Available in: https://palaeo-electronica.org/2001_1/past/issue1_01.htm. Access in: 28 apr. 2021.

HILTNER, U. *et al*. Simulation of succession in a neotropical forest: high selective logging intensities prolong the recovery times of ecosystem functions. **Forest Ecology and Management**, Amsterdam, v. 430, p. 517-525, dec. 2018.

KHAI, T. C. *et al*. Effects of directional felling, elephant skidding and road construction on damage to residual trees and soil in Myanmar selection system. **International Forestry Review**, Oxford, v. 18, n. 3, p. 296-305, sep. 2016. Available in: https://www.ingentaconnect.com/contentone/cfa/ifr/2016/00000018/00000003/art00003. Access in: 11 dec. 2019.

LOCONTE, C. O. **A sustentabilidade volumétrica do manejo florestal madeireiro Amazônia**. 2018. Dissertação (Mestrado em Recursos Florestais) - Escola Superior de Agricultura Luiz de Queiroz, Piracicaba, 2018. Available in: https://www.teses.usp.br/teses/disponiveis/11/11150/tde-17072018-183751/pt-br.php. Access in: 24 feb. 2021.

MARTIN, P. A. *et al*. Impacts of tropical selective logging on carbon storage and tree species richness: A meta-analysis. **Forest Ecology and Management**, Amsterdam, v. 356, p. 224-233, nov. 2015. Available in: https://www.sciencedirect.com/science/article/pii/S0378112715003837. Access in: 22 out. 2019.

MEDJIBE, V. P. *et al*. Natural regeneration of selected timber species in the Republic of Congo. **African Journal of Ecology**, Oxford, v. 52, n. 4, p.552-563, 2014. Available in: https://onlinelibrary.wiley.com/doi/abs/10.1111/aje.12167. Access in: 15 sep. 2020.

SANTOS, M. F. dos *et al*. Estrutura, distribuição espacial e dinâmica florestal de duas espécies nativas após extração manejada de madeira na Flona do Tapajós. **Advances in Forestry Science**, Cuiabá, v. 5, n. 2, p. 351-356, jun. 2018. Available in: http://periodicoscientificos.ufmt.br/ojs/index.php/afor/article/view/5921. Access in: 22 oct. 2019.

SHEIL, D.; BURSLEM, D. F. R. P.; ALDER, D. The Interpretation and Misinterpretation of Mortality Rate Measures. **The Journal of Ecology**, Oxford, v. 83, n. 2, p. 331-333, apr. 1995.

SHEIL, D.; MAY, R. M. Mortality and Recruitment Rate Evaluations in Heterogeneous Tropical Forests. **Journal of Ecology**, New York, v. 84, n. 1, p. 91-100, feb. 1996. Available in: https://www.researchgate.net/publication/216814351_Mortality_and_Recruitment_Rate_Evaluations_in_Heterogeneous_Tropical_Forests. Access in: 02 oct. 2018.

SILVA, D. A. **Efeito da intensidade de colheita sobre a estrutura remanescente de uma floresta secundária manejada em Guaramirim – SC**. 2016. Dissertação (Mestrado em Engenharia Florestal) - Universidade Regional de Blumenau, Blumenau, 2016.

SILVA, D. A. *et al*. Forest management in a secondary Atlantic Rainforest: assessing the harvest damage. **Advances in Forestry Science**, Cuiabá, v. 4, n. 4, p.187-193, dec. 2017. Available in: http://periodicoscientificos.ufmt.br/ojs/index.php/afor/article/view/5154. Access in: 07 sep. 2018.

SIST, P. Large trees as key elements of carbon storage and dynamics after selective logging in the Eastern Amazon. **Forest Ecology and Management**, Amsterdam, v. 318, p. 103-109, apr. 2014. Available in: https://www.sciencedirect.com/science/article/abs/pii/S0378112714000073. Access in: 28 feb. 2021.

SOUZA, M. A. S. *et al*. Dinâmica e produção de uma floresta sob regime de manejo sustentável na Amazônia Central. **Floresta**, Curitiba, n. 1, p. 55-63, mar. 2017.

VIBRANS, A. C. *et al*. **IFFSC**: Floresta Ombrófila Densa. Blumenau: Edifurb, 2013. v. 4. 576 p.

WREGE, M. S. *et al*. **Atlas climático da região Sul do Brasil**: estados do Paraná, Santa Catarina e Rio Grande do Sul. Brasília, DF: Embrapa, 2012. Available in: https://ainfo.cnptia.embrapa.br/digital/bitstream/item/143521/1/Atlas-climatico-da-regiao-Sul-do-Brasil.pdf. Access in: 03 aug. 2020.

## Authorship Contribution


### 1 – Janine Kervald Likoski

Forest Engineer, MSc.

https://orcid.org/0000-0002-9284-0319 • janinelikoski@hotmail.com


Contribution: Conceptualization, Methodology, Investigation, Formal Analysis, Validation, Writing – original draft, Writing – review & editing


### 2 – Alexander Christian Vibrans

Forest Engineer, Ph.D.

https://orcid.org/0000-0002-8789-5833 • acv@furb.br


Contribution: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Resources, Supervision, Writing – review & editing


### 3 – Daniel Augusto da Silva

Forest Engineer, MSc.

https://orcid.org/0000-0002-4454-7142 • danielaugusto@furb.br


Contribution: Methodology, Formal Analysis, Writing – review & editing

## How to quote this article

Likoski, J. K.; Vibrans, A. C.; Silva, D. A. Recruitment exceeds mortality in subtropical secondary forest after conventional selective logging. Ciência Florestal, Santa Maria, v. 32, n. 1, p. 333-350, 2022. DOI 10.5902/1980509855265. Available from: https://doi.org/10.5902/1980509855265.