Open Journal of Forestry, 2022, 12, 248-262
https://www.scirp.org/journal/ojf
ISSN Online: 2163-0437
ISSN Print: 2163-0429

Impact of Timber Logging on Neighbouring Stands in a Forest of the South Western Cameroon

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How to cite this paper: Namuene, K. S., & Egbe, A. E. (2022). Impact of Timber Logging on Neighbouring Stands in a Forest of the South Western Cameroon. *Open Journal of Forestry, 12,* 248-262.
https://doi.org/10.4236/ojf.2022.122014

Received: March 2, 2022
Accepted: April 26, 2022
Published: April 29, 2022

Abstract

During conventional logging operations, there is always some damage to nearby stands. This study therefore assessed the damage caused after logging operations to surrounding stands in a Forest Management Unit (FMU) in south western Cameroon after logging operations. The damages assessed were snapped branches/trunks and uprooted trees. A total of 304 trees with a diameter ≥ 30 cm were cut and a total of 770 neighbouring harvestable and future trees were affected. It was observed that 375 of the neighbouring stand had their trunks snapped, 312 had their branches snapped, and 15 were uprooted. It was noted that 80% of the trees affected were those with diameters between 30 - 50 cm, which were called future trees for the next harvest, while the least damage was on protected/seed trees. *Lophira alata* caused the highest stand damage due to its abundance and large size, while *Distemonanthus benthamianus* caused the least domino damage. Damage to future trees negatively affects future concession holders as these trees are supposed to mature before the next harvest, hence the yield will be greatly reduced. Sustainable timber exploitation will greatly reduce residual damage as care will be taken to ensure falling timber causes less damage to the surrounding stand.

Keywords

Timber Exploitation, Domino Damage, Illegal Logging, Annual Cutting Area

1. Introduction

Tropical rainforests are highly biodiverse, harbouring about half of all species on earth. Hence are ecologically, economically, and culturally crucial for issues in global food security, climate change, biodiversity, and human health (Gallery, 2014). An integral part of the central African tropical rainforest has been allotted to timber exploitation (Biwolé et al., 2019). Cameroon ranks among the world's top tropical timber exporting countries, and the European Union and Asia are the highest importers of Cameroon timber (ITTO, 2020). Following the 1999 Forestry law in Cameroon, Forest Management Units (FMUs) were established, and then handed to the highest bidding company as a forest concession in consultation with local Communities. Concession holders are responsible for developing management plans within which each concession is divided into Annual Cutting Areas (ACA) to be logged during a five-year time frame, with an overall rotation period of 25 years (Bobo et al., 2013).

At least a fifth of tropical forests have been logged recently, with concerns about their long term sustainability and impacts on biodiversity and carbon storage (Mackey et al., 2020). This may lead to a reduction in biodiversity and carbon stock loss. It may also result in an increased post-logging rate of timber stock regeneration to sustain timber yield through a series of cycles (Hwang et al., 2018; Lima et al., 2018; Ellis & Putz, 2019; Matangaran et al., 2019; Stas et al., 2020).

Although It is impossible to log timber without a certain degree of damage to surrounding trees, current practices can endanger the long-term sustainability of timber production (Gourlet-fleury et al., 2013; Lima et al., 2018; Cruz et al., 2021; Mackey et al., 2020). Conventional harvesting methods involve little or no prior planning. Hence they incur more damage to surrounding forest stands. Reduced impact logging (RIL) involves profound planning prior to logging to reduce residual damage to surrounding trees. Regeneration depends on the level of injury on the residual stand (Lima et al., 2018; Butarbutar et al., 2019).

Logging impacts the recruitment of residual trees and thus affects forest structure. The injured residual trees lose a considerable amount of timber volume and economical value, and they become more vulnerable to insect and fungal attacks (Hwang et al., 2018). A higher logging intensity leads to a greater reduction in above-ground biomass as many large trees are logged, and their domino damage on non-target forest stand is very high, which varies with the logging method used (Hawthorne et al., 2011, Stas et al., 2020). As logging intensity increases, so does the proportion of residual trees that are damaged and this is worse if conventional harvesting is employed (Picard et al., 2012; Burivalova et al., 2014; Ellis & Putz, 2019). There is substantial variation in logging impacts on tree damage, biomass and biodiversity, necessitating a need for evaluation of logging impacts. In this light, little work has been done to study the impact of logging disturbances on surrounding trees in tropical rainforests. The main objective of this study was to assess the domino effects of falling trees on surrounding trees in a logging concession in south western Cameroon.

2. Materials and Methods

2.1. Study Site

The study was carried out in Manyu Division of South western Cameroon. Manyu Division lies at the north western end of the region, bordered by Universal Transverse Mercator (UTM) coordinates 48,234, 629,115 m to the West, 597,372, 615,667 m to the East, 572,470, 722,248 m to the North and 522,168, 586,781 m to the South (all UTM values based on the N32, World Geodetic System (WGS) 24 base datum). It covers a surface area of about 945,720.6 ha. Manyu is a low plateau with undulating topography and an altitude of 135 to 1000 m (Egbe & Tabot, 2011).

There are two seasons, a dry season from November to March, and a wet season from April to November. The rainy season peaks in July and August with a second peak in September. From November to April, the climate is mainly dry; some months, usually January and February, may receive no rain at all. Mean annual rainfall of 2000 - 2500 mm is recorded, with a mean annual temperature range of 26˚C to 35˚C (Egbe & Tabot, 2011; Wanji, 2001; Protus et al., 2012).

The natural vegetation is the lowland equatorial rainforest, interspersed with secondary regrowth as a result of agricultural practices and logging of timber in some areas. Its forests have a higher diverse flora, richer in species than any other African rainforest for which comparable data are available. The soils are acidic and predominantly sandy-loam which are heavily leached as a result of low water retention capacity and frequent heavy rainfall (Egbe & Tabot, 2011; Wanji, 2001).

Agriculture is the main economic activity, with previously large expanses of vegetation replaced by agroforestry schemes ranging from subsistence farms and smallholder schemes to private plantations (Egbe & Tabot, 2011; Protus et al., 2012).

2.2. Field Assessments

A field study was carried out to evaluate residual stand damage during logging operations in forest management unit 11-006 (FMU 11-006) in Manyu Division, South West Region, Cameroon (**Figure 1**). This Forest management unit was divided into five annual cutting areas (ACA); ACA001, ACA002, ACA003, ACA004 and ACA005. This study was carried out in annual cutting area 003 (ACA003) with surface area 2,374,000 m^2. ACA 003 was chosen for this study because the timber exploiting company had just finished logging timber there at the time hence the affected surrounding trees could be easily identified. Annual cutting areas are periodic block systems in a polycyclic selective timber harvesting system. One block is opened and exploited per year and, at the end of the exploitation period, the block is closed and left to regenerate for 30 years (Gräfe et al., 2020). To analyse stand damages after logging operations, a total of 304 cut trees with a diameter ≥ 30 cm were sampled.

2.3. Sampling Technique

Simple random sampling was used to evaluate domino damage on surrounding

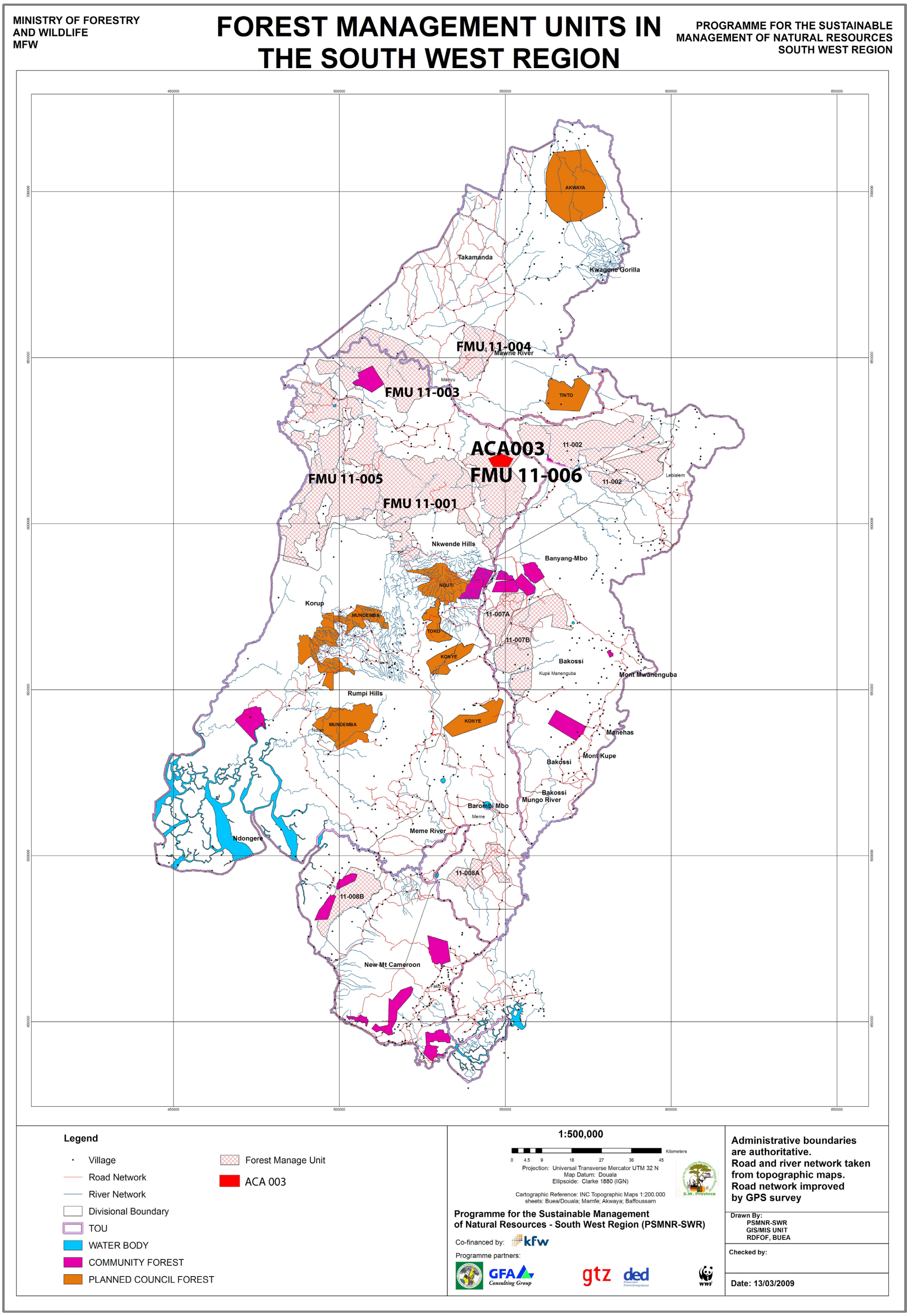

Figure 1. Location of FMUs in the south-western Cameroon (Source: PSMNR-SWR-SWR, Buea).

trees by falling cut timber. The Slovin formula was used to calculate sample size at a 95% confidence interval (Adam, 2020).

$$n = \frac{N}{1 + Ne^2}$$

where;

n = Sample size;

N = Population size;

e = Sampling error.

Estimating the Sample Size (n) Using the Slovin Formula

A total of 1270 cut timber were identified, which constituted the population size. The sample size was estimated using the above (Slovin's) formula as follows:

$$n = \frac{1270}{1 + 12700.05^2} = 304$$

Therefore, 304 cut timber were sampled. All identified cut timber were tagged with numbers from 1 to 1270. Papers were cut into small pieces and each piece was numbered from 1 to 1270. The pieces of paper were then twisted and shuffled, then 304 were picked at random from the lot. The number on each of the picked 304 pieces of paper was matched with the number tags on the 1270 identified cut timber as the trees to be sampled.

2.4. Estimating the Diameter of Cut Timber Trees that Caused Domino Damage

The stump diameter of each cut timber was estimated using the FAO (2009) field handbook method because the stumps of all sampled timber species were not round. The big end and small end diameters of each cut timber were measured using a diameter tape and denoted d_1 and d_2 respectively. The d_1 and d_2 measurements were then converted to diameters denoted d, as a measure of central tendency, the mean, using the formula below from the Directorate of Forests Government of West Bengal (2016) field manual.

$$d = \frac{d_1 + d_2}{2}$$

where,

d = diameter.

2.5. Sampling Trees Affected by Falling Cut Timber

The domino damage of falling timber to surrounding trees was evaluated. The diameter of each affected tree was measured and the trees were categorized as follows; trees within diameters class of 30 - 50 cm were considered as future trees (trees that will be ready for harvest in the next 30 years), while trees greater than 50 cm were considered as harvestable trees with respect to their minimum cutting diameters (which corresponds to the diameter below which a tree cannot be harvested profitably) (Likaa et al., 2021). All protected, seed and other important trees that were affected were also sampled.

2.6. Evaluation of Domino Damage on Injured Surrounding Trees

The damage to surrounding trees was categorized as follows; all branches that were snapped were classified in the snapped branch category, all trunks that were snapped were classified in the snapped trunk category, and all trees that were uprooted were classified in the uprooted category. Domino damage was also classified as severe if they lead to death of the affected tree, that is snapped trunks and uprooted trees, or mild if the affected tree will continue growing to produce timber, that is snapped branches. To evaluate if the level of domino stand damage increased with increase diameter of cut timber, diameters were grouped in various size classes to analyse the level of domino damage per class. The diameters were grouped in 6 classes; 60 - 79, 80 - 99, 100 - 119, 120 - 139, 140 - 159 and 160 - 179. The class interval was estimated to 20 using the following formula:

$$\text{Class interval} = \frac{\text{Highest diameter} - \text{Lowest diameter}}{\text{Number of classes}}$$

2.7. Statistical Analysis

Data was analysed using R statistics, with RStudio 2022.02.1 Build 461 (RStudio Team, 2022) and Microsoft Excel 2021 (Microsoft Corporation, 2022). A bar chart was used to qualitatively illustrate the level of domino damage on future trees, harvestable trees, protected trees, seed trees and other important trees. Another bar chart illustrated mild (snapped branches) and severe (snapped trunks and uprooted trees) stand damages.

The relative abundance of all cut timber that caused domino damage was estimated using the following formula (Bhadra & Pattanayak, 2016):

$$\%\ \text{RA} = \frac{\text{Number of trees sampled}}{\text{Total Number of trees sampled}} \times 100$$

Percentage stand damage per cut timber species was estimated from the density of each species per domino damage as follows (Bhadra & Pattanayak, 2016):

$$\%\ \text{stand damage} = \frac{\text{Density of damage by cut timber}}{\text{Sum of density of damage by all cut timbers}} \times 100$$

Principal component analysis (PCA) was used to determine which species caused the highest domino damage to surrounding trees by comparing the number of snapped branches, snapped trunks and uprooted trees per species.

Multiple linear regression was used to test if domino damage increases with increase diameter of cut timber at $P < 0.05$, and a scatter plot with linear regression lines was used to illustrate the relationship between diameter of cut timber and domino damage.

3. Results

3.1. Identifying Cut Timber Trees that Caused Domino Damage

A total of 304 cut timber belonging to 10 species in 6 families, with diameter ≥ 50 cm caused domino damage after felling operations in FMU 11-006, ACA003. Table 1 illustrates the most abundant species sampled was *Lophira alata* with a relative abundance (RA) of 71.7%, while *Afzelia pachyloba* and *Distemonanthus benthamianus* Baill were the least abundant with 0.3% relative abundance.

3.2. Surrounding Trees Affected by Cut Timber

During felling operations, the 304 cut timber affected a total of 770 trees; where 80.4% were future trees, 19.2% were harvestable trees and 0.4% were protected/seed trees (Figure 2). That is, cut timber affected more future trees, while the least damage was on protected/seed trees.

3.3. Domino Damage on Surrounding Trees

Among the 770 trees affected by falling cut timber, 375 had their trunks snapped, while 312 had their branches snapped, and 83 were uprooted (Figure 3). More future tree trunks were snapped (336) than branches (216), while for harvestable trees, more branches were snapped (96) than trunks (37), and for both, the least were uprooted by falling trees (68 and 15 respectively). For protected/seed trees, out of the 3 affected, 2 had their trunks snapped and 1 was uprooted.

Lophira alata had higher Eigenvalue of 1250.8 than all other sampled species and caused the highest domino damage on surrounding trees with a percentage stand damage of 71.7%, while *Distemonanthus benthamianus* caused the least

Table 1. Timber trees that cause domino damage in FMU 11-006, ACA003.

Common name	Scientific name	Family	Total sampled	% RA
Azobé	*Lophira alata* Banks ex Gaertn	Ochnacea	218	71.7
Bilinga	*Nauclea diderrichii* De Wild.	Rubiaceae	3	1.0
Doussié blanc	*Afzelia pachyloba* Harms	Leguminosae	1	0.3
Framiré	*Terminalia ivorensis* A. Chev.	Combretaceae	27	8.9
Movingui	*Distemonanthus benthamianus* Baill.	Leguminosae	1	0.3
Ngollon	*Khaya ivorensis* A. Chev	Meliaceae	11	3.6
Niové	*Staudtia kamerunensis Warb.*	Myristicaceae	4	1.3
Okan	*Cylicodiscus gabunensis* Harms.	Leguminosae	11	3.6
Padouk rouge	*Pterocarpus soyauxii* Taub.	Leguminosae	12	3.9
Tali	*Erythrophleum ivorense* A. Chev	Leguminosae	16	5.3
	Total		304	100

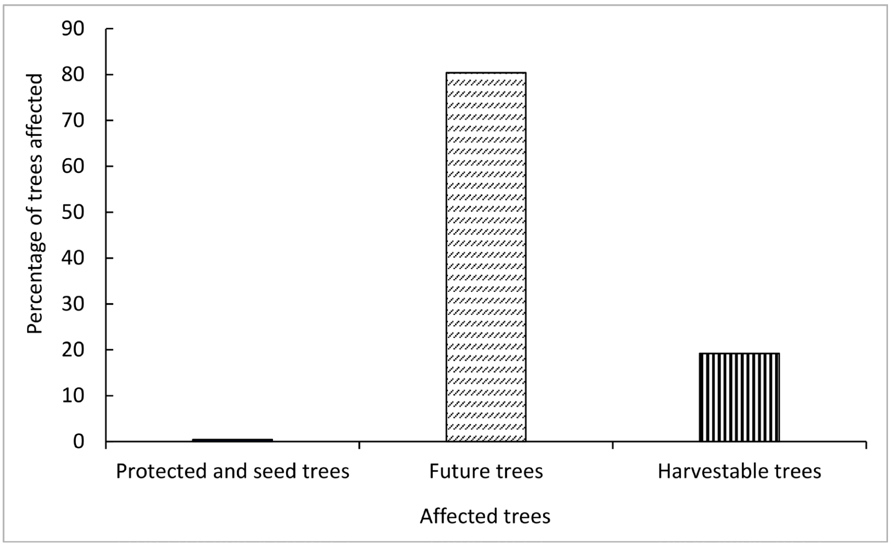

Figure 2. Bar chart showing domino damage of cut timber on surrounding future, harvestable and protected/seed trees in FMU 11-006.

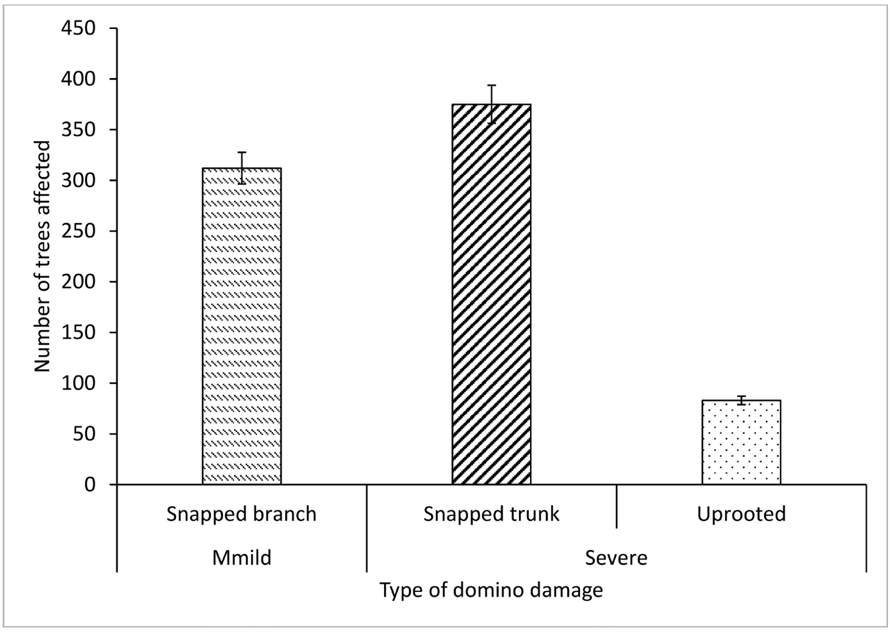

Figure 3. Bar chart showing domino damage of cut timber on surrounding trees trunks, branches and those that were uprooted in FMU 11-006.

with an Eigenvalue of 0.1 and a percentage stand damage of 0.3%, as shown in Table 2.

Multiple linear regression at $P \leq 0.05$ showed no significant increase in domino damage with increase diameter of cut timber, and this is confirmed by the very low value of R^2, which is 0.014 (Table 3). Diameter size class 81 to 99 cm caused the highest domino damage, while the diameter size class 160 to 179 cm caused the least. Figure 4 shows how domino damage is more concentrated in the 80 to 139 cm diameter size class than in the higher size classes of 140 to 179 cm.

Table 2. All sampled felled timber species, the trees they affected and their Eigenvalues.

Timber species	Protected and seed trees affected			Future trees affected			Harvestable trees affected			% stand damage	Eigen-value
	SB	ST	UR	SB	ST	UR	SB	ST	UR		
Lophira alata Banks ex Gaertn	0	2	1	132	244	56	60	32	10	71.7	1250.8
Nauclea diderrichii De Wild.	0	0	0	0	6	1	2	0	0	1	0.8
Afzelia pachyloba Harms	0	0	0	1	1	0	2	0	0	0.3	0.3
Terminalia ivorensisA. Chev.	0	0	0	25	35	1	9	2	1	8.9	41.8
Distemonanthus benthamianus Baill.	0	0	0	2	1	0	0	1	0	0.3	0.1
Khaya ivorensis A. Chev	0	0	0	10	15	1	6	1	0	3.6	8.3
Staudtia kamerunensis Warb.	0	0	0	3	6	0	2	1	0	1.3	1.4
Cylicodiscus gabunensis Harms.	0	0	0	11	11	5	4	0	1	3.6	2.3
Pterocarpus soyauxii Taub.	0	0	0	12	9	1	2	0	0	4	4.8
Erythrophleum ivorense A. Chev	0	0	0	20	8	3	9	0	2	5.3	19
Totals	0	2	1	216	336	68	96	37	15	100	

(SB = Snapped Branch, ST = Snapped Trunk, UP = Uprooted).

Table 3. Diameter size classes of sampled felled trees and their domino damage.

Diameter size class (cm)	Total stand damage			Totals
	SB	ST	UR	
60 - 79	47	55	14	116
80 - 99	119	136	25	280
100 - 119	98	118	20	236
120 - 139	45	52	19	116
140 - 159	3	9	3	15
160-179	0	5	2	7
$P < 0.05$	0.576	0.583	0.868	
$P < 0.05$		0.125		
R^2		0.014		

(SB = Snapped Branch, ST = Snapped Trunk, UR = Uprooted).

4. Discussion

Tree mortality in logged forests is high due to the domino effects of harvested falling trees and skidders winching operations which cause injuries to surrounding trees (Picard et al., 2012; Martin et al., 2015), exacerbated by poor felling techniques (Hughes, 2017). Disturbances due to logging have the potential to damage surrounding trees of all sizes (Stas et al., 2020). *Lophira alata* caused the highest stand damage among all sampled species because of its large size and

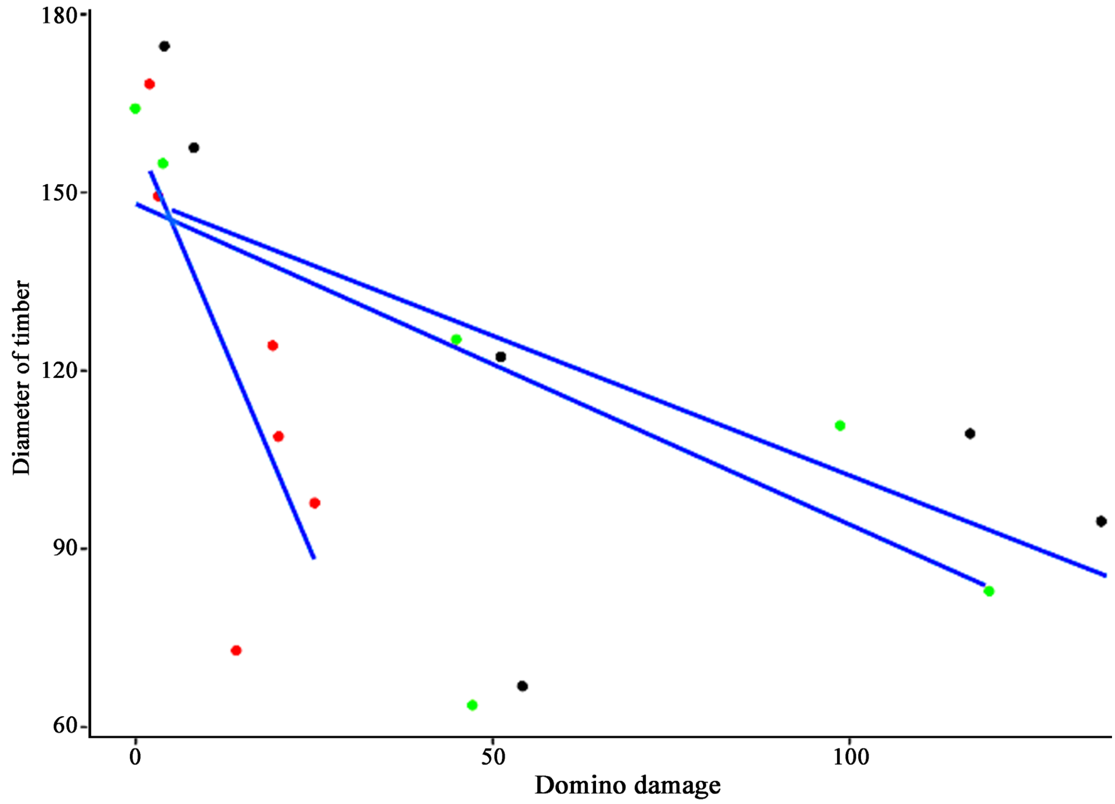

Figure 4. Scatter plot showing that domino damage does not increase with increased diameter at FMU 11-006, ACA 003 (green points = snapped branches, black points = snapped trunk, red points = uprooted, blue lines = regression lines per variable)

long bole, so more cautiousness should be taken when logging this tree (Biwolé et al., 2019). However, domino damage to surrounding trees; snapping of branches, snapping of trunks and uprooting of trees did not increase with increased diameter of cut timber. When trees have reached 50 cm in diameter, they have attained their maximum height so that the length of trunk falling differs little between diameters (Oliveira & Braz, 1995). The growth of the commercial stand should be such that trees lost during the logging operation are replaced within one cutting cycle (Jonkers, 2011; Martin et al., 2015).

More future or young trees had their branches and trunks snapped, and most were uprooted than the more mature harvestable trees. Same results were recorded by Jonkers (2011) and Tavankar et al. (2013), Danilović et al. (2015) and Ellis & Putz (2019) who found that young trees are more vulnerable to destruction and severe damage than large trees. Also, more trunks were snapped than branches, while the least was uprooted. Danilović et al. (2015) also reported that more trunks are snapped during logging operations. Increased severe damages may be due to lack of chainsaw operating skills in controlling the direction of tree fall (Matangaran et al., 2019). It is important to minimize damage, both to the number of trees damaged and the extent of residual damage (Tavankar et al., 2013; Burivalova et al., 2014; Butarbutar et al., 2019). While some damage is unavoidable during logging operations, felling operations should be undertaken with greater care since it may lead to substantial ecological damage (Hawthorne et al., 2011; Tavankar et al., 2013; Hughes, 2017; Butarbutar et al., 2019), especially on natural regeneration (Butarbutar et al., 2019). Regeneration requires attention to be paid to the damage caused by falling trees on surrounding trees, which is influenced by the felling operation (Hughes, 2017; Butarbutar et al., 2019).

Damaging young trees results in a long term impact on regeneration process (Danilović et al., 2015), and diameter growth can be reduced by 10% to 20% due to surface injuries (Yilmaz & Akay, 2008). Damages to stand regeneration may set a risk for the future of stand sustainability (Ellis & Putz, 2019) because, the future of forests depends on adequate and safe natural regeneration (Matangaran et al., 2019; Cruz et al., 2021). There were more severe damages than mild damages. Similar results were obtained by Tavankar et al. (2013) and Ellis & Putz (2019), who reported that there was more uprooted and snapped trees in logged timber concessions. Trees with mild forms of injuries such as snapping of branches mostly recover and regenerate (Ellis & Putz, 2019). Trees with severe logging injuries such as snapped trunk and those that were uprooted shall either die or develop a defective hollowed, deformed or decayed stems, generally affecting future harvests (Jonkers, 2011; Tavankar et al., 2013; Hwang et al., 2018; Ellis & Putz, 2019; Matangaran et al., 2019). Future timber production depends on the maturity of young trees, so, in the case of the ecosystem in this study, yield in the next exploitation period (in about 30 years) will be reduced because of the large number of future trees with snapped trunks, and those uprooted. Moreover, timber production in the present exploitation period is not greatly affected as less tree trunks are snapped than branches. The growth of commercial volume in a given forest is mainly determined by diameter growth and mortality (Matangaran et al., 2019). These trees lose a considerable amount of timber volume and economical value, as the wounded stems and branches plus exposed roots become more vulnerable to insect and pathogenic fungi attacks (Yilmaz & Akay, 2008; Hwang et al., 2018). Biotic agents such as pathogenic fungi and insects easily attack wood through injuries, subjecting them to considerable amount of value loss in the long run due to reduced height growth and poorer forms of infested trees (Akay et al., 2006; Yilmaz & Akay, 2008; FAO, 2009; Tavankar et al., 2013; Hwang et al., 2018). Fungal attack cause decay on injured tree trunks and branches, and the amount of decay development is related to the length of the time since injury, size of injury, tree species, location of the wound on the tree and to the vigour of the tree (Tavankar et al., 2013; Hwang et al., 2018). Insect attacks weaken the tree, exposing them to attack by other insects and fungi and with repeated infestations mortality can occur, with significant impact on the population dynamics of the species (FAO, 2009).

Actions to reduce logging damage may lead to higher sustained yields (Jonkers, 2011; Martin et al., 2015; Gräfe et al., 2020). With growing awareness of the fragility of the tropical rainforest ecosystem, forest operations have to be carefully planned and executed so as not to unbalance the ecosystem, that is, employing RIL techniques (Martin et al., 2015; Gräfe et al., 2020). RIL methods improve protection of the environment and ensure sustainable production of the harvested forests (Martin et al., 2015; Gräfe et al., 2020).

To minimize felling injuries, RIL operations such as directional felling should be applied considering skidding trails in logging maps, and loggers should be experienced and well trained (Martin et al., 2015; Gräfe et al., 2020). Directional felling is very important for safe exploitation and logging damage reduction (Tavankar et al., 2013; Umunaya et al., 2019). In tropical rainforests, the form and weight distribution of the canopy decide the direction of felling. It is good to do all to change the direction of fall of trees, towards skidding trails preferably, taking into account the possible damage to nearby vegetation, and efficient positioning for winching, which will greatly reduce the damage on surrounding trees by falling trees (Hughes, 2017; Umunaya et al., 2019). High destruction of stand regeneration and more damages to remaining trees indicate poor logging practices (Ellis & Putz, 2019; Matangaran et al., 2019; Gräfe et al., 2020). Inadequate and poor logging operations may cause serious damage to residual stands due to existence of various tree species with different age and size classes (Hwang et al., 2018; Gräfe et al., 2020).

5. Conclusion

Concession holders have to put more emphasis on directional felling and management of damage to surrounding trees by falling trees to minimize damage to the ecosystem and also to maintain yield in the next cycle of timber exploitation. Direction of fall has to be integrated into logging maps to direct falling trees towards skidding trails, hence minimizing damage to surrounding trees. Emphasis has to be put on regeneration after logging activities for future trees which are more affected by the domino effect of falling cut timber. Loggers have to be more experienced in cutting trees, and also, directional felling should be employed to reduce the domino damage.

Acknowledgements

This research was carried out with a grant from the International Tropical Timber Organization (ITTO). I am very grateful for this support. I also appreciate the collaboration of Dr. Godswill Ntsomboh Ntsefong and Dr. Akamu Jude Ewunkem throughout the publication process of this article. Their willingness to give their time so generously has been very much appreciated. I would like to express my very great appreciation to Prof. Chuyong George Bindeh and Dr. Gildas Peguy Tchouto Mbatchou for their valuable and constructive suggestions during the planning and development of this research work.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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