The effects of burning and logging on the regeneration and the survival of commercial tree species in a tropical dry forest in Santa Cruz, Bolivia.

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List of abbreviations

Cm	Centimeter
DBH	Diameter breast height, the diameter of a standing tree measured at a height of 137 centimeter from the ground
Df	Degree of freedom (see definitions)
et al.	Et alii: (Lat.) “and others”
F	Probability distribution, named after Fisher
F-L	Fire+Logging; idem sized plot treated with a combination of fire and logging
F-NL	Fire-No Logging: Fire-plot idem sized plot treated with of only fire, without logging
FSC	Forest Stewardship council: A non-profit-organization, which promotes responsible forest management all over the world
Ha	Hectare
IBIF	Instituto Boliviano Investigacion Forestal, Bolivian institute for forestry research
LLP	Long lived pioneer species (See definitions)
M	Meter
NF-L	No Fire-Logging: Logging plot, idem sized plot treated with only logging, without fire
NF-NL	No Fire-No Logging, Also known as Ex-control (See definitions)
N	Number
p	Probability
pH	Scale to measure acidity
PST	Partial shade tolerant species (see definitions)
SFM	Sustainable forest management (see definitions)
Sp.	Species
TST	Total shade tolerant species (See definitions)
St. dev.	Standard deviation

Definitions:

Abiotic environment	The non-living environment
Alkaline	A substance with a pH > seven
Bromeliads	Part of the family of Bromeliaceae
Canopy gap	An area within the forest where the canopy is significantly lower than in surrounding area as a consequence of natural or anthropogenic disturbance due to branch or tree fall
Commercial species	In this study: All 17 species on a list provided by the INPA saw mill
Degree of freedom	the number of values in the final calculation of a statistic that are free to vary
Densiometer	Measuring equipment to measure the canopy over
Epiphytes	A type of plant that grows on another plant to benefit from the mechanical properties from its host, without extracting nutrients
Ex-control	The 300m by 300m sized control plot in the previous study (Grootemaat 2008) but due to logging activities in 2010 renamed. Also known as NF-NL
Forbs	Herbaceous flowering plants
Forest community	A group of populations of different organisms living together within a certain place, in this case a forest
Forestry reform initiative	An Initiative started to obtain governmental and institutional reformation in order to make the forest management more socially, ecologically and economically sustainable on a national level
Gap colonization	The successful establishment of plant species in a canopy gap
Guild	A group of species which exploit environmental resources in a similar way, regardless their taxonomic position (Simberloff&Dayan 2011)
Light demanding	Plant species that need light conditions to survive and grow
Long lived pioneer	Pioneer species that can live longer than 30 years, and require intermediate light conditions to survive and to grow towards the forest canopy where light is more available
Niche	The functional position of an organism or population in its environment, comprising of its habitat, time in which the organism occurs, is active and obtains the natural resources.
One-way-ANOVA	A statistical method to compare means of two or more samples
Pioneer	Species that colonize previously uncolonized pieces of the ecosystem, in this study considered as gap colonizing species
Partial shade tolerant species	A species able to establish in the shaded conditions of the understory. But will need more light in later stages of the life cycle to reach the maximum dimensions in the forest canopy
Pathogens	Any microorganism that causes a disease or infection
Recruitment	The increase in a natural population of a certain species as progeny grow and new members arrive
Sapling	A juvenile tree, in this study height between 1 and 4.5 meters
Seedling	A juvenile tree, height up to 1 meter
Shade intolerant species	Species that need light conditions for establishment, survival and completion of life cycle

Sustainable Forest Management	Forest management according to the principles of sustainable development, thus socially, ecologically and economically sustainable
Total Shade Tolerant Species	A species that can fulfill its complete lifecycle in shaded conditions
Tukey post hoc test	A statistical test to determine which means are significant different from one another
Understory	The lower canopy, normally a mixture of seed- and saplings and shade tolerant species

1. Abstract

The effects of two silvicultural treatments (fire and logging) were evaluated in this study. The effects on the tree survival, regeneration density, species richness growth rate, mortality rate of commercial and non-commercial tree species, the structure and composition of competing vegetation, and soil acidity and structural properties were evaluated in a dry tropical forest in eastern Bolivia.

Seven years after logging and six years after burning, the highly disturbed fire+logging treatment had the highest mortality rate of residual stems, and the highest density of commercial tree species. However, the overall tree density was the highest in the logging treatment.

Canopy openness and soil cover differed between the four treatments, and additionally four out of nine factors of the vegetation cover differed. The regeneration density, species richness and mortality of all tree species was found to differ within the four treatments. The differences in regeneration density and species richness were found to be caused by the influence of the vegetation cover. For the commercial tree species it was found to be the influence of the abiotic environment that cause the difference. These results show that different silvicultural treatments have different effects on the regeneration of commercial and non-commercial tree species.

2. Introduction

Dry forest

In Eastern Bolivia lays the Chiquitano dry forest, is with its 142,941 km²(Portillo-Quintero et. al. 2010) one of the most extensive and diverse tropical dry forests in the Neotropics (Fredericksen et al. 2000, Killeen et al. 1998). It is also one of the world's most endangered ecosystems (Janzen, 1986; Dinerstein et al. 1995, Hoekstra et al., 2005). Until the 1990's these forests were mostly intact but since then the deforestation rate has increased mainly due to the conversion to intensive soybean production and cattle ranching (Rojas et al., 2003; Killeen et al., 2007). An additional threat is wildfires, as this forest type has one of the highest incidence of wildfires in the country (Resnikowski and Wachholtz, 2007).

Role disturbance

Disturbance, like wildfires or natural tree fall, occur naturally in forests. Tree fall represent a source of relatively small scale disturbances while wildfires represent a source of large scale disturbance. Both types of disturbance can be defined as a ''rapid release or reallocation of community resources'' (Sheil and Burslem, 2003). Wildfires have probably played an important role in the development of the Bolivian forests and dry forests. This is expected because they include species which are adapted or resistant to fires (Gould et al. 2002, Vieira & Scariot 2006).

Although disturbance is a source of mortality for some individual plant species, the gaps they create are an opportunity for to colonize and regenerate for others (Denslow, 1980). Species composition after gap colonization is determined both by niche partitioning and collection of stochastic processes (Brokaw and Busing, 2000; Schnitzer and Carson, 2000). One of the factors on which niche partitioning is based is the reaction to disturbance. The regeneration of some species, including the commercial ones, may be favoured by disturbance (Nabe-Nielsen et al. 2007, Van Rheenen et al. 2004). High intensity disturbance, like wildfires are probably even part of the requirements to regenerate of the majority of commercial timber species in this region. These commercial species are light demanding and require disturbance of larger spatial scales to regenerate than the relatively small-scale disturbances caused by selective logging operations (Fredericksen 1998; Pinard et al. 1999).

Forest management

The favourable effects of disturbance, especially fire and logging, on regeneration are the reason why it is applicable as a management practice (Kennard, 2004, Otterstrom et al. 2006, Pinard & Huffman 1997, Pinard et al.1999). For example the application of logging to create favourable conditions for the establishment of seedlings and to promote safe arrival of seeds in these areas (Dickinson 1998). In the 1990s, Bolivian forest managers became aware of the potentials of fire as a potential tool to stimulate the regeneration of shade-intolerant commercial species. Evidence has suggested that fire, from both natural and anthropogenic origins, has a pervasive influence on dry Bolivian forests (Pinard and Huffman 1997; Gould et al. 2002; Kennard 2001). Fire removes vegetation and, exposures mineral soil, and contributes to release of nutrient, all these effects have been identified as beneficial for regeneration shade-intolerant species(Hungerford et al.1990 in Kennard 2004; Bond and van Wilgen 1996).

Logging is an intensifying factor for fire as it makes forests more susceptible to fire (Holdsworth & Uhl 1997, Siegert et al. 2001, Uhl & Kauffman 1990, Woods 1989) and the impact of fires is far more severe in logged forests than in unlogged forests (Blate 2005, Siegert et al. 2001). This is because there is an increase in fuel loads by logging waste (Blate 2005, Siegert et al. 2001, Uhl & Kauffman 1990) and solar radiation will reach the understory in logging gaps, which will dry out the fuel (Holdsworth & Uhl 1997, Uhl & Kauffman 1990).
Both fire and logging have an effect on seed generation because both cause soil compaction. During high intensity fires the soil organic matter content is burned which is likely to influence the soil strength, bulk density and water infiltration rate(Kennard & Gholz 2001, Rab 1996). Soil particles and ash fill up the space of organic matter. (Durgin & Vogelsang 1984 in Certini 2005). This increases the soil strength and bulk density(Rab 1996).
Another negative effects of fire for forest management is its effect upon the vegetation. In the Chiquitania region lianas tend to increase in general in density after natural and anthropogenic forest disturbance (Hegartly and Caballé, 1991). The regeneraton of mainly shade intolerant commercial species is complicated after large-scale disturbance due to high levels of competitive vegetation, especially lianas (Fredericksen 1998; Mostacedo et al. 1999). The newly created gaps often become colonized with vines and other competitors that suppress commercial tree regeneration (Fox, 1976; Buschbacher, 1990; Webb, 1997; Mostacedo et al., 1998).

Problem with regeneration

Besides the threat of agricultural conversion and rapid deforestation the forests of Bolivia have been exploited for decades for a small number of commercial species mainly: *Swietenia macrophylla*, *Cedrela fissilis* and *Amburana cearinsis,* causing these commercial timber supplies to decline. This decline was one of the factors leading to a major forestry reform initiative (Contreras and Vargas 2002). The forestry reform initiative has lead to an increase of forest certification. During the early 2000s, Bolivia had the highest number of hectares of forest certified any country in the tropics, 2.2 million ha in total. The certification was according to the guidelines of FSC (Snook *et al.* 2006).
Certified or not, in most managed dry forests in the Chiquitania region, sustainable forest management (SFM) is threatened due to lack of regeneration of most of the valuable timber species (Mostacedo et al. 1999; Pinard et al.1999). Lack of regeneration might be caused by over harvesting in the past, but also tree species that have only recently been harvested suffer from poor regeneration (Fredericksen 1999; Mostacedo et al. 1999). The burning and logging have been prescribed as methods to enhance the regeneration and survival rate of commercial species in Bolivian dry forest (Heuberger et al., 2001, Fredericksen et al., 1999). This study examines the effects, both positive and negative, of fire and logging on the regeneration of commercial species, and on survival of the tree stand.

3. Research Objectives

3.1 Overall Objective

The overall objective of this research is to increase the understanding of the effects of burning and logging as a factor of disturbance on the regeneration in the Chiquitano dry forest, to improve the forest management.

3.2 Research Questions

1. What are the effects of fire and logging on tree survival?

2. What are the effects of fire and logging on the abiotic environment?

3. What are the effects of fire and logging, on the forest vegetation?

4.a What are the effects of the abiotic environment and vegetation cover on the regeneration of the tree species?

4.b What are the effects of fire and logging on the regeneration of the commercial tree species?

3.3 Hypotheses

1.
The tree mortality caused by the fire-treatment will be significantly higher than from the logging. And within the fire plots, a significant difference will be between the Fire and the Fire+Logging plot, due to the fact that first opening up the forest by logging, followed by burning has a higher impact on the effects caused by fire only.

2.
For this study the pH, canopy openness and soil cover were recorded. By using fire as a treatment, the plot will not lose its biomass, as happens when using logging as a treatment, but it will be changed into ash. This ash will make the soil more alkaline, thus resulting in a higher pH-level in the fire plots than in the logging plots.
Logging decreases the canopy cover at a height above three meter. While fire opens up the lower layers of the canopy, working from bottom to top. Thus we expect that the canopy openness will be higher at one meter in the fire plots than in the logging plots, on three meters we expect it to be the opposite.
The soil cover will be more mineral in the Fire plot than in the logging plot, as organic material is burned during the fire. Woody debris cover will be higher in the logging plot

3.
The forest vegetation is expected to be influenced by fire and logging. We expect that trees, forbs, bromeliads and palms will have decreased during the fire, while fast growing vegetation has increased. In the logging plots we expect an increase of herby and woody vines while cover of other

vegetation types did not change. Due to the high level of disturbance in Fire+logging plot, it is expected that the abundance of grasses and climbers will be relatively high in these plots.

4.a

The regeneration density, species richness, mortality and growth of tree regeneration is expected to be different in the four treatment combinations. The fire plots are expected to have a higher regeneration density, growth and mortality than the logging plots because fire has a higher disturbance intensity than logging, which provides the species with light and less competition by removing the understory. Additionally is the species richness expected to have decreased in the Fire plot

5.

As the majority of the commercial species, are light demanding it is obvious to expect that the commercial species will do well in the highly disturbed plots. These light demanding species are expected to grow significantly more after a fire.
As the acidity of the soil drops, it is likely that the growth of the commercial species will drop as well. The canopy openness on the other hand, will also greatly influence the abundance and the growth rate of the commercial species. For that, it will allow other species of herby and woody plants to compete with the commercial species for light.

4. Methodology

4.1 Location

This research was executed in the 30.000 ha private forest owned by INPA Parket Ltda. The research was carried out in cooperation with IBIF (Instituto Boliviano de Investigacion Forestal) which have their main office in Santa Cruz, Bolivia. The forest is situated in the province of Nuflo de Chavez (16˚6'S, 61˚42'W) of the department of Santa Cruz, in the eastern lowlands of Bolivia (Figure 1 and 2) (IBIF 2006). The mean altitude of the study area is 458 m above sea-level (Grootemaat 2008).

The mean annual temperature at Concepción, circa 40 km from the study site, is 24.3˚C. The mean annual rainfall is 1.160 mm and the area has a distinct dry season from May until October (with monthly precipitation less than 100 mm per month) (IBIF 2006, Markesteijn et al. 2007). During this dry season 95% of the species drop their leaves (IBIF 2006).

4.2 Forest characteristics

The natural vegetation is classified as 'Dry Chiquitano Forest' or tropical dry forest (IBIF 2006). 115 Tree species with diameter >10 cm have been identified, and the average species richness is 34 species per ha. Of those 115 species circa 17 species are classified as commercial species. The forest has a density of 437 stems per ha and the basal area is 19.7 m² per ha (IBIF 2006, Markesteijn et al. 2007). The forest canopy has an average height of 22 m with some trees reaching up to 30 m (Markesteijn et al. 2007).

Figure 1: Location of Bolivia in South America (IBIF, 2012)

Figure 2:, Location of the study site. Red dot indicates Location of INPA ltda. private forest in Concepcíon (IBIF, 2012)

4.3 Management history

The forest owner has been managing and harvesting trees from the forest since 2000 (INPA 2011) They have subdivided the forest into management blocks, each block has a authentic number and treatment (Personal observations). Logging practice in the study area started in 2004, followed by a low intensity fire in 2005. The FSC certified forest is owned by INPA (A Dutch hardwood parquet company) and is managed at a low logging intensity (4-6 trees/ha). The rotation cycle of the forest is 20 years and a minimum diameter cutting limit of 40 cm is used (Mostacedo Personal Comment in Grootemaat 2008)

4.4 Experimental design

To study the effects of fire and logging on the regeneration of tree species, IBIF has established four 9-ha plots in the forest owned by INPA. The experiment was a full factorial design with only one repetition per treatment combination. In December 2004 two plots have been logged. In September 2005 one logged and one unlogged plot have been burned. Research on the effects of fire logging on the abiotic and biotic factors was done 2 years after burning and 3 years after logging (Grootemaat 2008). The experiment influenced the abiotic conditions as followed:

Table 1: Outcome of study by Grootemaat 2008: the influence of Fire and Logging on abiotic factors

Abiotic factor	Fire	Logging	Fire +Logging
canopy openness	+	0	+
pH	+	+	0
Soil density	0	0	0
water infiltration rate	-	0	0
litter cover	-	0	0
woody debris	+	0	0
mineral soil cover	+	+	0

A +sign indicates an increase, a – indicates a decrease and 0 indicates no difference (Grootemaat 2008)

This resulted in the conclusion that in the Bolivian tropical Dry forests abiotic factors can be changed both by fire and logging. But fire has a larger impact because it changes the abiotic factors more significantly. This was different for the biotic factors because fire did negatively affect the bromeliads and trees unlike climbers and forbs, these life forms did not seem to be affected. Logging did not affect cover percentage of any of these life forms. The regeneration density of trees was not influenced by fire or logging. This regeneration consisted mostly out of seedlings. Species richness decreased by disturbance by fire or logging, while commercial species showed no difference in abundance between the four treatments. (Grootemaat 2008).

4.4.1 Plot set-up

During the establishment of the fire-experiment four study-sites of 300 x 300 m received two different treatments: logging (yes or no), and fire (yes or no) (Grootemaat 2008). So there is one site without fire or logging (the “control”), one with only fire, one with only logging and one study-site with both treatments(figure 3(Grootemaat 2008)).

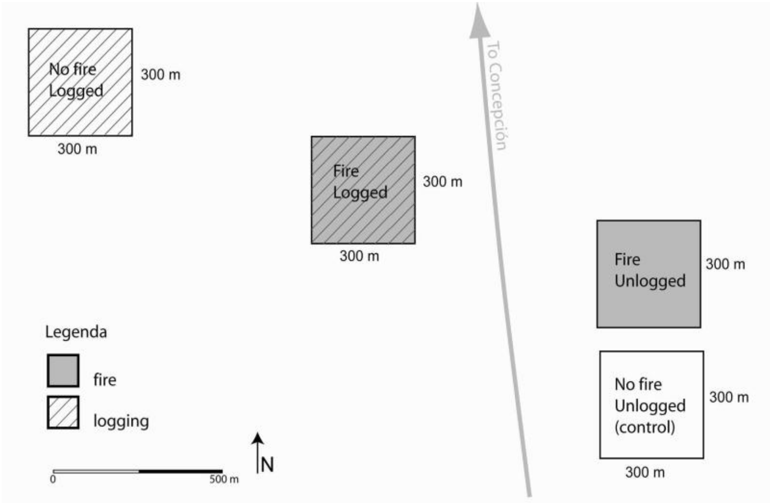


Figure 3. Schematic drawing (Grootemaat 2008) of the situation in the INPA forest up to 2010, however the two unlogged plots in the East of the figure have been logged during the final months of 2010.

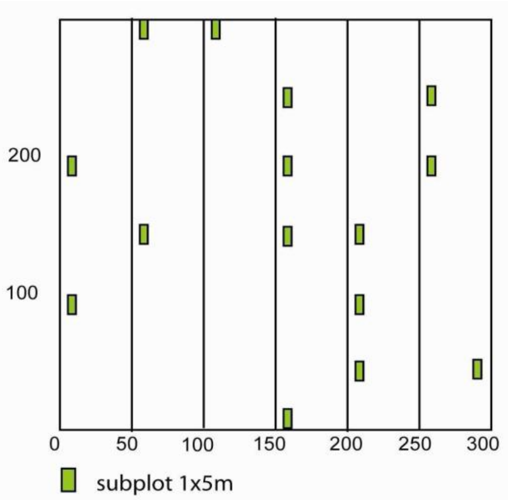


Figure 4: Schematic drawing (Grootemaat 2008) of location of subplots. Every treatment combination plot was sampled with 15 randomly chosen subplots 1x5. These subplots were had an inter-distance of at least 50m.

The sampling methodology was done in accordance with the methods described in the report of Grootemaat 2008. This way we were able to compare the field data with the results from the research data collected by Grootemaat in 2007. The data was collected with the following methodology:

4.4.2 Subplot set-up

In each plot seven North-South lines were established at a distance of 50m apart. Per treatment a total of 15 subplots, of 1 x 5 m, were placed at randomly chosen coordinates on these lines (Figure 4, Grootemaat 2008).
In total 60 plots (four treatments x 15 plots per treatment) were established and marked with PVC tubes. The sub plots were established at random on a line with a distance of at least five meters from the trails to prevent the negative effects of trampling.

To enlarge the amount of commercial individuals an increased subplot size was needed for that reason was the 1x5 plots was increased to 5x5 plots. The 5x5 plots was established by adding four meters to the East of every 1x5 meter plot, the borders were demarcated by PVC tubes.

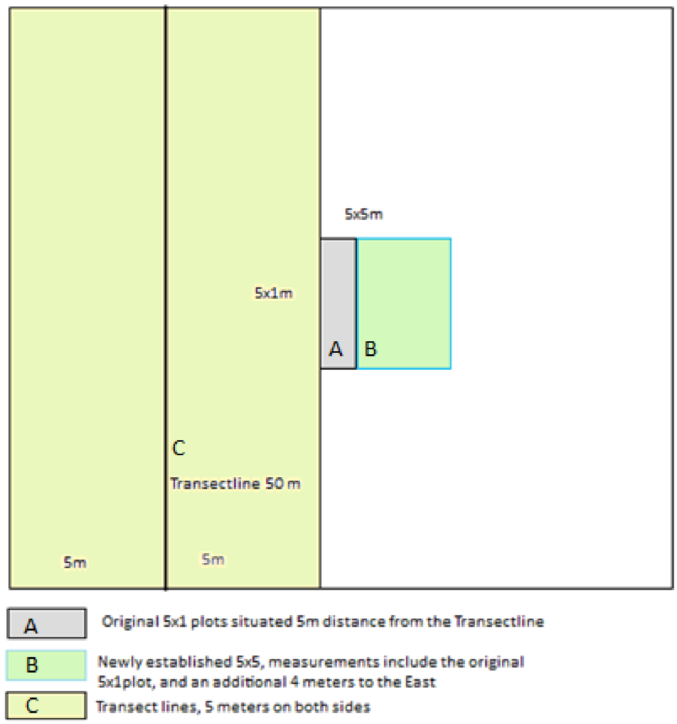


Figure 5: **Plot and Transect set-up. Overview original study sites and additional established study sites**

4.5 Forest inventory

4.5.1 Tree mortality (DBH >20 cm)

To gather information on the influence of the treatment on seed sources and commercial tree mortality by the fire or logging, trees were measured by walking transects in the four plots (figure 3). The transects are the same North-South lines as mentioned in chapter 4.4.2.
On the transects all standing trees, dead or alive, with a DBH above 20 cm were identified, five meters left and five meter right of the transect line. We recorded the diameter and the damage was estimated into four classes(Living tree, dead tree, dead but resprouted tree, heavily scarred tree). Also the shape of the tree crown was classified into: perfect, good, tolerable, bad and very bad. Finally, the liana cover of the tree was classified into four classes: free of lianas, lianas only on the stem, lianas on the stem and crown, the last class is lianas on stem, crown and hanging down.

4.5.2 Abiotic environment

- Canopy openness: was measured on two different levels. The first level is at 1m. height with a densiometer (Spherical Crown Densiometer, Concave – model C, Forestry Suppliers) at one meter above the ground. At each 1x5 subplot of an experimental plot one measurement was made, 15 measurements in total per plot. So in total 60 measurements have been performed. The second level of canopy openness (at 3m. height) has been estimated, dividing it into classes of 5% percent.
- Soil pH was estimated by mixing a bit of soil with demineralised water. Afterwards pH paper was used to indicate the soil pH.

- The cover of litter (%), woody debris (%) and mineral soil (%) were estimated in the 5 m^2 plot with an eye estimation in whole percentages up to 5% percentage precise.

4.5.3 Vegetation

The vegetation in the 1x5 plots has been divided (after Grootemaat 2008). Vegetation was divided into the following life forms: tree, palm, climber, forb, fern, grass, ground bromeliad and epiphytes. The % cover of these life forms was estimated up to the crownlayer (≤ 30 m). Climbers which grow in a subplot but do not have their roots in the subplot were recorded because their existence does form competition for other plants. Due to the multi-layered vegetation the total cover can exceed 100%.

4.5.4 Regeneration

The density, diameter growth, and survival rate was measured in the four treatments. This was done in the 1x5m plots established during the research of S. Grootemaat (2008) when all woody species > 2,5 cm height were labeled. Of these individuals height and survival rate have been measured during this research. Newly grown regeneration have been labeled, identified and measured with the help of a tree-spotter to determine past recruitment rate and to be able to monitor future growth and mortality.

4.5.5 Regeneration of commercial species

In the extended 5x5 plots regeneration of commercial species with a minimum height of 50cm were recorded. In case an individual is higher than 137cm of height also DBH(Diameter Breast Height) was measured. According to the list from the INPA sawmill the following species were commercial: Cari Cari Colorado (*Poeppigia sp.*), Curupau (*Anadenanthera colubrina*), Gabetillo (*Aspidosperma rigidum*), Jichituriqui (*Aspidosperma sp.*), Mani (*Sweetia fruticosa*), Momoqui (*Caesalphinia pluviosa*), Moradillo (*Machaerium sp.*), Morado (*Machaerium scleroxylon*), Paquio (*Hymenaea stigonocarpa*), Quina (*Myroxylon balsamum*), Sirari (*Copaifera chodatiana*) and Tipa (*Tipuana tipu*) (Grootemaat 2008)(See Annex I). The tree species were divided into classes of shade tolerance based on the list by (Markesteijn et al. (2007) and Kitajima (2007)).

4.5.6 Adjustments in the research

The initial idea of this research was to repeat the measurements, in the 1x5 plots, from the research of Grootemaat in 2007. Plus the additional information gained from the 5x5 plots and the transect lines. One major change in research is the role of the control plot. During the 2007 research this plot was untreated with fire or logging. However in between the study of Grootemaat and this study, a logging operation has been conducted in this specific plot. For that reason we cannot call it No Fire-No Logging (NF-NL) but Ex-control. The other treatments were compared with the Ex-control plot during the analyses, but the outcomes were interpreted with caution.

5. Statistical analysis

In the process of analyzing the data collected in the field a number statistical tests were used, this chapter will explain, which statistical tests were used, how they were performed and which data was analyzed in the process.

5.1 Adaptations

Due to the adjustments in the fieldwork (See Chapter4.5.6), the original statistical analysis had to be adjusted to a different situation. This mean that because we do not have two equal sample sizes to analyze the effect of logging a two-way- ANOVA, cannot be used because the four treatments could not split into two equal groups for comparison. And thus was decided to use a one-way-ANOVA was used instead.

5.2 Statistical Methods

To test the difference between means of the treatments(ex-control, Logging, Fire, Fire+Logging) for each of the abiotic and biotic factors a one-way ANOVA was used. This was done by listing the total of 60 values, 15 representing each treatment. This was done for each of the abiotic factors, pH, canopy openness and soil cover, and for the biotic factors of life form cover. A Tukey post hoc test was used to analyze how they differ from each other. The results of the Tukey test were translated into letters, found in superscript behind mean values in the tables. The letters used to indicate significant difference:

- ^{a} equals Ex-control plot
- ^{b} equals Logging plot
- ^{c} equals Fire plot

A multiple regression has been used to see how the combined effect of the abiotic and biotic factors is upon the regeneration in the 1x5 plots. The effects of the abiotic and biotic factors has been tested for the following growth factors: seed-sapling density, species richness, growth, height and mortality rate. The multiple regression is also used to evaluate the effects of the treatments upon the commercial regeneration.

One-way-ANOVA's and post hoc Tukey tests were used, to see whether there is a significant difference in between the mean mortality rates of the treatments. The treatments each consisted out of 7 transect lines, so 7 mortality rates were used for each treatment.

6. Results

6.1 The effect of fire and logging on the mortality of trees

The tree mortality was highest in the Fire+Logging plot and was lower in plots with a decreased disturbance intensity. Fire, by itself, as a treatment was not a significant factor in the mortality of trees. However, fire combined with logging played a significant role in the mortality of trees.

6.1.1 Tree mortality per treatment

Mortality rates are clearly higher in the Fire+Logging plot (Table 2, Figure 6) and differ significantly between the four treatments (df =24, F= 4.61 ,p= 0.01). The significant difference of the lesser disturbed plots and the Fire+Logging plot was: Ex-control – Fire+Logging: p=0.01, and Logging – Fire+Logging: p=0.03.

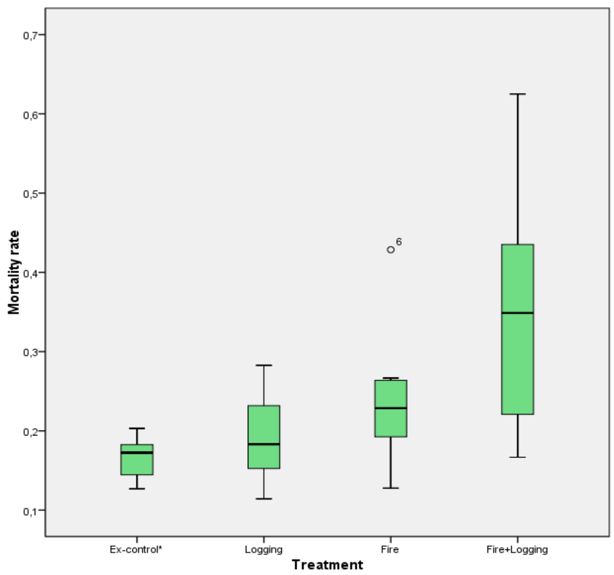
The mortality rate:

- Ex-control: 0.17
- Logging: 0.19
- Fire: 0.24
- Fire+Logging: 0.35

Table 2: Overview of the recorded individuals on the transect. Summary of the collected data in the four treatment combinations of fire and logging. Logged individuals were excluded from the mortality rate. A one-way-ANOVA was used to prove the significant difference. Highlighted p-values indicate significant difference. Letters in superscript indicate significant difference determined by a Tukey post hoc test.

	Ex-control*	Logging	Fire	Fire+Logging	df	F	p
Tree density (n/ha)	228.89	242.22	179.44	183.33	24	3,22	0.04
Dead individuals (n/ha)	38.33	46.11	42.22	60	24	2,24	0.11
Mortality rate	0.17^{a}	0.19^{a}	0.24^{ab}	0.35^{b}	24	4.61	0.01

*is biased by selective logging December 2010, see Chapter statistical analysis for more information.



Ex-control is biased by selective logging December 2010, see Chapter statistical analysis for more information.

Figure 6: The ranges of the different mortality rates over the seven transects. In the 'Fire' column a small number 6 indicates an extraordinary value of 0.43 while the maximum for the other transects was 0.27

6.1.2 Tree mortality per species

In total 336 dead individuals were recorded divided over 26 species (See Annex II). Some species only have been encountered once or twice for that reason only the 15 most common species are presented (Table 3). The latter part will be dealing with the ten most abundant commercial species and *Acosmium cardenasii* (Table 4).

Table 3: The mortality rates and commercial values of the 15 most abundant species. Per ecological guild combined. Numbers 1-4 in superscript indicate the rank of the species mortality. 1 = lowest mortality rate, 4 = highest mortality rate.

Species	Ex-control*	Logging	Fire	Fire+Logging	Guild	Commercial Value
Poeppigia sp.	0.09^{1}	0.27^{3}	0.13^{2}	0.40^{4}	LLP	2
A. culubrina	0.26^{1}	0.36^{3}	0.35^{2}	0.59^{4}	LLP	3
Schinopsis brasiliensis	0.75^{3}	1.00^{4}	0.00^{1}	0.50^{2}	LLP	3
Tabebuia impetiginosa	0.23^{2}	0.50^{4}	0.38^{3}	0.13^{1}	LLP	3
Centrolobium microchaete	0.30^{2}	0.44^{4}	0.31^{3}	0.00^{1}	LLP	2
Chorisia speciosa	0.04^{1}	0.09^{3}	0.17^{4}	0.05^{2}	LLP	1
A. tomentosum	0.25^{3}	0.15^{2}	0.13^{1}	0.47^{4}	PST	2
S. fruticosa	0.29^{1}	0.29^{1}	0.55^{3}	0.56^{4}	PST	2
C. pluviosa	0.11^{2}	0.04^{1}	0.15^{3}	0.50^{4}	PST	2
M. acutifolium	0.38^{3}	0.27^{1}	0.33^{2}	0.43^{4}	PST	2
M. scleroxylon	0.44^{3}	0.75^{4}	0.43^{2}	0.14^{1}	PST	3
Myrciaria spec.	0.00^{1}		0.25^{3}	0.09^{2}	PST	1
Combretum leprosum		0.00^{1}	0.17^{3}	0.00^{1}	TST	1
G. chodatiana	0.57^{4}	0.14^{2}	0.45^{3}	0.10^{1}	TST	3
A. cardenasii	0.09^{2}	0.07^{1}	0.20^{3}	0.28^{4}	TST	1

*is biased by selective logging December 2010, see Chapter statistical analysis for more information. Commercial value: 1 = None, 2 = Normal value, 3 = High value

Of the four treatments Fire+Logging had the highest average mortality rate of the Long Lived Pioneer species. A summary of the most influenced species in the Fire+Logging treatment (Table 4):

- *A. culubrina* (highest negative influence)
- *Poeppigia sp.* (highest negative influence)
- *C. microchaete* (lesser negative influence)

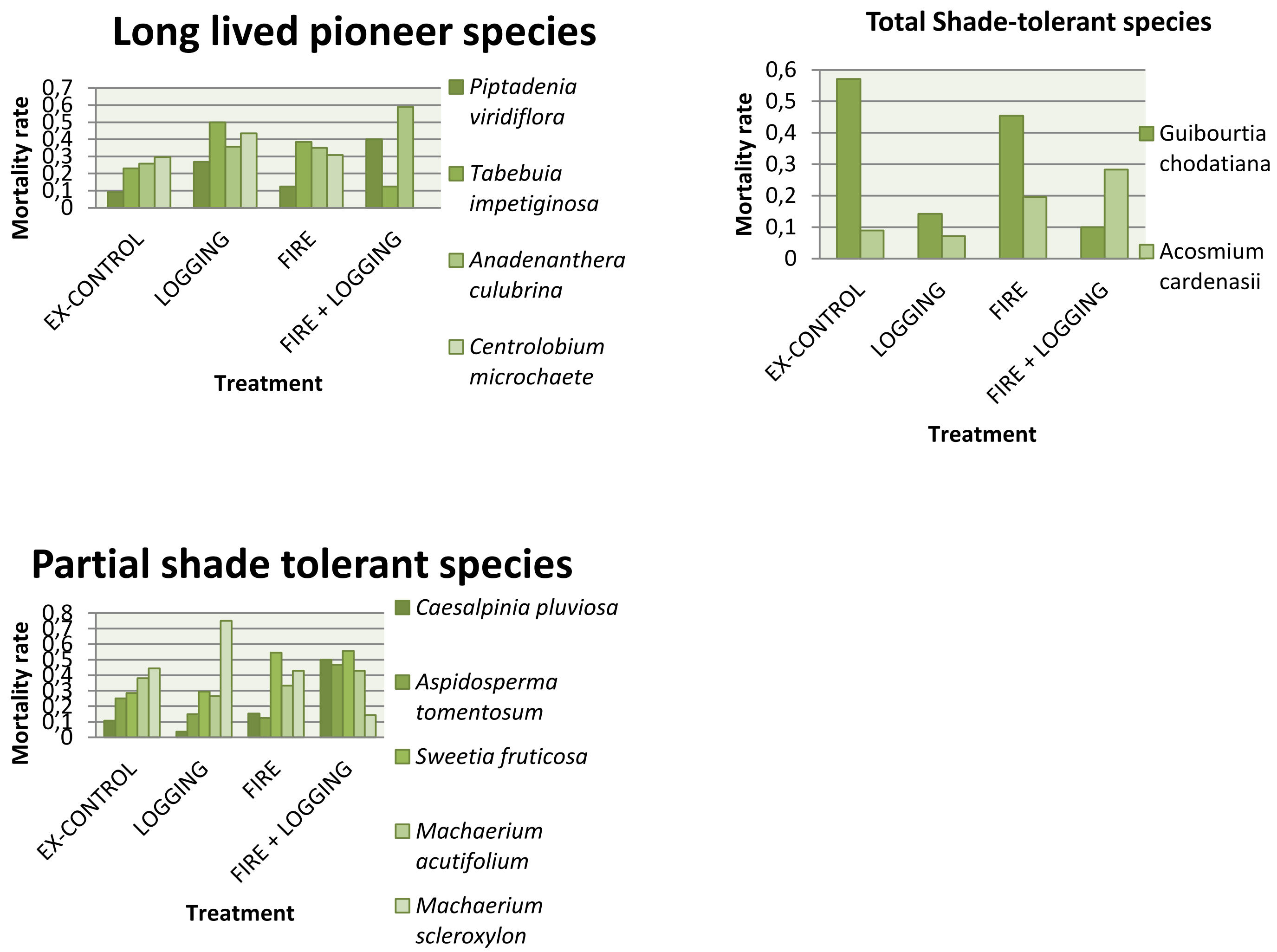
The only Partial Shade Tolerant species high level of disturbance is *M. acutifolium*. The three other Partial Shade Tolerant species (*A. tomentosum*, *S. fruticosa*, and *C. pluviosa*) had their lowest mortality rates in the lesser disturbed plots (Logging and Ex-control) (Table 4).

The commercial Total Shade Tolerant species (*G. chodatiana*) had the highest mortality rate in the Ex-control plot, and the lowest mortality rate in the Fire+Logging treatment. The non-commercial Total Shade Tolerant species (*A. cardenasii*) had the highest mortality rate in the Fire+Logging treatment, and the lowest mortality rate in the Logging treatment (Table 4).

Table 4: The mortality rates of the two most abundant species per ecological guild. Numbers 1-4 in superscript indicate the rank of the species mortality. 1 = lowest mortality rate, 4 = highest mortality rate.

Guild	Species	Ex-control*	Logging	Fire	Fire+Logging	Commercial Value
LLP	*A. culubrina*	$0{,}26^{1}$	$0{,}36^{3}$	$0{,}35^{2}$	$0{,}59^{4}$	3
	C. microchaete	$0{,}30^{2}$	$0{,}44^{4}$	$0{,}31^{3}$	$0{,}00^{1}$	2
PST	*C. pluviosa*	$0{,}11^{2}$	$0{,}04^{1}$	$0{,}15^{3}$	$0{,}50^{4}$	2
	M. acutifolium	$0{,}38^{3}$	$0{,}27^{1}$	$0{,}33^{2}$	$0{,}43^{4}$	2
TST	*G. chodatiana*	$0{,}57^{4}$	$0{,}14^{2}$	$0{,}45^{3}$	$0{,}10^{1}$	3
	A. cardenasii	$0{,}09^{2}$	$0{,}07^{1}$	$0{,}20^{3}$	$0{,}28^{4}$	1

*is biased by selective logging December 2010, see Chapter statistical analysis for more information. Commercial value: 1 = None, 2 = Normal value, 3 = High value



Ex-control is biased by selective logging December 2010, see Chapter statistical analysis for more information.

Figure 7: Mortality rate per species, per ecological guild combined, per plot, for the ten most abundant commercial species and *A. cardenasii*.

6.2 Abiotic environment

The one-way-ANOVA tests showed that the silvicultural treatments affected five out of six abiotic factors (Table 5, Figure 8). Canopy openness on one meter and mineral soil cover were affected most strongly. The Fire plot has the highest values for four out of six abiotic factors.

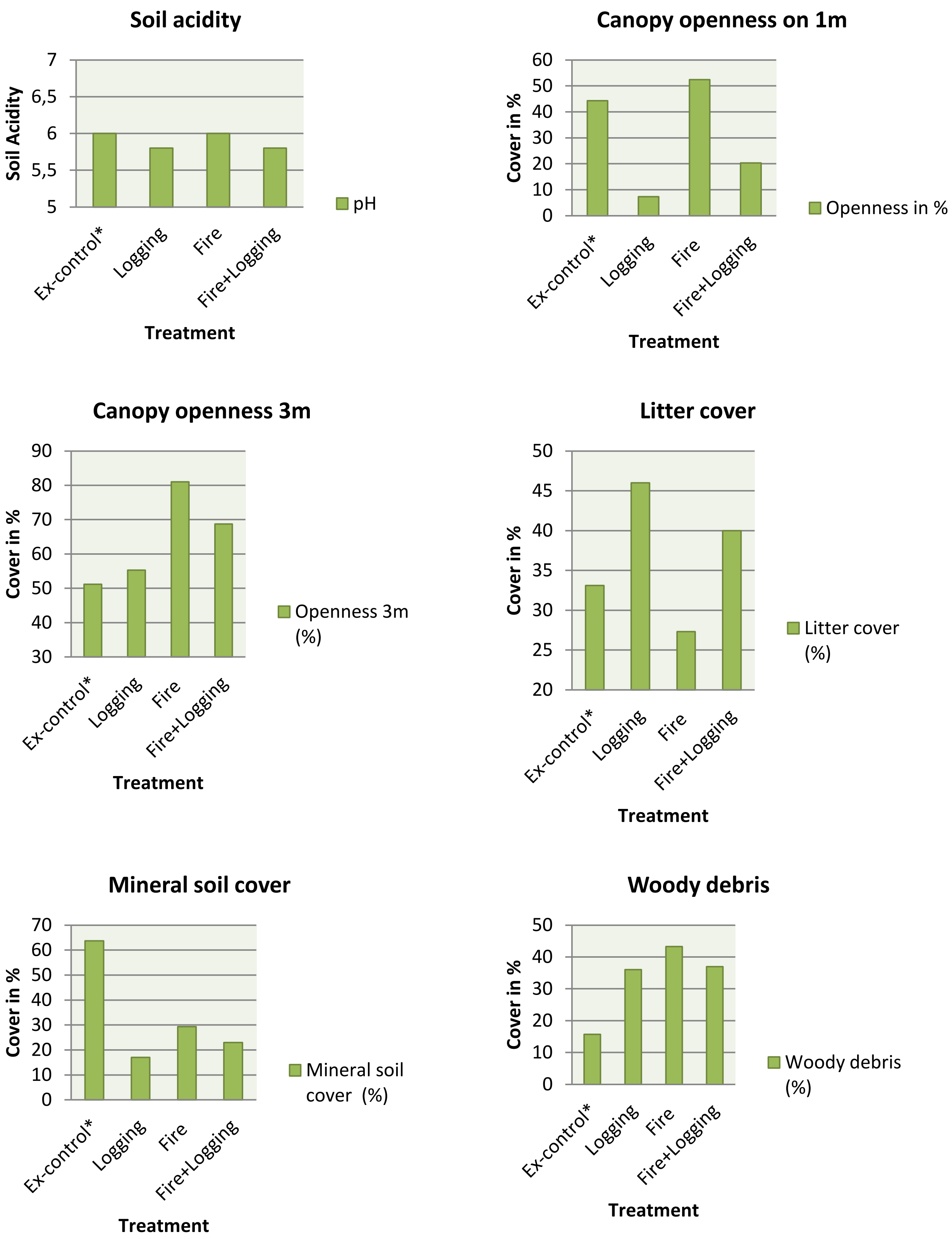
Description of the results of the abiotic factors, ranked by descending F-value:

- Mineral soil cover(df=56, F=16.67, p=0.00). It varies between 17% in the Logging plot and 63.7% in the Ex-control. The significant difference is between the Ex-control and the other plots(Table 5).
- Canopy openness on one meter (df=56, F=14.96, p=0.00) differs between 7.3% and 52.3%. The highest values are found in the Ex-control and Fire+Logging plots and are significantly higher than from in the Fire and the Logging plots.
- Woody debris cover (df=56, F=9.52, p=0.00). The cover is highest (43.3%) in the Fire plot and lowest (15.7%). in the Ex-control plot The ex-control plot differs significantly from the other treatments.
- Canopy openness on three meters (df=56, F=5.43, p=0.00) differs between 51.2% and 81.0%. Fire plot and Fire+Logging plot are significantly higher than the other treatments.
- Litter cover (df=56, F=2.87, p=0.04) differs between 46.0% in the Logging plot and 27.3% in the Fire plot. The Logging plot differs significantly from the Fire plot. The Logging plot varies significantly from the Fire plot.
- Soil acidity (df=56, F=0.68, p=0.57) is the only factor not differing significantly. This varied between pH 5.8 and pH 6.0. No further tests have been conducted on soil acidity.

Table 5: Effects of fire and logging on abiotic factors. Results of the* one-way ANOVA *for abiotic factors (soil acidity, canopy openness on 1 meter and 3 meter, and three types of soil cover: litter cover, woody debris and mineral soil), in tropical dry forest Bolivia after four different treatment combinations of fire and logging. Letters in superscript indicate significant difference determined by a Tukey post hoc test, highlighted p values indicate significant difference.

		Mean values				One-way Anova			
	Unit	Ex-control*	Logging	Fire	Fire+Logging	St. dev.	df	F	p
Soil acidity	pH	6.0^{a}	5.8^{a}	6.0^{a}	5.8^{a}	0.60	56	0.68	0.57
canopy openness 1m	%	44.3^{a}	7.3^{b}	52.4^{a}	20.3^{b}	27.16	56	14.96	0.00
canopy openness 3m	%	51.2^{a}	55.3^{a}	81.0^{b}	68.7^{ab}	25.15	56	5.43	0.00
Litter cover	%	33.1^{abc}	46.0^{ab}	27.3^{ac}	40.0^{abc}	19.32	56	2.87	0.04
Mineral soil cover	%	63.7^{a}	17.0^{b}	29.3^{b}	23.0^{b}	26.65	56	16.67	0.00
Woody debris	%	15.7^{a}	36.0^{b}	43.3^{b}	37.0^{b}	17.87	56	9.52	0.00

*is biased by selective logging December 2010, see Chapter statistical analysis for more information.



*Ex-control is biased by selective logging December 2010, see Chapter statistical analysis for more information.

Figure 8: Mean values for the abiotic factors per treatment. The trend is that the mean values of the Ex-control plot and the Fire plot are higher than of the Logging and Fire+Logging plot.

6.3 Vegetation cover

The one-way-ANOVA test has shown that the silvicultural treatments affected four out of nine vegetation types significantly (Table 6). Woody vine cover has been affected most strongly.
Also Herby vine, Epiphyte and Bamboo cover were affected significantly. The Tree, Forb and Bromeliad cover are highest in the logging plot. The woody vine, epiphyte and bamboo cover is highest in the Ex-control plot (Figure 9).

The following vegetation components were significantly affected by the treatments:

- Woody vine cover(df=56, F=18.51, p=0.00) is highest in the Ex-control plot (48.1%) this plot differs significantly from the other plots. The lowest cover was found in the Fire plot (1.6%). The Fire plot is significantly different from the Fire+Logging plot.
- Epiphytes cover (df=56, F=5.09, p=0.00) differs between the plots from 0.0% to 2.1%. Only the Ex-control plot differs significantly from the other plots. This vegetation type is however only abundant in two out of 4 plots.
- Herby vines(df=56, F=4.73, p=0.01). The herby vines vary between 25.1% in the Fire plot and 3,1% in the logging plot. The Ex-control plot (5.1%) differs significantly with the Fire plot. The Logging plot compares with the Ex-control plot.
- Bamboo cover(df=56, F=3.37, p=0.02). The mean bamboo cover is highest in the Ex-control plot(2.4%), and the lowest in 0.0% in the Logging and Fire+Logging plots. Significant differences can be found between the Ex-control and Fire+Logging plot.

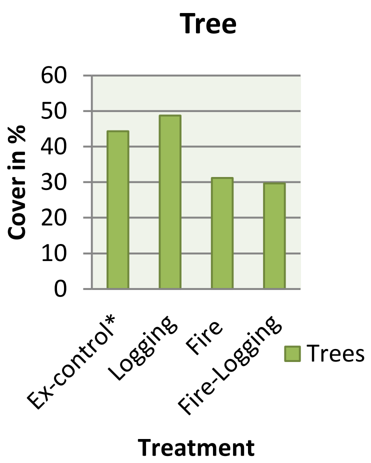
The following vegetation components were not show a significant relation with the treatments:

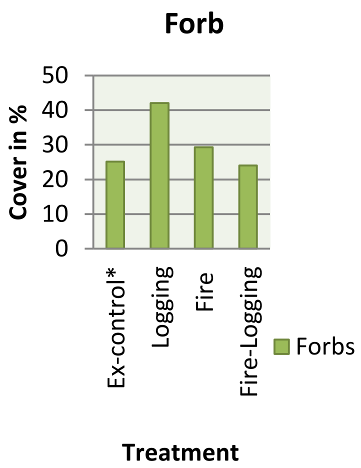
- Bromeliad cover did not differ significantly (df=56, F=2.66, p=0.06) but is the highest in the Logging plot, with 32.3% and lowest, with 12.5% in Fire+Logging.
- Grass cover (df=56, F=2.23, p=0.09). Grasses were most abundant in the Fire and Fire+Logging plot, both 2.1%. And were not abundant in the Logging plot.
- Tree cover does not differ significantly (df=56, F=1.97, p=0.13) between the four treatment plots. The highest values were found in the Logging plot (48.7%) and the lowest in the Fire+Logging plot (29.7%). F
- orb (df=56, F=1.78, p=0.16). The average forb cover varies between 42.0% in the Logging plot and 24.0% in the Fire+logging plot.
- Palm cover (df=56, F=0.89, p=0.45). The cover was 0.3% in the Ex-control plot, and 0.0% in the Fire, and in the Logging plot.

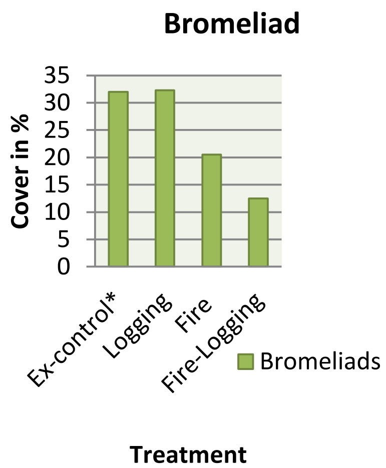
Table 6: Effects of fire and logging on vegetation cover. The results of the one-way-ANOVA for the trees, forbs, bromeliads, herby vines, woody vines, Epiphytes, grasses, bamboo and palm cover in tropical dry forest Bolivia after four different treatment combinations of fire and logging. Letters in superscript indicate differences determined by a Tukey post hoc test. Highlighted p values indicate significant difference.

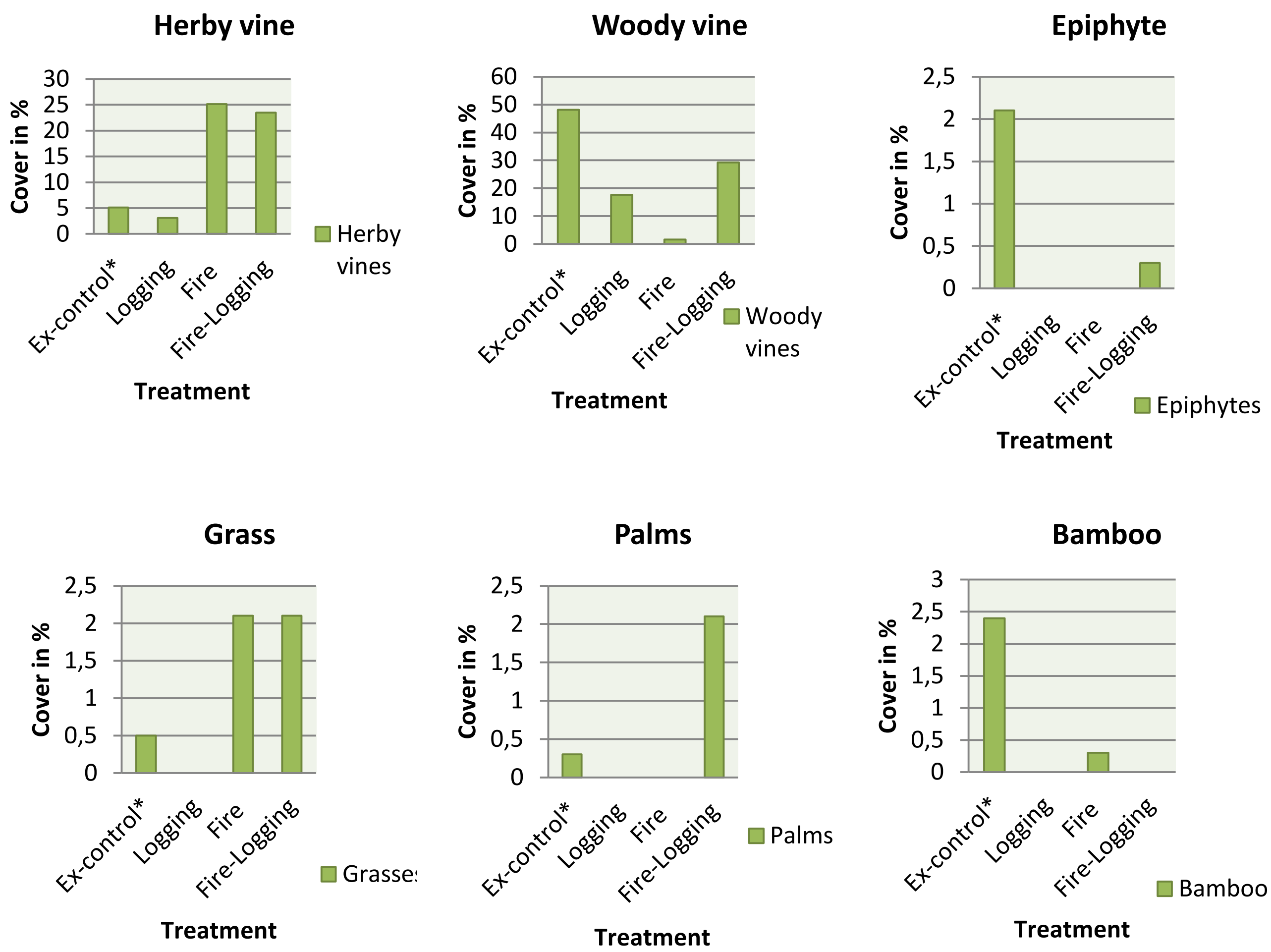
		Mean values				One-way-Anova			
	Unit	Ex-control	Logging	Fire	Fire-Logging	St dev	df	F	p
Trees	%	44.3[a]	48.7[a]	31.2[a]	29.7[a]	26.33	56	1.97	0.13
Forbs	%	25.1[a]	42.0[a]	29.3[a]	24.0[a]	23.89	56	1.78	0.16
Bromeliads	%	32.0[a]	32.3[a]	20.5[a]	12.5[a]	24.66	56	2.66	0.06
Herby vines	%	5.1[abd]	3.1[ab]	25.1[cd]	23.5[acd]	22.49	56	4.73	0.01
Woody vines	%	48.1[a]	17.7[bc]	1.6[bc]	29.3[b]	23.55	56	18.51	0.00
Epiphytes	%	2.1[a]	0.0[b]	0.0[b]	0.3[b]	1.94	56	5.09	0.00
Grasses	%	0.5[a]	0.0[a]	2.1[a]	2.1[a]	2.90	56	2.23	0.09
Bamboo	%	2.4[a]	0.0[ab]	0.3[ab]	0.0[b]	2.59	56	3.37	0.02
Palms	%	0.3[a]	0.0[a]	0.0[a]	2.1[a]	4.19	56	0.89	0.45

Ex-control is biased by selective logging December 2010, see Chapter statistical analysis for more information.









*Ex-control is biased by selective logging December 2010, see Chapter statistical analysis for more information.

Figure 9: Mean values of the vegetation cover of nine life forms per treatment.

6.4 Regeneration -density, -species richness, -mortality and -growth

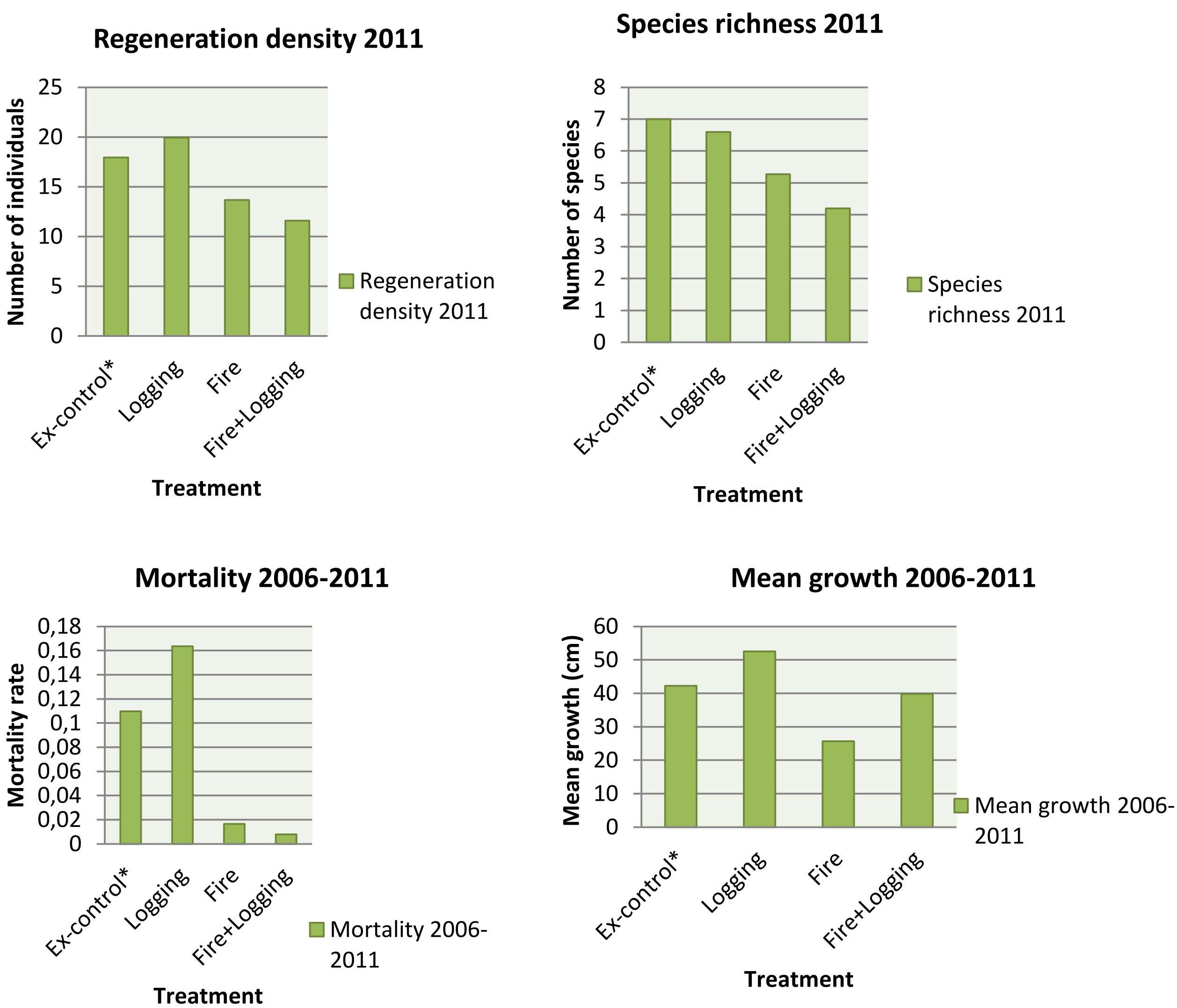
The mortality rate, -density, -species richness, differ significantly between the four treatments (Table 7). The mean values for the growth factors are in general highest in the less disturbed Ex-control and logging plot(Figure 10).

The Mortality rate is most strongly affected by the treatments (df=56, F=6.21, p= 0.01), varying between 0.16 in the logging plot and 0.02 in the fire plot. The species richness is also strongly affected by the treatments(df=56,F=4.93,p=0.00) and varies between 6.6 species in the Logging plot to 4.2 in the Fire+Logging. Species richness is significantly lower in the Fire and Fire+Logging plot. Also the regeneration density is affected significantly (df=56,F=2.85,p=0.05). It varies between a mean of 19.9 individuals in the logging plot and 11.6 individuals in the Fire+Logging plot.

Table 7: The growth factors of the regeneration in the four treatments. Regeneration density and species richness are sampled in 2011. Mortality rate and mean growth are sampled between 2006-2011.

	Mean values				one-way-ANOVA			
	Ex-control	Logging	Fire	Fire+Logging	St. dev	df	F	p
Regeneration density	17,93	19.93	13.67	11.60	9.17	56	2.85	0.05
Species richness	7	6.60	5.27	4.20	2.57	56	4.93	0.00
Mortality rate	0.10	0.16	0.02	0.01	17.72	56	6.21	0.01
Mean growth	42,26	52.55	25.65	39.83	48.23	56	0.77	0.52

Ex-control is biased by selective logging December 2010, see Chapter statistical analysis for more information.



*Ex-control is biased by selective logging December 2010, see Chapter statistical analysis for more information.

Figure 10: Mean values of the growth factors in the 1m x 5m subplots per treatment.

6.5 The effects of the abiotic and biotic environment on the regeneration of tree species

The biotic environment has a significant effect on the regeneration density and species richness, in the Fire plot. The One-way-ANOVA indicates that the effects of the abiotic factors on all growth factors are insignificant

Only for the fire treatment we found a clear relation between vegetation cover and regeneration (density and species composition). Regeneration density was influenced by the vegetation cover in the Fire plot (df=9, F=5.316, p=0.02)(Table 8). The R-square indicates that 84.2% of the variation in regeneration density, in the Fire plot, is caused by vegetation cover.
The difference in species richness of the tree regeneration is very likely caused by the vegetation cover in the Fire plot (df=6, F=5.316, p=0.041). The R-Square indicates that 74.3% of the species richness in the Fire plot is related to the vegetation cover. No significant influence of the abiotic factors on the growth factors have been found.

Table 8: The effect of the abiotic factors and vegetation cover on the growth factors. The effects of abiotic factors and vegetation cover were tested on four growth factors: regeneration density, species richness, mortality and mean growth of the regeneration in 2006-2011. Analysis has been conducted by One-way-Anova, values highlighted indicate a significant (p<0.05) influence.

			Vegetation cover			
	Treatment	Mean	R-square	df	F	p
Regeneration density	Ex-control	17.93	0.562	9	0.712	0.69
	Logging	19.93	0.171	5	0.331	0.88
	Fire	13.66	0.842	7	5.316	0.02
	Fire-Logging	11.60	0.645	8	1.361	0.36
Regeneration species richness	Ex-control	7.20	0.393	8	0.485	0.83
	Logging	6.60	0.317	4	1.048	0.44
	Fire	5.27	0.743	6	3.857	0.04
	Fire-Logging	4.20	0.596	7	1.474	0.31
Regeneration Mortality	Ex-control	0.10	0.713	9	1.513	0.34
	Logging	0.16	0.226	5	0.626	0.69
	Fire	0.02	0.281	7	0.291	0.94
	Fire-Logging	0.01	0.731	8	1.861	0.23
Mean regeneration growth	Ex-control	39.43	0.881	8	2.609	0.13
	Logging	52.55	0.676	4	1.895	0.20
	Fire	25.65	0.577	6	0.667	0.68
	Fire-Logging	39.83	0.691	7	2.235	0.16

Ex-control is biased by selective logging December 2010, see Chapter statistical analysis for more information.

6.6 The effects of fire and logging on the regeneration of commercial species

6.6.1 Share of commercial species within the regeneration of tree species

The recorded individuals in this study were categorized into three classes of commercial value: No commercial value, low commercial value or high commercial value. Significant difference in the proportion of high value species was found between the four treatments.
The high commercial value species (df=56, F= 3.94, p=0.01),were most abundant in the Fire+Logging plot (22%), Fire 8%, Ex-control 7% and Logging 4%. This is caused mainly by the abundance of *A. culubrina*. In this treatment, 45 out of 187 individuals were *A. culubrina* (24.06%), while the second highest abundance of *A. culubrina* was in the Fire plot (3.77%).

6.6.2 Effect of the vegetation cover and the abiotic environment on the regeneration of commercial species

The vegetation cover did not affect the number of commercial individuals, nor the commercial species richness. The abiotic environment significantly affected the regeneration density(df=5, F=4.15, p=0.03) and species richness (df=5, F=4.50, p=0.03)of the commercial species in the Fire plot(Table 9).

Table 9: The effect of the vegetation cover on the regeneration the commercial species. The regeneration density and the species richness of commercial species(Height >50 cm). Analysis has been conducted by Linear Regression, values highlighted indicate a significant influence.

		Abiotic			
		R-square	df	F	P
Regeneration density	Ex-control*	0.34	5	0.91	0.51
	Logging	0.42	6	0.97	0.50
	Fire	0.70	5	4.15	0.03
	Fire-Logging	0.37	5	1.04	0.45
Species richness	Ex-control*	0.38	5	1.09	0.43
	Logging	0.71	6	3.30	0.06
	Fire	0.71	5	4.50	0.03
	Fire-Logging	0.42	5	1.30	0.35

*is biased by selective logging December 2010, see Chapter statistical analysis for more information.

For the five most abundant commercial species there was no significant difference (Table 10) found in the influence of the vegetation cover on the number of individuals per plot, per treatment.
Two out the five most abundant commercial species (*G. chodatiana* and *A. tomentosum*) showed to have a significant difference in the amount of individuals per plot, influenced by the abiotic

environment. For *G. chodatiana* (df=6, F=4.91, p=0.02)it was found in the Logging treatment, and for *A. tomentosum* (df=5, F=6.46, p=0.01) it was found in the Ex-control plot.

Table 10: The effect of the abiotic factors upon the regeneration density of five commercial species. Regeneration (Height >50cm) of *M. acutifolium*, *A. culubrina*, *G. chodatiana*, *C. pluviosa* and *A. tomentosum*, after four different treatment combinations of fire and logging. Analysis has been conducted by Linear Regression, values highlighted indicate a significant influence.

		Abiotic			
		R-square	df	F	P
M. acutifolium	Ex-control*	0,19	5	0,41	0,83
	Logging	0,17	6	0,28	0,93
	Fire	0,56	5	2,27	0,14
	Fire-Logging	0,25	5	0,59	0,71
A. culubrina	Ex-control*	0,44	5	1,40	0,31
	Logging				
	Fire	0,13	5	0,26	0,92
	Fire-Logging	0,42	5	1,32	0,34
G. chodatiana	Ex-control*	0,30	5	0,76	0,60
	Logging	0,79	6	4,91	**0,02**
	Fire	0,62	5	2,97	0,08
	Fire-Logging	0,43	5	1,36	0,33
C. pluviosa	Ex-control*	0,18	5	0,40	0,84
	Logging	0,44	6	1,05	0,46
	Fire	0,14	5	0,29	0,91
	Fire-Logging	0,34	5	0,91	0,51
A. tomentosum	Ex-control*	0,78	5	6,46	**0,01**
	Logging	0,30	6	0,56	0,75
	Fire	0,59	5	2,56	0,11
	Fire-Logging	0,42	5	1,32	0,34

*is biased by selective logging December 2010, see Chapter statistical analysis for more information.
\ = No data

7. Discussion

7.1 The effects fire and logging on tree survival

The present study did find the hypothesized significant difference in tree mortality between fire and logging. This contradicts previous studies, which state that the mortality rate after a fire treatment in a logged and unlogged forest shows no significant difference(Woods 1989, Blate 2005).

The mortality rates of the Ex-control plot (0.17) and the Logging treatment (0.19) are coinciding with the study of Webb, 1997. The mortality rate of the residual stems in a forest which has been low-impact logged is 0.176 (Webb 1997).

The mortality rates after fire were higher than after logging, which is in accordance to earlier studies. (Holdsworth & Uhl 1997, Van Nieuwstadt & Sheil 2005). As hypothesized, significant difference was found in the mortality rate of the Logging treatment and the Fire treatment in this type of forest. In this study no trends were recorded in the mortality rates of the three different guilds over the four different treatments.

7.2 The effects of fire and logging on the abiotic environment

The soil acidity in the fire regimes is lower in comparison with the previous study on this site by Grootemaat (2007). Grootemaat found a significant increase of soil pH in the Fire plots two years after the site was burned. The present study did not find a significant difference in pH levels between the fire and logging plots (Table 11). This concurs with the known data (Úbeda et al., 2005, Bauhus et al. 1993) stating that soil pH decreases to the pre-fire levels in a period of several years. For this study that would mean that directly after the fire the soil has become more basic due to the alkaline effects of ashes (Certini 2005). But in the period between the 2007 and 2011 the effects of fire have been levelled out, explaining the insignificant result.

The canopy openness on one meter was, as expected, higher in the Fire plot than in the Logging plot. The canopy openness in the Fire+Logging plot was found to be lower than in the only with fire treated plot, which is not conform with the expected results. Also the ex-control plot has an unexpectedly high canopy openness (Figure 9 Vegetation cover) which might be the result of the logging operation in 2010 which disturbed the control plot. The results are contradictory to earlier findings, from the same location, in which the canopy openness in logged plots is not influenced in the three years following a burning (Veldman 2009). This might be caused by the slower gap colonization after fire than after logging in the years after the treatment as observed earlier (Veldman 2009). And thus the logging gaps have been colonized by trees and forbs, in none fire affected areas more intensively resulting in a lower canopy openness.

Significant difference in litter cover as indicated in Grootemaat (2007), couldn´t be confirmed during this study. This can be explained by the decomposition rate in dry forest. Results from a similar forest indicate significant loss of biomass after eight weeks, varying between 18.1 and 75.3 percent (Bakker 2011).

Mineral soil and woody debris cover are showing heavily deviant results, partly as expected, but in extraordinary levels. Mineral soil cover was unexpectedly high in the ex-control plot, due to unforeseen logging activities, while the other plots do not differ significantly from each other. This

can be explained by the influence of the logging operation in 2010, as a number of plots were heavily disturbed by this unforeseen event.
The woody debris cover is very low in the ex-control plot, while the others do not vary significantly. Although the results of this study are biased by unforeseen events it is an interesting and important topic, since the major share of all forest related carbon emissions come from decomposing or burning woody detritus during the process of forest clearing (Harmon et al. 1993).

Table 11: Overview of the expected results and our findings for the abiotic factors. The values are compared with the control plot, 0 = not significantly, - = decreased, + = increased. Green colour indicates that the outcome of the study meets the expected results.

	Fire		Logging		Fire and logging
Abiotic factor	Expected	Result	Expected	Result	Result
Soil acidity	+	0	0	0	0
Canopy openness 1m	+	+	0	-	-
Canopy openness 3m	0	+	+	+	+
Soil cover: Litter	0	0	0	0	0
Soil cover: Mineral	+	-	-	-	-
Soil cover: Woody	-	-	+	+	+

7.3 The effects of fire and logging on the vegetation cover

Forb, Bromeliad and palm cover in the Fire plot did not decrease significantly, compared with the Ex-control plot, although it was expected that the cover of these vegetation types would have decreased. Bromeliad cover was significantly lower in the Fire plots in 2007 (Grootemaat 2008), but it was not significant in 2011 (Table X). The growth of herby vines in the two with fire treated plots, Fire- and Fire+Logging, was significantly higher than in the logging plot, and the ex-control plot. Therefore it is expected that this vegetation type is benefiting a lot from disturbance caused by forest fire. Wildfires do stimulate the proliferation of herbaceous and vines (Pinard et al., 1999). In comparison to the herby vines did the woody vines not increase after the disturbance.

Epiphyte cover was low in all plots. They have been found in seven out of 60 plots. Even though the difference was significant the standard deviation was higher than three of the mean covers combined, indicating a highly varying Epiphyte cover. The Grasses, Bamboo and Palm cover in general was very low: out of the 60 plots Grasses were abundant in 13 plots, Bamboo in five and Palms in two plots. All three vegetation types have standard deviations higher than the mean cover, indicating that there general abundance of the vegetation type is low, with one or a few exceptions. This also was the case in 2007 (Grootemaat 2008).

Table 12: Overview of the expected results and our findings for the vegetation cover. The values are compared with the control plot, 0 = not significantly, - = decreased, + = increased. Green colour indicates that the outcome of the study meets the expected results.

	Fire		Logging		Fire and logging
Vegetation cover	Expected	Result	Expected	Result	Result
Trees	0	0	-	0	0
Forbs	-	0	0	0	0
Bromeliads	-	0	0	0	0
Herby vines	+	+	+	0	+
Woody vines	+	-	+	-	-
Epiphytes	0	-	0	-	-
Grasses	+	0	0	0	0
Bamboo	+	0	0	0	-
Palms	-	0	0	0	0

7.4 The effects of fire and logging upon the regeneration

The regeneration density was hypothesized to be higher in the burned plots than in the logged plots. As fire may be beneficial for shade-intolerant species as it removes vegetation, exposes mineral soil and releases nutrients (Kennard 2004). The results show that the opposite was the case, both plots treated with fire have significantly lower regeneration density. This may be the result of a higher intensity of fire, killing the seeds buried in the surface soil (Brinkmann and Vieira, 1971; Uhl et al., 1981). Another explanation could be the influence of the high levels of herby vine in these plots, increasing competition for the regeneration (Figure 9).

As hypothesized has the species richness decreased in the burned plots. The species richness is highest in the lesser disturbed plots, and lowest in the most strongly disturbed Fire+Logging plot(Table 8). According to the Intermediate Disturbance Hypothesis; an intermediate level of disturbance results in a maximum number of species on a regional scale (Connell 1978). Although wildfires and anthropogenic fires have played an important role in these forests (Gould et al. 2002), our results show that it is not beneficial for the species richness and it support a study from Cochrane. Namely that it is likely that logging will maintain a higher species richness than fire, as it creates a heterogenic patchwork of disturbances, unlike the large-scale disturbance created by fire (Cochrane in 2003).

Mortality rates were expected to be higher in the plots which endured fire. The results however show the opposite. Mortality rates were a tenfold higher in the ex-control plot than in the Fire+Logging plot and an eightfold higher in the Logging plot compared with the Fire plot. Apparently has fire created beneficial circumstances for the seed- and saplings under which the level of competition for light and/or nutrients is low, compared the plots which only have experienced logging as a treatment. The fact that tree mortality rates after fire are significantly lower might be an addition to what to what Kennard stated in 2004. That fire decreases competitive vegetation and increasing soil nutrient availability, improving regeneration of shade intolerant species, as the majority of the recorded seed and saplings are.

No significant difference in growth was found between the plots. This however might be because of no more than 301 Individuals height was recorded in 2007. These individuals were recorded in four treatments and 24 species, varying from 5 cm up to 4.5 meter. To analyse growth rates classification based on height, species and ecological trait is necessary. Classification and more detailed analysis would have been possible if a larger sample was available from previous years.

7.5 The effects of the growth factors on the regeneration of commercial species

It was hypothesized that the highest density of commercial species would be found in the highly disturbed plots. In accordance to the hypothesis, the highest density of commercial individuals were found in the Fire+Logging treated plot. The higher regeneration density in the intense disturbed treatment (Fire+Logging) can be largely explained by the fact that logging and fire opened the canopy more, allowing more light to reach the regeneration (Peña-Clarosa, 2007).
The regeneration density of Long Lived Pioneers increased with the intensity of disturbance (Peña-Claros, 2007; Kennard, 2004). For *A. culubrina*, there was a significant difference found between the regeneration density of the heavily disturbed Fire+Logging treatment and the three other treatments. Since the Ex-control only recently has been disturbed, the presence of this species could be a proof of the level of disturbance of the recent logging activity.

Fire did not have a positive effect on the regeneration density of the Partial Shade Tolerant Species and the Total Shade Tolerant species. This coincides with previous studies, according with the study of Kennard (2004), these two guilds have a higher regeneration density in the lesser disturbed treatments. These two guilds showed significant difference in the regeneration density between the logging and the fire treatment (Table 4).

After fire treatment a decrease in timber species was found by Holdsworth et Uhl (1997). The commercial species richness did not differ significantly.

8. Conclusions

The effects fire and logging on tree survival

The effects of fire and logging, upon the tree survival of the residual stems had a significant effect. The highest mortality rates of residual stems were encountered in the plots which had been treated with fire. From these findings we may conclude that fire does lead to an increased mortality of mature trees within the forest stand.

The effects of fire and logging on the abiotic environment

In general we can conclude that most of the abiotic factors are still significantly affected by six years after fire and seven years after logging.
In the years after burning, the effects of the treatments on the soil acidity were decreased to such an extent, that they were no longer found significant. The canopy openness at one meter was still higher six years after the fire treatment than seven years after the logging treatment. Unequal burning over the whole fire and logging combination treatment led to contradicting results. The recent logging practices in the control plot resulted in the formation of the Ex-control plot and biased the canopy openness.
The decomposition rate in this type of dry forest, after six years of fire and seven years of logging, led to a more uniform litter cover over the four different treatments. The mineral soil and woody debris cover was heavily influenced in the Ex-control plot due to the recent logging activities.

The effects of fire and logging on the vegetation cover

From a management perspective, the effects of fire on the vegetation cover was not beneficial. The effects are mainly visible in the availability of herby vines, which have a high abundance within the fire plots. This make the plot very difficult to access. In addition, fire had a negative effect on the bromeliad cover and on the density of the woody vines.

The effects of fire and logging upon the regeneration

The high level of disturbance in the burned plots had a negative effect on the overall regeneration density. However, the highest regeneration abundance of commercial species were found in the heavily disturbed plot. Lower numbers of regeneration were found after a combination of fire and logging, but the share of highly valuable commercial species had increased.
For the regeneration of a commercial long lived pioneer species such as *A. culubrina*, a combination of fire and logging showed to be beneficial. Solely fire showed to have a negative effect on the overall species richness, so a more monotonous species composition was found after burning.

The effects of the growth factors on the regeneration of commercial species

The share of commercially valuable individuals increased after high intensity disturbance, although it mainly was caused by an increased density of *A. culubrina*. Furthermore had fire a significant impact on the regeneration density and number of the commercial tree species in the plots.

9. Recommendation

- The continuation of monitoring of the tagged individuals of the study in 2007 and the tagged individuals of this study in 2011 can be very useful for increasing the understanding of the long term growth and survival of tree regeneration after fire and logging.
- In order to gain more insight and knowledge on the advanced regeneration of commercial species after burning and logging further research is needed, whereupon the newly created five by five plots can function as a baseline.
- High disturbances caused by a combination of fire and logging might have a positive effect on the regeneration density of some commercial tree species, such as *A. culubrina*. However, the high intensity of disturbance decreases species richness, and thus should be researched thoroughly before application.

Applicability of this study

This study was implemented to increase the understanding of burning and logging as a factor of disturbance on the regeneration of the Chiquitano dry forest. Although the study increased understanding of the effects of these forms of disturbances, extrapolation to the entire Chiquitano region or other dry forests around the world should be not be done with a study like this. Firstly, because the results of our study were biased by unforeseen logging activities in our control plot.
Secondly because the scale of this study is too small to use the data as a representative for an area of several hundred thousands of km² like the Chiquitano dry forest.

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11. Annexes

Annex I List of commercial species, Values and their Ecological Guilds

Species list		Guild
Local name	Commercial value	
Ajo	None	PST
Cari Cari Colorado	Low	LLP
A. culubrina	High	LLP
Gabetillo amarillo	Low	PST
A. tomentosum	Low	PST
Jichituriqui Colorado	Low	PST
S. fruticosa	Low	PST
C. pluviosa	Low	PST
M. acutifolium	Low	PST
Morado	High	PST
Paquio	Low	PST
Quina	Low	TST
G. chodatiana	High	TST
Soto	High	LLP
Tajibo Negro	High	LLP
C. microchaete	Low	LLP
Tarara colorada	Low	LLP
A. cardenasii	Low	TST
Tipa	Low	PST

Annex II List of species

Local name	Scientific name	Family	
Ajo	*Gallesia integrifolia*	Phytolaccaceae	Harms
Azucaro	*Spondias mombin*	Anacardiaceae	L.
Cari Cari Blanco	*Acacia spec.*		
Cari Cari Colorado	*Piptadenia viridiflora*	Leguminosae-Mimosoideae	Benth.
Carne del toro	*Combretum leprosum*	Combretaceae	Mart.
Chirimoya de Monte	*Rollinia herzogii*	Annonaceae	R.E. Fr.
Comomosi	*Bougainvillea modesta*	Nyctaginaceae	Heimerl
Curupau	*Anadenanthera culubrina*	Leguminosae-Mimosoideae	Brenan
Cuse	*Casearia gossypiosperma*	Flacourtiaceae	Briq.
Cusecillo	*Galipea ciliata*	Rutaceae	Taub.
Cuta cascara gruesa	*Lonchocarpus spec.*	Papilionoideae	
Gabetillo amarillo	*Aspidosperma rigidum*	Apocynaceae	Rusby
Galipea	*Galipea ciliata*	Rutaceae	Taub.
Guapuru	*Myrciaria cauliflora*	Myrtacaea	O. Berg
Guapurucillo	*Myricia guianensis*	Myrtacaea	DC.
Isiga	*Protium heptaphyllum*	Burseraceae	Marchand
Jichituriqui Amarillo	*Aspidosperma tomentosum*	Apocynaceae	Mart.
Jichituriqui Colorado	*Aspidosperma cylindrocarpon*	Apocynaceae	Mart.
Leche Leche	*Tabernaemontana cymosa*	Apocynaceae	Jacq.
Lemoncillo	*Achatocarpus nigricans*	Achatocarpaceae	Heimerl
Mani	*Sweetia fruticosa*	Leguminosae-Papilionoideae	Spreng.
Mapabi	*Neea hermaphrodita*	Nyctaginaceae	S. Moore
Mapajo	*Ceiba samauma*	Bombacaceae	K. Schum
Maria pretinha	*Phyllanthus sp. nov*	Phyllantheae	
Momoqui	*Caesalpinia pluviosa*	Leguminosae-Caesalpinioideae	G.P. Lewis
Moradillo	*Machaerium acutifolium*	Leguminosae-Papilionoideae	Vogel
Morado	*Machaerium scleroxylon*	Leguminosae-Papilionoideae	Tul.
Negrillo	*Machaerium sp.*	Leguminosae-Papilionoideae	
Pacobillo	*Capparis prisca*	Capparidaceae	J.F. Macbr.
Paquio	*Hymenaea courbaril*	Leguminosae-Caesalpinioideae	L.
Pata de pollo	*Allophyllus edulis*	Sapindaceae	St.-Hil.
Patarillo	*Simira rubescens*	Rubiaceae	Steyerm.
Penoco	*Samanea tubulosa*	Fabaceae Mimosoideae	Benth.
Picana blanca	*Cordia alliadora*	Boraginaceae	Ruiz & Pav.
Piton	*Talisia esculenta*	Sapindaceae	Radlk.
Quina	*Pogonopus tubulosus*	Rubiaceae	K. Schum
Sahuinto	*Myrciaria spec.*	Myrtacaea	O. Berg
Sama Colorada			
Sirari	*Guibourtia chodatiana*	Leguminosae-Caesalpinioideae	J. Leónard
Soto	*Schinopsis brasiliensis*	Anacardiaceae	Engl.
Tabacachi			
Tajibo Negro	*Tabebuia impetiginosa*	Bignoniaceae	Standl.
Tarara Amarilla	*Centrolobium microchaete*	Leguminosae-Papilionoideae	G.P. Lewis
Tarara colorada	*Platymiscium ulei*	Leguminosae-Papilionoideae	Klitgaard
Tasaa	*Acosmium cardenasii*	Leguminosae-Papilionoideae	H.S. Irwin
Tipa	*Machaerium villosum*	Leguminosae-Papilionoideae	Vogel
Toborochi	*Chorisia speciosa*	Bombacaceae	St.-Hil.
Turino	*Ximenia sp.*	Olacaceae	L.
Uña de gato	*Zanthoxylum fagara*	Rutaceae	HBK.
Yesquero Blanco	*Cariniana ianeirensis*	Lecythidaceae	R. Knuth

Annex III Plot locations and coordinates

Treatment	Plot number	Location in subplot	N	Y
Fire+Logging	1.01	250-0	640570	8198907
Fire+Logging	1.02	150-0	640427	8198869
Fire+Logging	1.03	0-50	640319	8198885
Fire+Logging	1.04	0-100	640310	8198937
Fire+Logging	1.05	0-200	640291	8199034
Fire+Logging	1.06	50-50	640363	8198899
Fire+Logging	1.07	100-250	640427	8198869
Fire+Logging	1.08	200-200	640426	8199074
Fire+Logging	1.09	200-200	640480	8199084
Fire+Logging	1.10	300-50	640632	8198978
Fire+Logging	1.11	100-200	640447	8198229
Fire+Logging	1.12	100-50	640427	8198869
Fire+Logging	1.13	200-150	640493	8199035
Fire+Logging	1.14	250-250	640603	8198958
Fire+Logging	1.15	300-0	640602	8198907
Logging	2.01	0-0	639657	8198883
Logging	2.02	50-200	639638	8199075
Logging	2.03	100-250	639684	8199134
Logging	2.04	150-300	639715	8199194
Logging	2.05	200-250	639772	8199156
Logging	2.06	200-50	639812	8198977
Logging	2.07	250-300	639807	8199214
Logging	2.08	250-150	639844	8199063
Logging	2.09	300-0	639938	8198937
Logging	2.10	300-250	639868	8199211
Logging	2.11	0-50	639636	8198922
Logging	2.12	50-250	639621	8199123
Logging	2.13	50-150	369647	8199029
Logging	2.14	100-300	639689	8199188
Logging	2.15	300-300	639862	8199228
Ex-control	3.01	300-300	641249	8198478
Ex-control	3.02	250-250	641216	8198419
Ex-control	3.03	250-100	641249	8198268
Ex-control	3.04	250-0	641266	8198180
Ex-control	3.05	200-150	641187	8198308
Ex-control	3.06	200-200	641176	8198353
Ex-control	3.07	150-300	641110	8198446
Ex-control	3.08	100-100	641106	8198245
Ex-control	3.09	50-100	641054	8198233
Ex-control	3.10	0-100	640013	8198219
Ex-control	3.11	300-150	641283	8198336
Ex-control	3.12	300-250	641267	8198431
Ex-control	3.13	200-300	641165	8198457
Ex-control	3.14	50-300	641026	8198429
Ex-control	3.15	0-300	640973	8198419
Fire	4.01	150-150	641050	8198667
Fire	4.02	150-200	641040	8198720
Fire	4.03	150-250	641032	8198771

Fire	4.04	250-200	641140	8198743
Fire	4.05	200-50	641136	8198586
Fire	4.06	50-150	640956	8198647
Fire	4.07	150-0	641085	8198523
Fire	4.08	300-50	641224	8198614
Fire	4.09	100-300	640972	8198810
Fire	4.10	150-150	641050	8198667
Fire	4.11	250-250	641127	8198789
Fire	4.12	300-50	641224	8198614
Fire	4.13	200-150	641110	8198681
Fire	4.14	0-100	640911	8198591
Fire	4.15	0-200	640896	8198689