UNIVERSITY OF APPLIED SCIENCES VAN HALL LARENSTEIN

Inventory of Natural Regeneration and the Recovery of Logging Gaps in the Nkrabia Forest Reserve in Ghana

A Comparison between Chainsaw Milling and Conventional Logging

Thorsten Dominik Herrmann

VAN HALL LARENSTEIN

PART OF WAGENINGEN UR

Hochschule für Forstwirtschaft Rottenburg

University of Applied Forest Sciences

Bachelor Thesis

to obtain the academic degree

Bachelor of Science in Forestry

and Bachelor in Forest and Nature Management

at the

University of Applied Sciences Van Hall Larenstein,

Part of Wageningen University and Research Center

Topic: Inventory of Natural Regeneration and the Recovery of Logging Gaps in the Nkrabia Forest Reserve in Ghana – A Comparison between Chainsaw Milling and Conventional Logging

Author: Thorsten Dominik Herrmann

Rieslingstraße 29

71364 Winnenden, Germany

Herrmann_Thorsten@web.de

1. Examinor: Jaap de Vletter
2. Examinor: Mr. Zambon

External supervisor: Robbert Wijers

Closing date: Velp, 03 / January 2011

Key words: *Ghana, natural regeneration, logging gaps, chainsaw milling*

ACKNOWLEDGEMENT

This study was carried out on the behalf of Houthandel Wijers BV and the Forestry Research Institute of Ghana (FORIG) between March and November 2010. The presented research is a continuation of several forestry related studies that had been carried out in the Nkrabia forest reserve in Ghana by students of the University of Applied Sciences Van Hall Larenstein.

My special thanks goes to the Forestry Research Institute of Ghana (FORIG) and Robbert Wijers (Houthandel Wijers BV) for giving me the opportunity to conduct the field work in Ghana by financial means and technical as well as logistical support. Furthermore I would like to thank Jonathan Dabo (Technician, FORIG) and Seth Kankam Nuamah (Service Personnel, FORIG) for their indispensable and sedulous support during the field work and data collection for this study. In addition I would like to thank the Forestry Commission (FC) in Kumasi for providing me with cartographic material and the permission to perform the data collection in the Nkrabia forest reserve. I would like to express my gratitude to Jaap de Vletter, my supervisor on behalf of Van Hall Larenstein and Peter van der Meer for support and supervision during the preparation of this study and all stages of thesis writing.

Last but not least I would like to sincerely thank my parents, Klaus and Inge Herrmann for their never-ending support and backup during all the years of my studies. Special thanks goes to Tina Bauer (Student of Geoecology, University of Tübingen) for her helpful and inspiring comments on this report throughout the whole preparation process and Isabelle Uitz (Student of the HAN, Nijmegen) for her corrections on the draft version of this document.

Non statim pusillum est,
si quid maximo minus est.

TABLE OF CONTENTS

1. **Abstract** 1
2. **Introduction** 2
3. **Overall objective** 4
   3.1 Research questions 4
   3.2 Hypotheses 4
4. **The study site** 5
   4.1 Forest features 5
   4.2 Logging activities 5
5. **Methodology** 7
   5.1 Selection of logging gaps 7
   5.2 Selection of undisturbed forest sites 7
   5.3 Assessment of gap characteristics 7
   5.4 Inventory of natural regeneration 8
6. **Data analysis** 10
   6.1 Calculation of gap size 10
   6.2 Classification of logging gaps 10
   6.3 Classification of natural regeneration 11
      6.3.1 Successional classes *11*
      6.3.2 Growth form classes *11*
      6.3.3 Commercial classes *11*
      6.3.4 Star categories *12*
   6.4 Statistical analysis 12
7. **Results** 13
   7.1 Gap characteristics 13
      7.1.1 Gap size *13*
      7.1.2 Gap border trees *14*
      7.1.3 Gap makers *14*
   7.2 Species composition and stand structure of natural regeneration 16
      7.2.1 Species composition *16*
      7.2.2 Stem density *18*
      7.2.3 Height class distribution *20*
   7.3 Regeneration of successional classes 21
   7.4 Regeneration of growth form classes 23

7.5 Regeneration of commercial classes 24

7.6 Regeneration of star categories 26

8 **Discussion** 29

8.1 General scope of this study 29

8.2 Gap characteristics 30

8.3 Status and species composition of natural regeneration 31

8.4 Regeneration of successional classes in relation to gap size 32

8.5 Regeneration of lianas and small climbers in relation to gap size 33

8.6 Regeneration of economic timber species in relation to gap size 34

8.7 Comparison of chainsaw milling and conventional logging 36

9. **Conclusions and recommendations** 37

9.1 Conclusions 37

9.2 Recommendations 38

10. **List of references** 39

11. **Annexes** 44

Annex 01: Species description 44

Annex 02: Characteristics of logging gaps 49

Annex 03: GPS coordinates of logging gaps / inventory spots 50

Annex 04: GPS coordinates of undisturbed sites / inventory spots 51

Annex 05: Location of inventory spots 52

Annex 06: Species list of gap border trees 53

Annex 07: Species list and classification 55

Annex 08: Species abundance and frequency 60

Annex 09: Gap size assessment and definition of the gap center 65

List of figures:

Figure	*page*
01: Map of southern Ghana	6
02: Compartment map of the Nkrabia forest reserve	6
03: Survey plot design	9
04: Abundance of gap size classes	13
05: Correlation between DBH of Gap maker and gap size	15
06: Species frequency table	17
07: Stem density per inventory unit - sapling category	19
08: Stem density per inventory unit - seedling category	19
09: Stem density per height class - sapling category	20
10: Abundance of successional classes per inventory unit - sapling category	22
11: Abundance of successional classes per inventory unit - seedling category	22
12: Abundance of growth form classes per inventory unit	23
13: Abundance of Commercial Class I per inventory unit - sapling category	25
14: Abundance of Commercial Class I per inventory unit - seedling category	25
15: Abundance of High Priority species per inventory unit - sapling category	28
16: Abundance of High Priority species per inventory unit - seedling category	28

List of tables:

Table	*page*
01: Selection and location of logging gaps	7
02: Definition of the seedling and sapling category	8
03: Definition of the inventory units	11
04: Mean gap size of different logging practices	13
05: Mean DBH of Gap makers per gap size class	14

Table	*page*
06: Mean DBH of Gap makers per logging practice	14
07: Most abundant tree spp. in the sapling category	16
08: Most abundant tree spp. in the seedling category	16
09: Most abundant shrub-/large woody herb spp. in the seedling category	16
10: Most abundant liana spp. in the seedling category	16
11: Most abundant small climber spp. in the seedling category	16
12: Definition of frequency classes	17
13: Stem density per inventory unit - sapling category	18
14: Stem density per inventory unit - seedling category	18
15: Stem density per logging practice - sapling category	18
16: Stem density per logging practice - seedling category	18
17: Definition of height classes	20
18: Abundance of successional classes per inventory unit - sapling category	21
19: Abundance of successional classes per inventory unit - seedling category	21
20: Abundance of growth form classes per inventory unit - seedling category	23
21: Most abundant Commercial Class I spp. in the sapling category	24
22: Most abundant Commercial Class I spp. in the seedling category	24
23: Abundance of Commercial Class I per inventory unit - sapling category	24
24: Abundance of Commercial Class I per inventory unit - seedling category	24
25: Most abundant Red Star spp. in the sapling category	26
26: Most abundant Red Star spp. in the seedling category	26
27: Most abundant Scarlet Star spp. in the sapling category	26
28: Most abundant Scarlet Star spp. in the seedling category	26
29: Abundance of High Priority species per inventory unit - sapling category	27
30: Abundance of High Priority species per inventory unit - seedling category	27

List of abbreviations:

AAC	Annual Allowable Cut
CL	Conventional logging
CM	Chainsaw milling
DBH	Diameter breast height
FC	Forestry Commission
FORIG	Forestry Research Institute of Ghana
GB	Gap border tree
GC	Gap center
GPS	Geographical Positioning System
ha	Hectare
L	Liana(s)
LLL	Logs and Lumber Limited
M	Mean
N	Number
NPLD	Non-pioneer Light-demander(s)
P.	Pioneer(s)
p.	Significance level / critical p-value
SB	Shade-bearer(s)
SC	Small climber(s)
SD	Standard deviation
SH	Shrub- or large woody herb(s)
Spp.	Species
T	Tree(s)
TUC	Timber Utilization Contract
US	Undisturbed forest site
YAF	Yield Allocation Formula

Definitions:

Annual Allowable Cut:	The amount of timber permitted to be harvested within a one year period to ensure the sustainability and productivity of the forest, [AAC].
Black Star species:	Category of the Ghanaian Star Classification; plant species that are globally rare and of high priority for careful management (Hawthorne & Abu-Juam, 1995).
Blue Star species:	Category of the Ghanaian Star Classification; plant species of some rarity value in Ghana but widespread internationally (Hawthorne & Abu-Juam, 1995).
Canopy gap:	A canopy gap refers to an area within the forest where the canopy is noticeably lower than in adjacent area as a product of disturbance, created by branch fall or the death of one or several trees (Runkle, 1992).
Chainsaw milling:	Illegal on-site conversion of logs into lumber with the help of a chainsaw (Marfo, 2010), [CM].
Climber:	A climbing plant; in this study "small climbers" differ from lianas as they are not able to reach the top strata (canopy) of the forest.
Commercial Class I:	Timber tree species that have been exported from Ghana at least once during the period 1973 to 1988, including all main economic species plus some lesser-known species being actively promoted for export (FAO, 1995).
Commercial Class II:	Timber tree species that attain 70 cm DBH (marketable size) and occur in relevant frequency but have not been previously exported (FAO, 1995).
Commercial Class III:	All remaining tree species, not considered to have potential for timber production (FAO, 1995).
Conventional logging:	Logging operations in Ghana that are conducted by the formal timber production sector under the official mandate of the Forestry Commission, [CL].
Diameter breast height:	The diameter of the tree trunk at 1,30 m height above ground, [DBH].
Frequency:	The percentage (%) of inventory spots that contains individuals of a species or group of species.

Gap border tree:	Trees that are part of the surrounding forest (Runkle, 1992); in this study defined as trees with DBH ≥ 20 cm and height ≥ 20 meters, [GB]
Gap maker:	The tree that had been felled and consequently created the canopy gap within the forest, through its impact on other trees, ground and vegetation.
Gap recovery:	In this study defined as the seedlings and saplings that occur within a logging gap in a stage of succession.
Gold Star species:	Category of the Ghanaian Star Classification; plant species that are globally restricted and fairly rare internationally (Hawthorne & Abu-Juam, 1995).
Green Star species:	Category of the Ghanaian Star Classification; plant species of little conservation concern (Hawthorne & Abu-Juam, 1995).
Guilds:	A group of species that overlap significantly in their niche requirements as they exploit the same class of environmental resources in a similar way, regardless their taxonomic position (Simberloff & Dayan, 1991).
Liana:	A woody, climbing plant that is able to grow to large size and reach the top strata (canopy) of the forest.
Logging gap:	In this study defined as a canopy gap created by the felling and on-site processing of a timber tree by chainsaw milling and conventional logging.
Non-Pioneer Light-demander:	Species that germinate and survive in deep forest shade, but show a higher mortality under such conditions and die mostly before exceeding one meter in height as they require increased solar radiation in later growth stage (Hawthorne, 1993), [NPLD].
Pink Star species:	Category of the Ghanaian Star Classification; plant species that are of commercial interest, moderately exploited but not yet under pressure from exploitation (Hawthorne & Abu-Juam, 1995).
Pioneer:	Species that depend on gap conditions for seed germination and seedling establishment as they need special conditions for their seed dormancy to be broken and require high solar radiation after germination (Swaine & Whitmore, 1988), [P].
Red Star species:	Category of the Ghanaian Star Classification; plant species that are common but under pressure from exploitation (Hawthorne & Abu-Juam, 1995).

Relative species abundance:	An expression of how rare or common a species or a species group is compared to other species in a defined location or community; in this study expressed as percentage (%) of the total number of individuals, ≙ Abundance.
Sapling:	A young tree; in this study defined as woody plant with a total height between ≥ 100 cm and ≤ 500 cm.
Scarlet Star species:	Category of the Ghanaian Star Classification; plant species that are common but under serious pressure from exploitation (Hawthorne & Abu-Juam, 1995).
Seedling:	Young plant that is grown from a seed; in this study defined as a woody plant with total height < 100 cm.
Shade-bearer:	Species that germinate in deep forest shade, show lower mortality and are able to continue growth without increased solar radiation and eventually become established trees under such conditions (Hawthorne, 1995), [SB].
Star categories:	All plant species in Ghana have been assigned to different Star categories based on their rarity, in Ghana and internationally, with subsidiary consideration of the ecology and taxonomy of the species (Hawthorne & Abu-Juam, 1995).
Stem density:	The stem density refers to a number of individual plants in a specified area; in this study the stem density is standardized to individuals per hectare.
Yield Allocation Formula:	Formula to determine the timber yield / number of stems to be exploited within a logging unit based on (1) the number of stems of a given species in the exploitable diameter class, (2) the number of stems of a given species in the diameter class below the felling diameter, (3) the retention percentage of mature stems and (4) the mortality percentage during the felling cycle (Adam, 1999), [YAF].

1. ABSTRACT

Logging of trees for timber production is nowadays one of the major impacts on the forests in Western Africa. Today, there exist two different logging practices in Ghana that are conducted on a larger scale, namely conventional logging which is carried out under the official mandate of the national forest authority and chainsaw milling, an illegal and uncontrolled logging method which is mostly practiced by local people for the supply of the domestic timber market.

This research was carried out in the Nkrabia forest reserve, situated in Moist Semi-deciduous forest formation in Ghana. The study presents a comparison between chainsaw milling and conventional logging with respect to the effects on natural regeneration within the particular logging gaps. Additionally, an overall evaluation of the logging activities in the Nkrabia forest reserve, with focus on the recovery of economic timber species, had been conducted in this study. It was found out that logging gaps created by chainsaw milling are smaller in average than those emerged from conventional logging, which resulted from the extraction of trees that mainly ranged below the species specific diameter limit which is binding for conventional operations in Ghana. As the natural regeneration within logging gaps was affected by the gap size it could be reasoned that logging gaps created by chainsaw milling are more favourable for the recovery of economic timber species in the Nkrabia forest reserve than the logging gaps that had been created by conventional operations. In general, it was observed that the recovery of high-value timber species was rather deficient in the forest reserve although commercial timber species were generally present as natural regeneration. This indicated the unsustainability of the management and timber utilization of the forest reserve during the past decades with respect to the natural recovery of high valuable timber species.

2. INTRODUCTION

The forests in Ghana have long been target of diverse anthropogenic influences like shifting cultivation, charcoal production and logging of timber for commercial and domestic purpose (Saaka et *al.*, 1999). Today, legal and illegal timber exploitation is recognized to be the major impact on forest area- and structure in Ghana (Glastra, 1999). The same applies to forest reserves which have originally been established to promote environmental stability and a basis for sustainable timber production (Hawthorne & Abu-Juam, 1995; Agyeman et *al.*, 1999; Donkor, 2003). Nowadays, those designated forest reserves present the major proportion of closed forest cover in Ghana (Agyarko, 2001).

Illegal logging, as it is defined to take place when "timber is harvested, transported, bought or sold in violation of national laws" (Brack, 2005) is known to be one of the major causes for forest destruction and the rapid decline of the global forest cover (EIA, 2002). On a worldwide scale illegal logging takes place in about 70 countries (Toyne et *al.*, 2002) most of which are tropical and developing (Tacconi, 2007). It is widely recognized that illegal logging also plays a major role in the national timber production of Ghana (Marfo, 2010) where 70 % of the annually harvested timber derives from illegal sources (Hansen & Treue, 2008). The main share (75 %) of illegal timber in Ghana is produced by the so-called chainsaw milling operations (Hansen & Treue, 2008) a logging practice that has been banned in Ghana since 1998 but nevertheless is nowadays the major supplier of timber for the domestic market (Marfo, 2010). The impact on the forest area caused by chainsaw milling can be assumed to be tremendous, as its annual lumber production exceeds the output of the formal timber industry by far (Marfo, 2010). Recent studies estimate a total annual volume of 2,2 to 2,9 million cubic meters of timber that is illegally harvested by chainsaw operators. This volume equates to approximately 970.000 trees that are consequently logged and processed by the chainsaw milling sector every year (Marfo, 2010).

The formal sector of timber production in Ghana, the conventional logging is nowadays regulated under the Timber Resource Management Act (Act 547) of 1997 and the Timber Resource Management Regulations (LI 1649) of 1998 (Oduru & Gyan, 2007). The right for commercial timber exploitation is issued as Timber Utilization Contracts [TUCs] to logging companies in form of permits that detail the area, the volume and species to be harvested (Marfo, 2010). The logging operation itself is regulated under the Logging Manual of the Forestry Commission (Oduru & Gyan, 2007) focusing on "good working practice", namely the reduction of logging damage and an increased production volume (Revised Logging Manual for Ghana, 2003). Forest management in Ghana that aims at timber production is conducted on a polycyclic selection system using a cutting cycle of 40 years. The tree selection for logging is based on the interim Yield Allocation Formula [YAF] which incorporates the health and regenerative capacity of the forest as well as the economic relevance of the harvestable tree species (Procedures Manual, 2003). According to the official timber allocation procedures the Annual Allowable Cut [AAC] is limited to around 2,0 million cubic meters (Marfo, 2010).

Although logging activities are often associated with collateral damage (Asner et *al.*, 2004) and extensive disturbance of the forest stand (Thiollay, 1997), selective logging has been expected to have a positive influence on the natural regeneration (Makana & Thomas, 2005). The felling and extraction of selected timber trees creates canopy gaps and thus increases the light availability on the forest floor which is essential for the growth and establishment of seedlings and saplings (Cannon et *al.*, 1994). Canopy gaps are generally presumed to be essential to maintain the high biodiversity of tropical rain forests (Brokaw, 1985). In fact many dominant canopy tree species are virtually absent in the understory (Poorter et *al.*, 1996) and fully dependent on large gaps for successful regeneration (Denslow, 1980). Especially in West Africa there is a considerable abundance of long-lived Pioneers and light demanding climax species (Gómez-Pompa et *al.*, 1991) including many highly commercial timber species (Hawthorne, 1993). Several studies have shown that canopy gaps provide good conditions for successful regeneration of those species (Denslow, 1980; Swaine & Hall, 1983; Nichols et *al.*, 1999; Hawthorne, 1995; Hall et *al.*, 2003). The natural regeneration of desired timber species in a sufficient abundance and frequency is crucial for sustainable forest management to compensate for the extraction of those species and guarantee adequate timber yields on future harvests (Poorter et *al.*, 1996).

In Ghana, ecological aspects of logging operations like gap size and the related effects on natural regeneration have rarely been assessed (Agyeman et *al.*, 1999). Furthermore there seems to be a lack of data about the ecological impacts of logging with the purpose to compare conventional operations with other forms of logging practice like chainsaw milling. Recent studies have mostly focused on logging intensity and exploited tree species to evaluate the impact on the forest (Agyeman et *al.*, 1999) though the effects on natural regeneration are crucial to evaluate the ecological long-term sustainability of logging operations with focus on the recovery of economic timber species (Garnica et *al.*, 2006; Karsenty & Gourlet-Fleury, 2006). Although regeneration processes in forest gaps depend on a wide range of biological and physical variables (Sapkota & Odén, 2009) it has often been reported that the gap size is one of the most important factors having influence on the gap recovery (Brokaw, 1985; Thompson et *al.*, 1998; Rose, 2000; Toledo-Aceves & Swaine, 2008) because it directly affects the light availability within the canopy gap (Barton et *al.*, 1989) which is the crucial parameter for the composition and structure of natural regeneration (Addo-Fordjour et *al.,* 2009).

3. OVERALL OBJECTIVE

The overall objective of this study is to demonstrate the status of the early natural regeneration in logging gaps, with gap size as the main parameter for the comparison of logging gaps created by chainsaw milling [CM] and conventional logging [CL] and to state the overall conditions of the natural regeneration in the Nkrabia forest reserve with particular focus on the recovery of economic timber species.

3.1 RESEARCH QUESTIONS

(1) What are the differences between logging gaps that had been created by chainsaw milling and conventional logging in the Nkrabia forest reserve?

(2) What are the overall conditions of natural regeneration in the Nkrabia forest reserve? What is the status of the natural regeneration, with respect to different ecological species groups and the abundance of economic timber species, within different sized logging gaps and undisturbed forest sites?

(3) Does the natural regeneration which occurs in logging gaps that had been created by chainsaw milling differ from the regeneration in gaps created by conventional logging?

3.2 HYPOTHESES

(1) Logging gaps created by chainsaw milling and conventional logging differ in average size since chainsaw operators mainly focus on the extraction of smaller trees while conventional logging is obliged to adhere to the species specific diamater limits.

(2) The structure and composition of natural regeneration within logging gaps is influenced by the gap size. The recovery of logging gaps differs from the natural regeneration in undisturbed forest sites.

(3) The natural regeneration within logging gaps differs between chainsaw milling and conventional logging due to divergent average gap size of both logging practices.

4. THE STUDY SITE

This study was conducted in the Nkrabia forest reserve (N 05°58´00´´, W 001°31´00´´) situated in the High Forest zone of south-western Ghana. The Nkrabia forest reserve is located within the Bekwai forest district of the Ashanti region approximately 80 kilometers south of the regional capital Kumasi. The gross area of the forest reserve amounts to 10.030 hectares. Timber production forest covers an area of 9.606 hectares, while 485 hectares are assigned for protection purpose and 39 hectares serve as farmland (Nuys & Wijers, 1992). The Nkrabia forest reserve was designated in 1940 under the local authority (Ashanti) Rule No. 15.

The reserve area is gently undulating to hilly mostly at an elevation range between 120 and 150 meters above sea level (Nuys & Wijers, 1992). The mean annual precipitation lies between 1.500 and 1.750 mm distributed over two wet and two dry periods a year. The main wet period occurs between March and July. This period is followed by a short dry season between August and September. The minor wet period begins mid of September and peaks at the end of October or early November. The major dry period lasts from November until early March. The mean annual temperature is 26°C (Climate Chart-Kumasi, 2007). The soils in the Nkrabia forest reserve fall into the major soil group of the Ochrosol-oxysol intergrades (Nuys & Wijers, 1992) and are classified as Ferric Acrisols and Ferric Lixisols (FAO, 2007a).

4.1 FOREST FEATURES

The Nkrabia forest reserve lies within the transition zone between the Moist Evergreen and the south-eastern subtype of the Moist Semi-deciduous forest formation in Ghana (Hawthorne & Abu-Juam, 1995). As it is typical for the Moist Semi-deciduous forest formation the stand is vertically subdivided into three distinct stories. The upper layer is presented by scattered emergent trees with a height of up to 50 meters. The middle story is open while the lower story is rather closed (Nuys & Wijers, 1992). The Nkrabia forest reserve features a good overall stand structure regarding stem density and basal area compared to other forest reserves in Ghana (GFIP, 1989). Although the good forest structure dominates the reserve area, it has previously been classified as slightly degraded (Hawthorne & Abu-Juam, 1995). The biodiversity of tree species is fairly low compared to other forest reserves of the same vegetation type (Nuys & Wijers, 1992). Typical dominant tree species of the Nkrabia forest reserve are *Celtis mildbraedii* Engl., *Petersianthus macrocarpus* (P.Beauv.)Liben and *Triplochiton scleroxylon* K. Schum which are common species throughout the High Forest zone in Ghana (Hall & Swaine, 1981; FAO, 2007b).

4.2 LOGGING ACTIVITIES

The Nkrabia forest reserve is formally managed under the Timber Utilization Contract [TUC] of the timber processing company "Logs and Lumber Limited" [LLL] since 1998. Previous to the TUC of LLL the Nkrabia forest reserve had been exploited over two cutting cycles (1958-1971 and 1972-1996) and has entered the third cycle (1996-2035) with the take-over by LLL (De Vries, 2008). Besides the conventional logging of the formal concession holder, chainsaw milling is widespread in the Nkrabia forest reserve (De Vries, 2008). It is conducted by chainsaw operators of the fringe communities or by strangers with assistance of local people in connivance with members of the fringe communities (De Vries, 2008; Krediet, 2009).

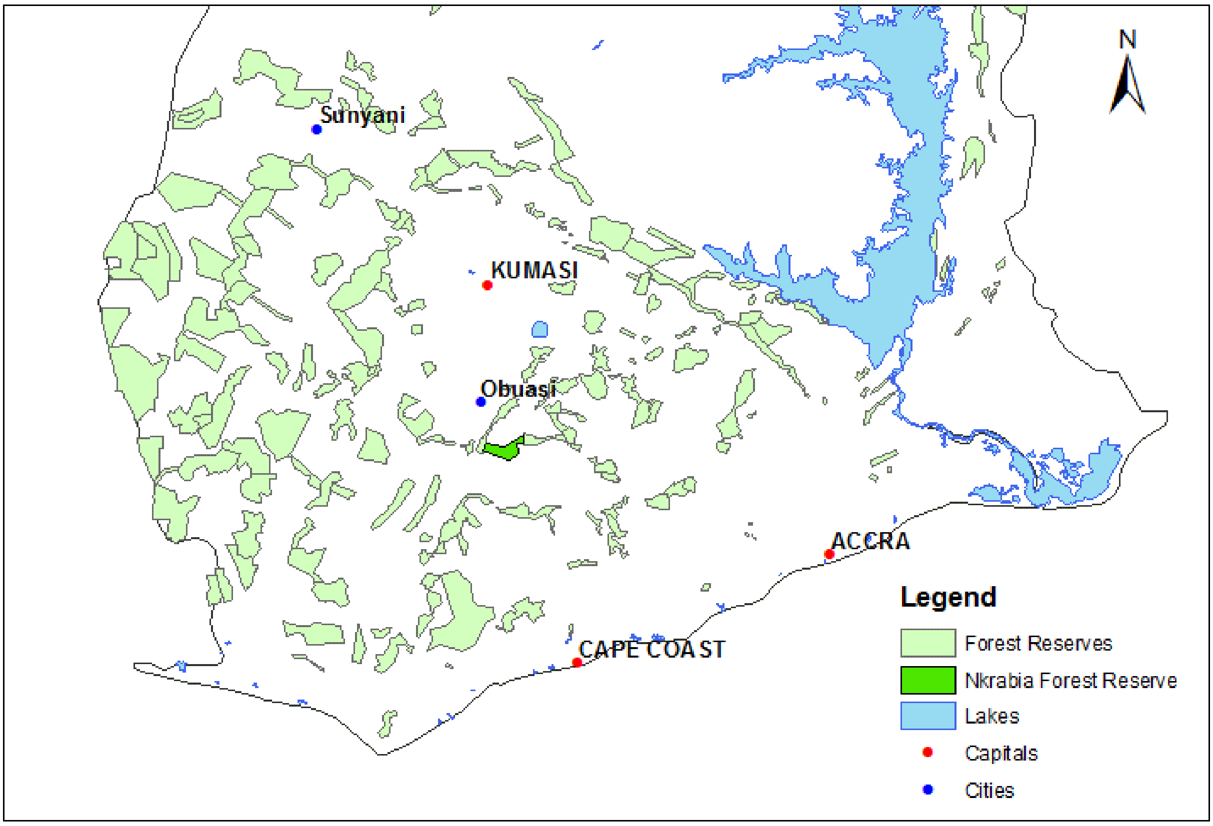


Figure 01: *Map of southern Ghana, location of the Nkrabia forest reserve [Scale 1 : 3.500.000]*

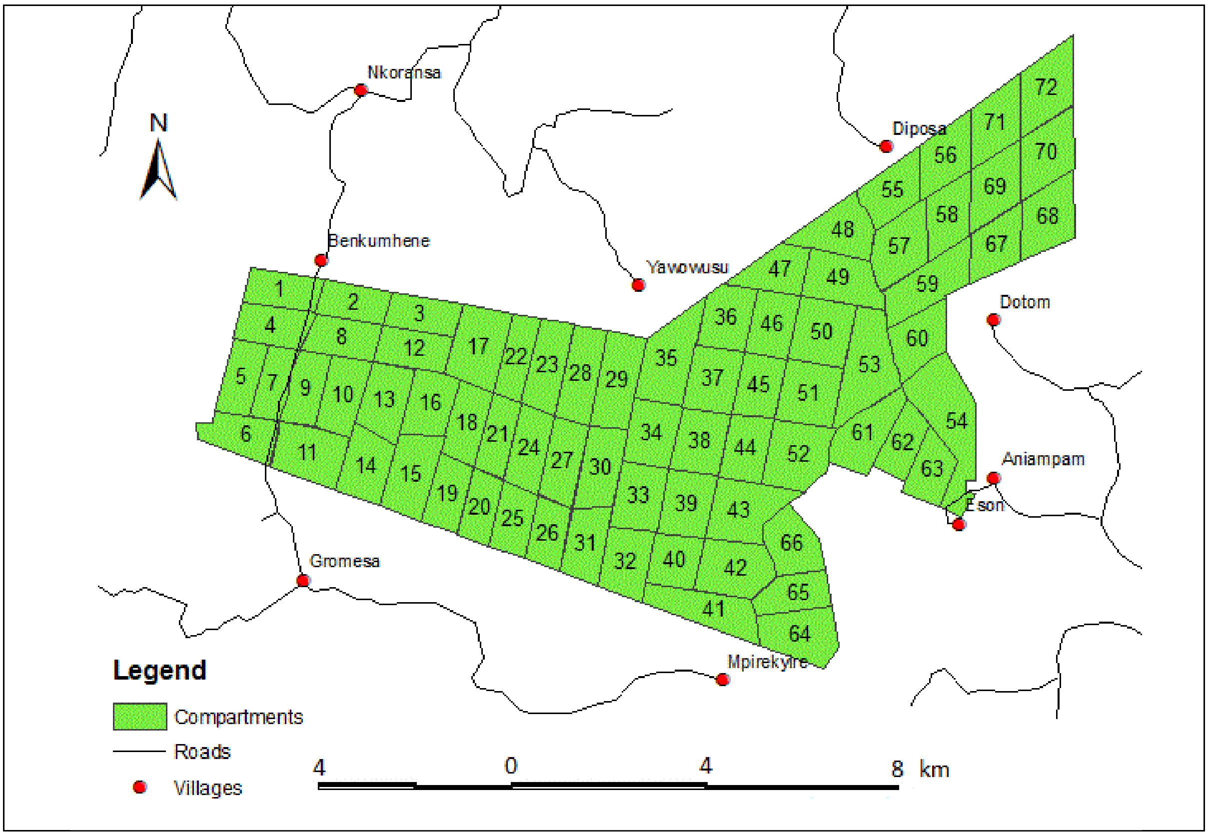


Figure 02: *Compartment map of the Nkrabia forest reserve [Scale 1 : 160.000]*

5. METHODOLOGY

5.1 SELECTION OF LOGGING GAPS

For this study a logging gap has been defined as a canopy gap created by the felling and on-site processing of a timber tree. The selection of gaps was conducted based on following criteria: (1) the applied logging practice and (2) the date of the logging operation. The logging gaps created by chainsaw milling [CM] were selected in Compartment 17 of the Nkrabia forest reserve. Logging gaps created by conventional logging [CL] were selected in Compartment 38. All considered logging gaps originate to beginning of the year 2008 and were approximately two years of age at the time of the data collection for this study [April/May, 2010].

The localization and age determination of logging gaps was conducted with the assistance of field staff of the Forestry Research Institute of Ghana [FORIG] with well-founded knowledge about legal and illegal logging activities in the Nkrabia forest reserve. The age of every logging gap was additionally controlled through the appraisal of the decay status of the stump and timber residues of the felled tree [Gap maker]. For the location of the selected logging gaps in Compartment 17 and 38, see Annex 05: Location of inventory spots, page 52.

Table 01: Selection and location of logging gaps

Logging practice	Gap age (years)	Amount	Location
Chainsaw milling [CM]	~ 2	20	Compartment 17
Conventional logging [CL]	~ 2	20	Compartment 38

5.2 SELECTION OF UNDISTURBED FOREST SITES

Locations that showed no sign of disturbance caused by recent logging operations were selected within the Nkrabia forest reserve. In total 20 inventory spots of undisturbed forest sites [US] were selected according to following criteria: (1) No recent logging activities in the visible surrounding of the location, (2) No natural tree fall of an entire dominant tree on the location. Canopy openings as a result of branch fall and broken crowns were accepted as natural forest disturbances, (3) No evidently deviant tree composition of the mature forest stand compared to the forest sites of the logging gap inventory, (4) Distance of approximately 100 meters between the defined locations of undisturbed forest sites. For the location of inventory spots in undisturbed forest sites, see Annex 05: Location of inventory spots, page 52.

5.3 ASSESSMENT OF GAP CHARACTERISTICS

The size of the logging gaps was defined and measured according to the method for the assessment of the expanded gap size by Runkle (1992). The area of the logging gap was delimited from the adjacent forest by the Gap border trees which were defined as the trees that surround the logging gap and have (1) a diameter breast height [DBH] of ≥ 20 cm and (2) a height of ≥ 20 meters. The gap center was defined as the location where the longest straight distance that fits into the logging gap [≙ the felling direction] and the longest distance that crosses the felling direction perpendicular coincide. From this defined center point the distance (m) and azimuth (°) to the Gap border trees was measured. For the definition of the gap center, see also Annex 09: Gap size assessment and definition of the gap center, page 65.

The location of each logging gap was recorded as GPS location point at the previously defined gap center with a *Garmin eTrex H* GPS-device. The distances within the logging gap were measured using the GPS-device. Control measurements were conducted with a forestry measuring tape (*Oregon Forestry Measuring Tape–Spencer*) at least once each logging gap and in cases of doubt of the GPS-device precision. The DBH (cm) of Gap border trees was measured using a forestry caliper. The height of Gap border trees was assessed through qualified estimation. Control Measurements were conducted once each logging gap with a *Suunto PM-5/1520* device for tree height measurement.

For every logging gap the Gap maker was identified and recorded. The DBH (cm) of the felled tree [Gap maker] was measured on timber residues at the stump site with the help of a measuring tape. Measurements were conducted at approximately former height of 1,30 m above ground for logs without buttresses. The DBH of buttressed trees was taken right above the end of the buttresses. The recorded DBH was always rounded down to the next whole number. The former tree height (m) was assessed with the help of the *Garmin* GPS-device as the distance from the tree stump to the top-end of the crown.

5.4 INVENTORY OF NATURAL REGENERATION

Within each selected logging gap [CM/CL] and defined spot of undisturbed forest site [US] the natural regeneration was recorded in two distinct categories: (1) Seedlings were defined as woody plants with a height < 100 cm. (2) Saplings were defined as woody plants with a height between ≥ 100 cm and ≤ 500 cm. In the seedling category all tree-, shrub- or large woody herb, liana- and small climber species were botanically identified and the number of individuals were counted for each species within the survey plot. In the sapling category all tree- and shrub species were botanically identified and the height (cm) was measured for all individuals that were located inside the survey plot. All stems that were rooted at the same place were counted as one individual. All shoots connected by a single runner were regarded as one individual. Individuals were considered as inside the plot if at least half of the stem basis was within the defined and demarcated survey plot area.

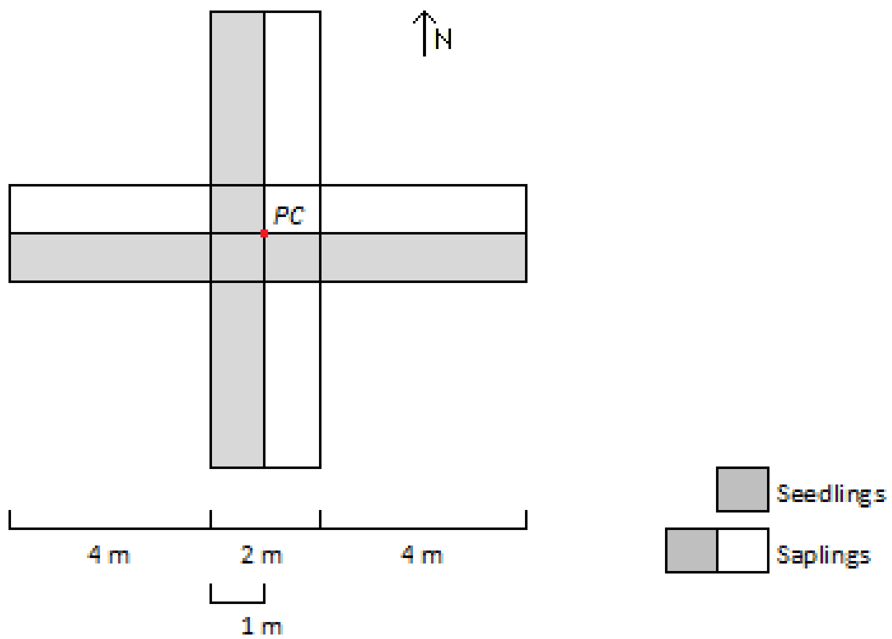
Table 02: Definition of the seedling and sapling category

(1) Category	Height range	Recorded growth forms
Seedlings	< 100 cm	trees
		shrubs- or large woody herbs
		lianas
		small climbers

(2) Category	Height range	Recorded growth forms
Saplings	≥ 100 cm / ≤ 500 cm	trees
		shrubs- or large woody herbs

The survey plots for the inventory of the natural regeneration were centered in logging gaps according to the defined gap center and in undisturbed forest sites according to the location of defined inventory spot. Saplings were recorded in two inventory strips with a length of 10 m and a width of 2 m that crossed perpendicular at the gap center [CM/CL] respectively at the location of defined inventory spot of undisturbed forest sites [US]. Seedlings were recorded in two inventory strips with a length of 10 m and a width of 1 m that crossed perpendicular and coincided with the western-, respectively southern half of the defined inventory strips for the sapling category.

The survey plot area each logging gap [CM/CL] and undisturbed forest site [US] was consequently 36 m² for the sapling category and 19 m² for the seedling category. Including all 40 assessed logging gaps [CM/CL] and the 20 defined spots in undisturbed forest sites a total surface area of 2.160 m² for the sapling category and 1.140 m² for the seedling category was inventoried in this study.



<u>Figure 03</u>: Survey plot design, for the inventory of natural regeneration [seedlings and saplings] within logging gaps [CM/CL] and undisturbed forest sites [US]. Plot center [PC] according to the defined gap center/defined inventory spot of undisturbed forest site

6. Data analysis

6.1 Calculation of gap size

According to the applied method for the gap size assessment (Runkle, 1992) every logging gap was defined by a variable number of triangles dependent on the number of Gap border trees. The location of two adjacent Gap border trees and the gap center defined a single triangle within the logging gap. For every triangle the side lengths (m) were recorded as the distances from the gap center to the adjacent Gap border trees. The enclosed angle (°) was calculated based on the recorded azimuth of the Gap border trees. Consequentially the surface area of a single triangle was calculated using the two following formulas:

(1) Law of Cosines:

$$\mathbf{b = \sqrt{(a^2 + c^2 - 2 * a * c * \cos \beta)}}$$

b = distance (m) between adjacent Gap border trees (1st & 2nd)

a = distance (m) from the gap centre to (1st) Gap border tree

c = distance (m) from the gap centre to (2nd) Gap border tree

β = enclosed angle (°) based on the recorded azimuth

(2) Formula of Heron:

$$\mathbf{A = \sqrt{(s * (s - a) * (s - b) * (s - c))}}$$

A = triangle surface area (m^2)

s = (a + b + c)/2

The surface areas of all single triangles in one logging gap were added up clockwise to gain the total surface area [gap size] of the logging gap (m^2). This calculation was conducted for all selected logging gaps in this study. For the underlying layout of the gap size calculation, see Annex 09: Gap size assessment and definition of the gap center, page 65.

6.2 Classification of logging gaps

Basically all selected logging gaps were classified with respect to the applied logging practice, namely chainsaw milling [CM] and conventional logging [CL]. This classification was *a priori* independent from the size of the logging gap. Regardless of logging practice, all logging gaps were additionally classified according to Broadbent (2005) into three gap size classes: (1) Small size gaps werde defined as gaps with an area ≤ 400 m^2. (2) Medium size gaps were defined as gaps with an area between 400 and 800 m^2. (3) Large size gaps were defined as gaps with an area ≥ 800 m^2. All together with the inventory spots in undisturbed forest sites [US] there have thus been set up four distinct inventory units in this study. The defined gap size classes are part of the inventory units.

Table 03: Definition of the inventory units

No.	Inventory unit	Gap size	Logging practice
1	Small gap size	≤ 400 m^2	CM and CL
2	Medium gap size	> 400/< 800 m^2	CM and CL
3	Large gap size	≥ 800 m^2	CM and CL
4	Undisturbed site	-	-

6.3 CLASSIFICATION OF NATURAL REGENERATION

6.3.1 SUCCESSIONAL CLASSES

All recorded seedlings and saplings were classified according to Hawthorne (1993) into three distinct classes that express the light requirements for regeneration and growth of each species: (1) Shade-bearers, (2) Pioneers and (3) Non-pioneer Light-demanders (Hawthorne, 1993). Species that were not pre-classified in Hawthorne (1993) were substituted into this classification system corresponding to the particular species description in Hall & Swaine (1981). Based on that information 100 % of the species in the sapling category and 90,2 % of the species in the seedling category could be classified into successional classes with respect to their light requirements. The species in the seedling category that could not be related to the defined classes only amount for 3,73 % of the total stem density and therefore can be assumed to be of marginal effect for the further data evaluation. For the classification of recorded species, see Annex 07: Species list and classification, page 55.

6.3.2 GROWTH FORM CLASSES

All recorded seedlings and saplings were classified according to Hawthorne (1993) into four distinct growth form classes that describe the particular botanical habit of each species: (1) trees, (2) shrubs- or large woody herbs, (3) lianas and (4) small climbers (Hawthorne, 1993). Species that were not pre-classified in Hawthorne (1993) were substituted into this classification system conforming to the particular species description in Hall & Swaine (1981). Based on that information 100 % of the species in the seedling and sapling category could be classified into growth form classes. For the classification of recorded species, see Annex 07: Species list and classification, page 55.

6.3.3 COMMERCIAL CLASSES

All recorded seedlings and saplings were classified according to their relevance as commercial timber species in Ghana. The Ghanaian Timber Classification System identifies all timber trees as economically relevant [Commercial Class I] that "have been exported from Ghana at least once during the period 1973–1988, including all the main economic species plus some lesser-known species being actively promoted for export" (FAO, 1995). Timber species of Commercial Class II and III have so far not been exported from Ghana and are only of local interest or generally not suitable for timber production (FAO, 1995). Those species have been classified as non-commercial species in this study. For the classification of recorded species, see Annex 07: Species list and classification, page 55.

6.3.4 *STAR CATEGORIES*

All recorded seedlings and saplings were classified into the "Star categories of conservation priority for species in Ghana" (Hawthorne & Abu-Juam, 1995) updated according to Hawthorne & Gyakari (2006) with focus on the Red- and Scarlet Star species separated from the Pink Star species to emphasize timber species that are (1) common but under pressure from exploitation [Red Star species] and (2) common but under serious pressure from heavy exploitation [Scarlet Star species] (Hawthorne & Abu-Juam, 1995). Red- and Scarlet Star species are not generally rare in Ghana but of special protection and management concern as they are commodities of high financial value and form an important item of the global timber market (Hawthorne & Abu-Juam, 1995). Therefore, Red- and Scarlet Star species are also named "High Priority" species in this study. All Red- and Scarlet Star species in Ghana additionally belong to Commercial Class I. For the classification of recorded species, see Annex 07: Species list and classification, page 55.

6.4 STATISTICAL ANALYSIS

The statistical analysis for the gap characteristics [Gap size/DBH of Gap maker] between the different gap size classes respectively the different logging practices was executed with the two-sample *F-test* for variances followed by the two-tailed *t-test* for equal variances respectively for unequal variances [M=mean; SD=standard deviation and N=number] with a significance level of $p \leq 0,05$ [critical p-value].

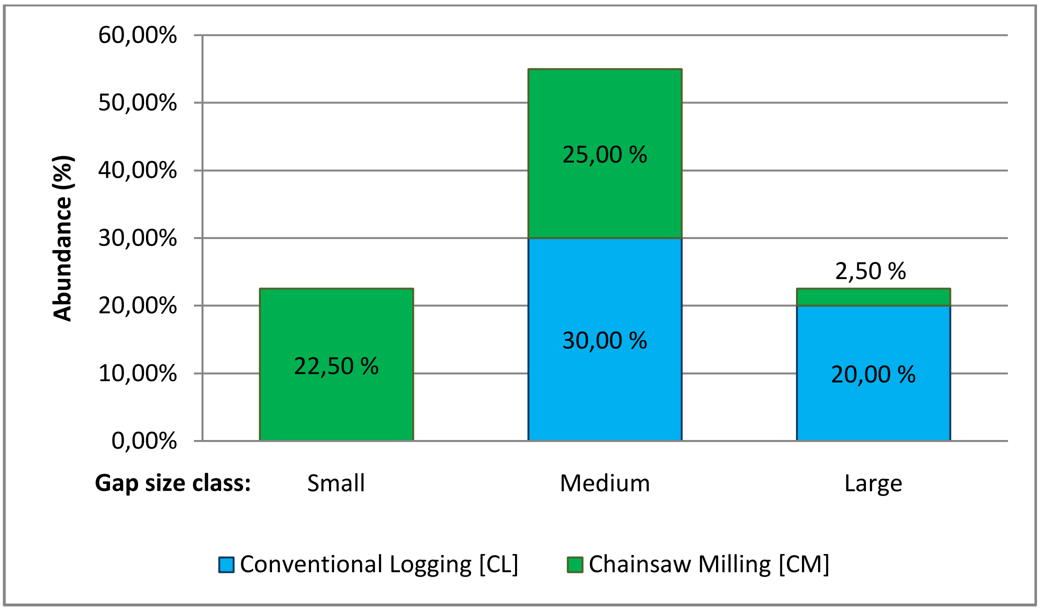
The statistical analysis for the collected data of the natural regeneration in logging gaps [CM/CL] and undisturbed forest sites [US] was conducted separately for the seedling- and sapling category. The variance of abundance between the classes in each inventory unit [Undisturbed site, small gap size, medium gap size and large gap size] was tested with the two-way *ANOVA* without replication for all previously defined classes [Successional classes, growth form classes, commercial classes and star categories] with a significance level of $p \leq 0,05$ [critical p-value]. Differences in abundance within the defined classes of natural regeneration between the different inventory units were tested with a two-sample *F-test* for variances followed by a two-tailed *t-test* for equal variances respectively for unequal variances [M=mean; SD=standard deviation and N=number] with a significance level of $p \leq 0,05$ [critical p-value].

7. Results

7.1 Gap characteristics

7.1.1 Gap size

In total 40 logging gaps were measured in this study. 20 of those gaps were created by chainsaw milling [CM] and 20 gaps emerged from conventional logging operations [CL]. The calculated gap size ranged between 197 m^2 and 1.504 m^2 over all assessed logging gaps with a mean gap size of 612,99 m^2. According to the classification into different gap size classes, 9 gaps (22,5 %) were classified as small size gaps, 22 gaps (55,0 %) were classified as medium size gaps and 9 gaps (22,5 %) were classified as large size gaps. Logging gaps created by chainsaw milling mainly ranged in the small- to medium gap size class, while the gaps created by conventional logging were limited to the medium- and large gap size class. For the detailed list of all assessed logging gaps, see Annex 02: Characteristics of logging gaps, page 49.



<u>Figure 04</u>: Abundance of gap size classes. Abundance of logging gaps over the different gap size classes [Small: ≤ 400 m^2, Medium: 400-800 m^2, Large: ≥ 800 m^2]. The fractions of chainsaw milling and conventional logging are illustrated in different colours

With respect to logging practice, the mean size of gaps created by chainsaw milling (M=456,96 SD=228,03 N=20) was significantly smaller than the mean size of logging gaps created by conventional logging operations (M=769,02 SD=258,63 N=20) using the two-tailed *t-test* for equal variances with $t(38)=-4{,}05$ and a significance level of $p \leq 0{,}05$. For the detailed list of all assessed logging gaps, see Annex 02: Characteristics of logging gaps, page 49.

<u>Table 04</u>: Mean gap size of different logging practices

Logging practice	Mean gap size (m^2)	SD (m^2)	N
Chainsaw milling [CM]	456,96	228,03	20
Conventional logging [CL]	769,02	258,63	20

7.1.2 GAP BORDER TREES

Over all assessed logging gaps, 625 Gap border trees had been recorded which were distributed over 94 different species. The most abundant species were *Celtis mildbraedii* Engl. (29,12 %), *Nesogordonia papaverifera* (A.Chev.)R.Capuron (3,52 %) and *Dacryodes klaineana* (Pierre)H.J.Lam (3,52 %). Out of the total number of Gap border trees, 59,4 % belonged to Commercial Class I while 36,3 % were classified as Red Star- respectively 8,7 % as Scarlet Star species. For further information about the abundance of Gap border tree species, see Annex 06: Species list of Gap border trees, page 53.

7.1.3 GAP MAKERS

In total 40 Gap makers [felled trees] were identified and recorded in this study. All Gap makers belonged to Commercial Class I with 40 % of them classified as Scarlet-, 17,5 % as Red- and 42,5 % as Pink Star species. All assessed logging gaps were created by single tree fall.

The diameter breast height [DBH] of Gap makers ranged between 45 cm and 161 cm with a mean size of 93,9 cm. Nearly 75 % of the trees that had been logged by chainsaw milling were below the species specific cutting limit which is binding for conventional logging operations in Ghana. The mean DBH of Gap makers was significantly lower in the small gap size- (M=65,44 SD=15,29 N=9) compared to the medium- (M=96,73 SD=22,06 N=22) and large gap size class (M=115,33 SD=29,42 N=9) using the two-tailed *t-test* for equal variances with $t(29)=-3,87$ and $p \leq 0,05$ respectively the two-tailed *t-test* for unequal variances with $t(12)=-4,51$, $p \leq 0,05$. The difference of the mean DBH between medium- and large size gaps was not significant using the *t-test* for equal variances with a significance level of $p \leq 0,05$.

Table 05: Mean DBH of Gap makers per gap size class

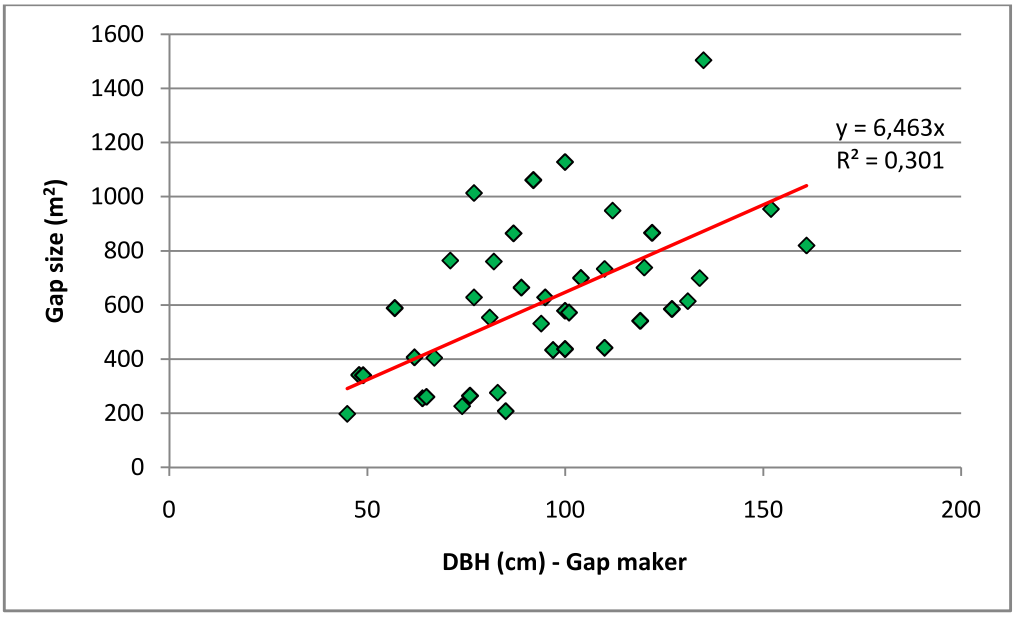
Gap size class	Mean DBH (cm)	SD (cm)	N
Small gap size	65,44	15,29	9
Medium gap size	96,73	22,06	22
Large gap size	115,33	29,42	9

With respect to logging practice, the mean DBH of trees that had been felled by chainsaw milling (M=78,55 SD=21,25 N=20) was significantly smaller than the mean DBH of trees that had been logged by conventional operations (M=109,2 SD=25,79 N=20) with $t(38)=-4,10$ and $p \leq 0,05$. For the list of gap makers, see Annex 02: Characteristics of logging gaps, page 49.

Table 06: Mean DBH of Gap makers per logging practice

Logging practice	Mean DBH (cm)	SD (cm)	N
Chainsaw milling [CM]	78,55	21,25	20
Conventional logging [CL]	109,20	25,79	20

The size of logging gaps increased with ascending DBH of the Gap maker [felled tree]. There was a correlation between logging gap size (m^2) and DBH (cm) of Gap makers with a *Pearson´s Coefficient* of correlation r = 0,56 and a linear regression with the formula y = 6,463 x that showed a coefficient of determination R^2 = 0,301.



<u>Figure 05</u>: Correlation between diameter breast height (cm) of the Gap maker and the created gap size (m^2). The red line represents the linear regression between DBH and gap size, with the formula: y = 6,463 x, with the coefficient of determination R^2 = 0,301

7.2 SPECIES COMPOSITION AND STAND STRUCTURE OF NATURAL REGENERATION

7.2.1 *SPECIES COMPOSITION*

In this study, 207 different species of trees, shrubs- or large woody herbs, lianas and small climbers that belonged to 60 different families had been recorded in the sapling- and seedling category within the survey plots in logging gaps [CM/CL] and undisturbed forest sites [US]. The families with the greatest species richness were *Malvaceae* (15 species), *Apocynaceae* (13 species), *Euphorbiaceae* (12 species) and *Meliaceae* (10 species). Only one recorded species, namely the Avocado *Persea americana* Mill. was an exotic. In the seedling category 172 different species were identified, of which 113 species were classified as trees and shrubs- or large woody herbs. In the sapling category 111 different species were recorded. In total 78 of the tree and shrub- or large woody herb species (69 %) that had been inventoried in the seedling category were also present in the sapling category. For the complete list of recorded species, see Annex 07: Species list and classification, page 55.

Table 07: Most abundant tree spp. in the sapling category, over all inventory units

Species	Abundance (%)	Stem density (stems/ha)
Baphia nitida	16,39	773,2
Strombosia glaucescens	9,32	439,8
Microdesmis puberula	7,95	375,0

Table 08: Most abundant tree spp. in the seedling category, over all inventory units

Species	Abundance (%)	Stem density (stems/ha)
Celtis mildbraedii	10,66	3.035,1
Baphia nitida	2,99	850,9
Bussea occidentalis	1,85	526,3

Table 09: Most abundant shrub-/large woody herb spp. in the seedling category, over all inventory units

Species	Abundance (%)	Stem density (stems/ha)
Sphenocentrum jollyanum	2,87	815,8
Culcasia striolata	2,65	754,4
Dracaena ovata	1,26	359,7

Table 10: Most abundant liana spp. in the seedling category, over all inventory units

Species	Abundance (%)	Stem density (stems/ha)
Griffonia simplicifolia	17,60	5.008,8
Acacia kamerunensis	3,91	1.114,0
Calycobolus africanus	3,39	964,9

Table 11: Most abundant small climber spp. in the seedling category, over all inventory units

Species	Abundance (%)	Stem density (stems/ha)
Chlamydocarya macrocarpa	3,91	1.114,0
Smilax kraussiana	1,63	464,9
Baissea baillonii	1,48	421,1

The highest frequency in the sapling category over all survey plots was found for *Baphia nitida* Lodd. (82 %), *Microdesmis puberula* J.Léonard (67 %) and *Celtis mildbraedii* Engl. (57 %). In the seedling category, the highest frequency was presented by the climbing plants *Calycobolus africanus* (G.Don)Heine (92 %), *Griffonia simplicifolia* (Vahl ex DC.)Baill. (90 %) and *Chlamydocarya macrocarpa* A.Chev. ex Hutch.&Dalziel (87%). The tree species with the highest frequency in the seedling category was *Celtis mildbraedii* Engl. which occurred in 80 % of all survey plots. For a brief description of the most important species that have been recorded in this study, see Annex 01: Species description, page 44.

Among the 207 different species that had been totally inventoried in the seedling and sapling category, 99 species (48 %) were rare with 2 to 10 recorded individuals and 41 species (20 %) were very rare with only one recorded individual. The overall heterogeneity of the natural regeneration is illustrated by the frequency table [see below, Figure 06]. The major share of species in the seedling and the sapling category showed a total frequency over all survey plots of only 1 to 20 %. Only 28 species in the seedling category and 11 species in the sapling category occurred in over 20 % of the survey plots. For more details about species frequency and abundance, see Annex 08: Species abundance and frequency, page 60.

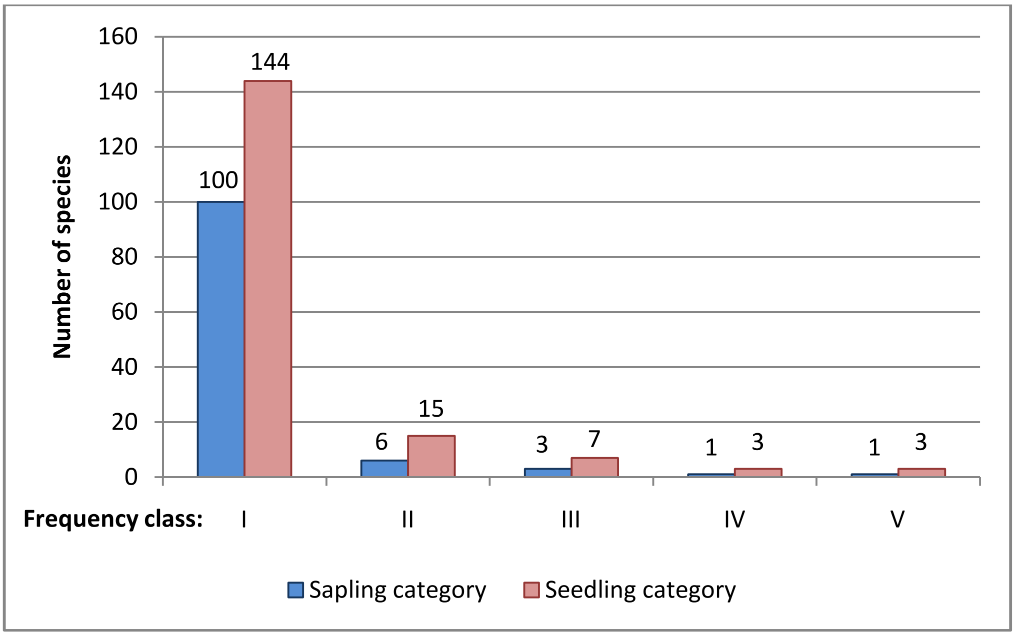


Figure 06: Species frequency table of the seedling and sapling category. The bars represent the number of species that occurred in each frequency class. Frequency classes: I to V [definition see below, Table 12: Definition of frequency classes]

Table 12: Definition of frequency classes

Frequency class	Lower limit (%)	Upper limit (%)
I	≥ 1	≤ 20
II	> 20	≤ 40
III	> 40	≤ 60
IV	> 60	≤ 80
V	> 80	≤ 100

7.2.2 *Stem density*

The average stem density of the natural regeneration in the sapling category [trees, shrubs- or large woody herbs] was 4.717,6 stems/ha over all inventory units. The average stem density in the seedling category [trees, shrubs- or large woody herbs, lianas and small climbers] was 28.464,9 stems/ha over all inventory units. Trees and shrub- or large woody herbs accounted for 13.394,7 stems/ha of the total stem density in the seedling category.

In the sapling category there were no significant differences in the stem density of the natural regeneration between the different inventory units, using the two-tailed *t-test* for equal variances with a significance level of $p \leq 0{,}05$.

Table 13: Stem density per inventory unit - sapling category

Inventory unit	Mean (stems/ha)	SD (stems/ha)	N
Small gap size	5.493,8	2.522,2	9
Medium gap size	4.419,2	2.285,7	22
Large gap size	4.012,3	1.483,7	9
Undisturbed site	5.013,9	1.605,8	20

In the seedling category there was a significant difference in the stem density of regeneration between the medium gap size (M=21.674,6 SD=9.655,2 N=22) and small gap size (M=30.350,9 SD=9.466,4 N=9) respectively undisturbed sites (M=36.500,0 SD=15.337,3 N=20) using the two-tailed *t-test* for equal and unequal variances, with $t(29)=-2{,}28$ and $t(40)=-3{,}79$, $p \leq 0{,}05$.

Table 14: Stem density per inventory unit - seedling category

Inventory unit	Mean (stems/ha)	SD (stems/ha)	N
Small gap size	30.350,9	9.466,4	9
Medium gap size	21.674,6	9.655,2	22
Large gap size	25.321,6	23.735,9	9
Undisturbed site	36.500,0	15.337,3	20

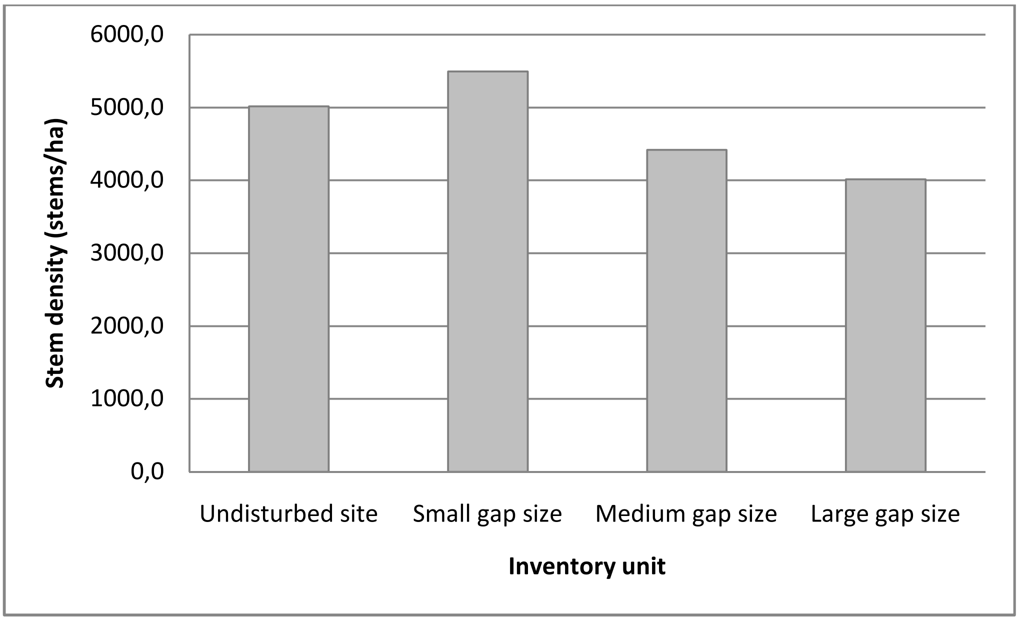
With respect to logging practice there was no significant difference in the stem density of natural regeneration between gaps created by chainsaw milling and conventional logging both for the seedling- and sapling category using the two-tailed *t-test* for equal respectively unequal variances, with a significance level of $p \leq 0{,}05$.

Table 15: Stem density per logging practice - sapling category

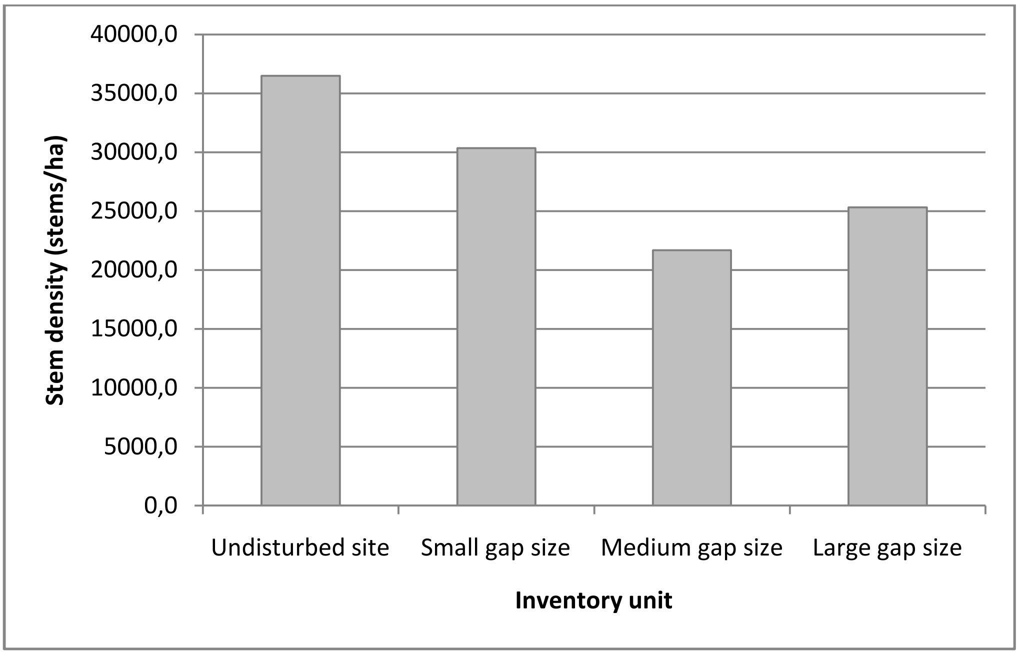
Logging practice	Mean (stems/ha)	SD (stems/ha)	N
Chainsaw milling [CM]	4.791,7	2.368,8	20
Conventional logging [CL]	4.347,2	2.059,6	20

Table 16: Stem density per logging practice - seedling category

Logging practice	Mean (stems/ha)	SD (stems/ha)	N
Chainsaw milling [CM]	29.921,0	16.908,9	20
Conventional logging [CL]	18.973,7	7.400,9	20



<u>Figure 07</u>: Stem density per inventory unit - sapling category. Stem density: stems/ha. Inventory units: [Undisturbed site, Small gap size: ≤ 400 m^2, Medium gap size: 400-800 m^2, Large gap size: ≥ 800 m^2]



<u>Figure 08</u>: Stem density per inventory unit - seedling category. Stem density: stems/ha. Inventory units: [Undisturbed site, Small gap size: ≤ 400 m^2, Medium gap size: 400-800 m^2, Large gap size: ≥ 800 m^2]

7.2.3 *HEIGHT CLASS DISTRIBUTION*

Classified into distinct height classes [definition: see below, Table 17], the natural regeneration in the sapling category showed a typical *reversed J-shaped* curve for the different inventory units except for the saplings in large sized logging gaps which were characterized by a noticeable drop in stem density within the lowest height class [Height class: I]. The saplings in undisturbed forest sites showed an higher average stem density in the height classes larger than 350 cm [Height class: VI, VII and VIII] compared to the regeneration within the other inventory units. The mean height of saplings consequently was highest in undisturbed forest sites (M=242,5 SD=107,4), followed by the large gap size (M=220,5 SD=85,6), small gap size (M=213,9 SD=89,7) and the medium gap size class (M=204,2 SD=79,1).

The differences in stem density between the inventory units within each height class were not significant using the two-tailed *t-test* for equal respectively unequal variances with $p \leq 0{,}05$.

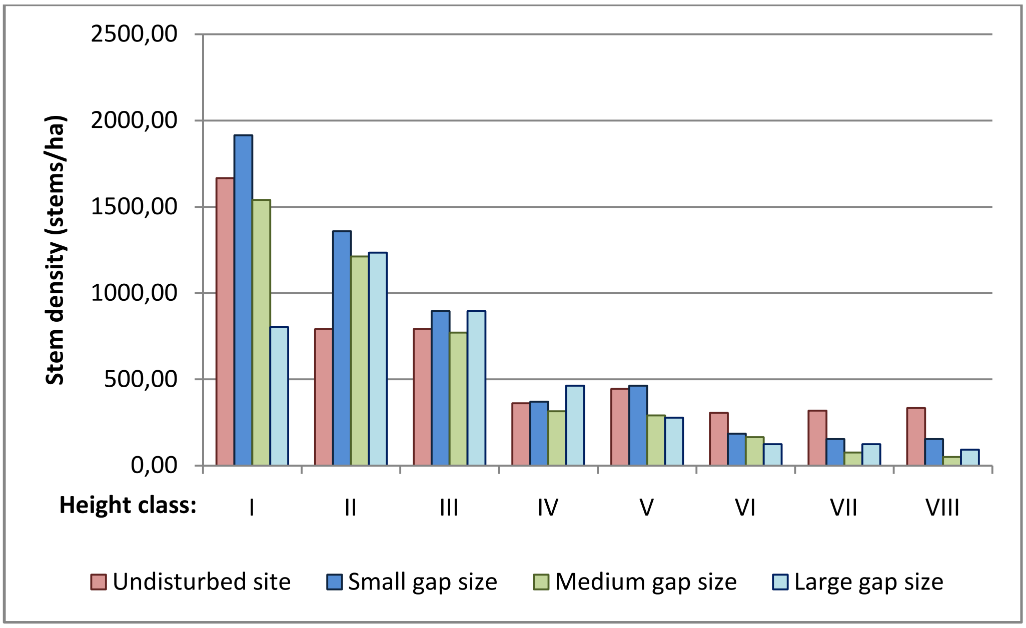


Figure 09: Stem density per height class - sapling category. The bars represent the stem density of the different inventory units over the defined height classes. Height classes: I to VIII [definition see below, Table 17: Definition of height classes]

Table 17: Definition of height classes

Height class	Lower limit (cm)	Upper limit (cm)
I	≥ 100	≤ 150
II	> 150	≤ 200
III	> 200	≤ 250
IV	> 250	≤ 300
V	> 300	≤ 350
VI	> 350	≤ 400
VII	> 400	≤ 450
VIII	> 450	≤ 500

7.3 REGENERATION OF SUCCESSIONAL CLASSES

According to the classification of the natural regeneration into successional classes, 91 species (43,96 %) were classified as Shade-bearers [SB], 54 species (26,09 %) as Non-pioneer Light-demanders [NPLD] and 45 species (21,74 %) as Pioneers [P]. Seventeen species (8,21 %) could not be assigned to one of the pre-defined classes or belonged to the class of Non-forest species [non] (Hawthorne, 1993).

In the sapling category over all inventory units, the most abundant successional class were the Shade-bearers (78,9 %, 3.722 stems/ha) followed by the Pioneers (12 %, 565 stems/ha) and Non-pioneer Light-demanders (9,1 %, 431 stems/ha). Over the different inventory units the abundance of Shade-bearers slightly decreased with ascending gap size class, having the highest mean abundance in undisturbed forest sites [US]. The abundance of Pioneers increased over the different inventory units with ascending gap size class, showing the highest abundance in the class of large sized logging gaps. The two-way *ANOVA* without replication showed a significant difference in abundance between the successional classes within each inventory unit with $p \leq 0,05$. There were significant differences in the abundance of the successional classes between different inventory units for Shade-bearers and Pioneers between undisturbed sites and the medium- respectively large gap size class, using the two-tailed *t-test* with a significance level of $p \leq 0,05$.

Table 18: Abundance of successional classes per inventory unit - sapling category

Successional class	US	Small gap size	Medium gap size	Large gap size
SB	85,6 %	79,7 %	74,6 %	70,8 %
NPLD	9,4 %	9,6 %	8,0 %	10,7 %
P	5,0 %	10,7 %	17,4 %	18,5 %
non	0,0 %	0,0 %	0,0 %	0,0 %

In the seedling category over all inventory units, the most abundant successional class were the Shade-bearers (51,5 %, 14.658 stems/ha) followed by the Non-pioneer Light-demanders (38,5 %, 10.956 stems/ha) and Pioneers (6,3 %, 1.790 stems/ha). The two-way *ANOVA* without replication showed a significant difference in the abundance between the successional classes within each inventory unit with $p \leq 0,05$. The abundance of Pioneers was significantly higher in the medium gap size compared to undisturbed sites [US] using the two-tailed *t-test* with $p \leq 0,05$. The abundance of Non-pioneer Light-demanders significantly differed between the inventory units except for undisturbed sites and the small gap size respectively medium- and large gap size class, using the two-tailed *t-test* with a significance level of $p \leq 0,05$.

Table 19: Abundance of successional classes per inventory unit - seedling category

Successional class	US	Small gap size	Medium gap size	Large gap size
SB	51,1 %	43,6 %	52,7 %	60,1 %
NPLD	40,5 %	49,7 %	33,9 %	27,7 %
P	4,4 %	5,2 %	8,8 %	8,3 %
non	4,0 %	1,5 %	4,6 %	3,9 %

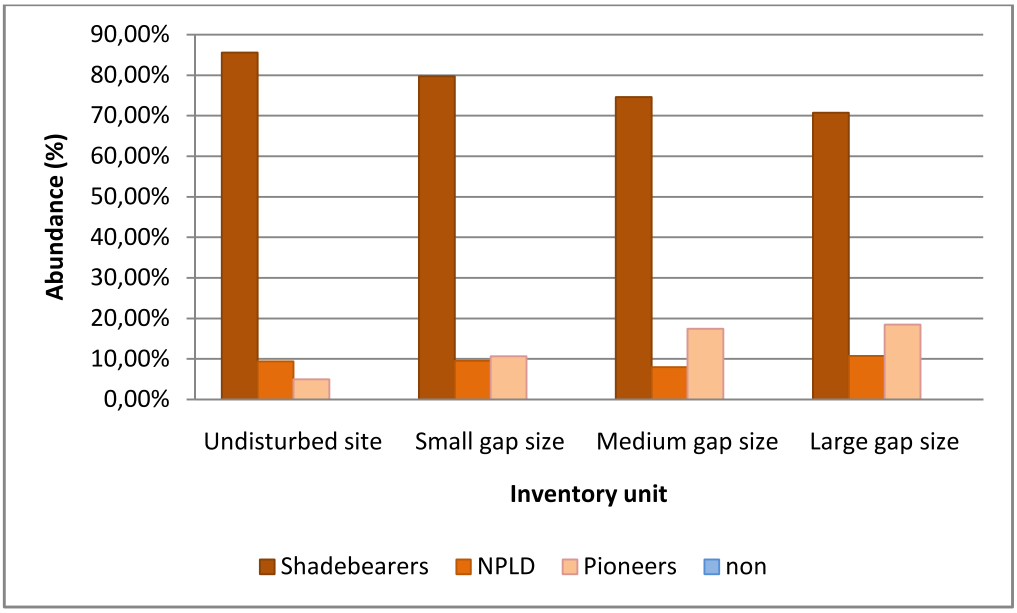


Figure 10: Abundance of successional classes per inventory unit - sapling category. Successional classes: [Shade-bearers, Non-pioneer Light-demanders, Pioneers]. Inventory units: [Undisturbed site, Small gap size: ≤ 400 m², Medium gap size: 400-800 m², Large gap size: ≥ 800 m²]

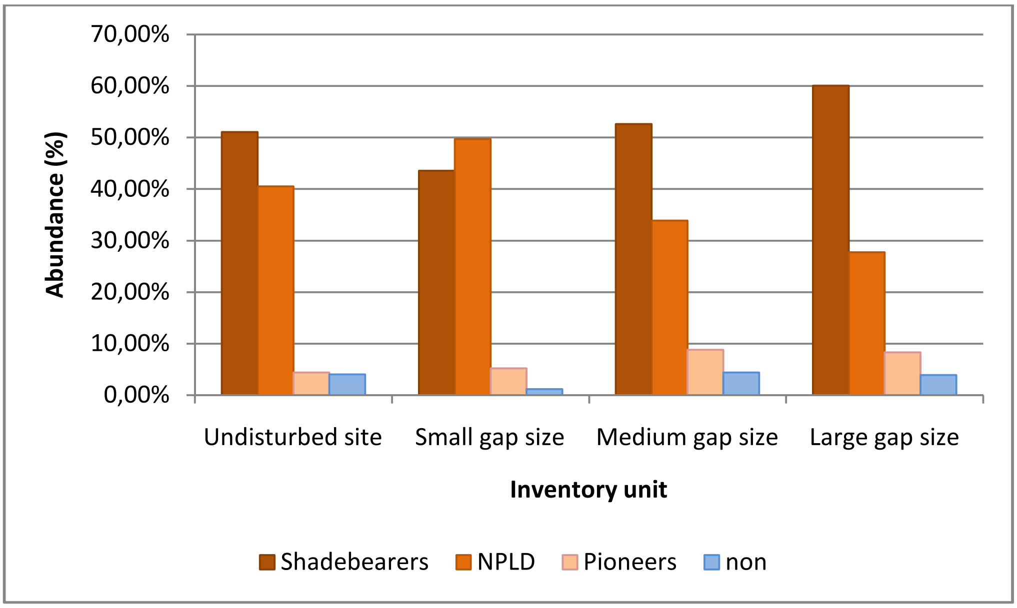


Figure 11: Abundance of successional classes per inventory unit - seedling category. Successional classes: [Shade-bearers, Non-pioneer Light-demanders, Pioneers]. Inventory units: [Undisturbed site, Small gap size: ≤ 400 m², Medium gap size: 400-800 m², Large gap size: ≥ 800 m²]

7.4 REGENERATION OF GROWTH FORM CLASSES

According to the classification of natural regeneration into different growth form classes, 93 species (54,1 %) were classified as trees [T], 20 species (11,6 %) were classified as shrubs- or large woody herbs [SH], 39 species (22,7 %) as lianas [L] and 20 species (11,6 %) belonged to the class of small climbers [SC]. As the natural regeneration of lianas and small climbers had only been recorded in the seedling category, the evaluation of successional classes was just conducted in this category of regeneration.

The most abundant growth form class in the seedling category over all inventory units was presented by the lianas (39,7 %, 11.325 stems/ha), followed by trees (35,9 %, 10.219 stems/ha), small climbers (13,2 %, 3.746 stems/ha) and shrubs- or large woody herbs (11,2 %, 3.175 stems/ha). The abundance of lianas decreased with ascending gap size class while the abundance of tree regeneration increased the same direction. The mean abundance of small climbers and shrubs- or large woody herbs was constantly low over all inventory units. The two-way *ANOVA* without replication showed a significant difference between the abundance of the different growth form classes within each inventory unit with $p \leq 0,05$. The two-tailed *t-test* showed a significant difference only for the abundance of lianas between the small- and large gap size class with a significance level of $p \leq 0,05$.

Table 20: Abundance of growth form classes per inventory unit - seedling category

Growth form class	US	Small gap size	Medium gap size	Large gap size
T	30,4 %	31,2 %	39,5 %	51,5 %
SH	15,3 %	7,9 %	8,5 %	7,4 %
L	40,6 %	49,3 %	37,6 %	30,3 %
SC	13,7 %	11,6 %	14,4 %	10,8 %

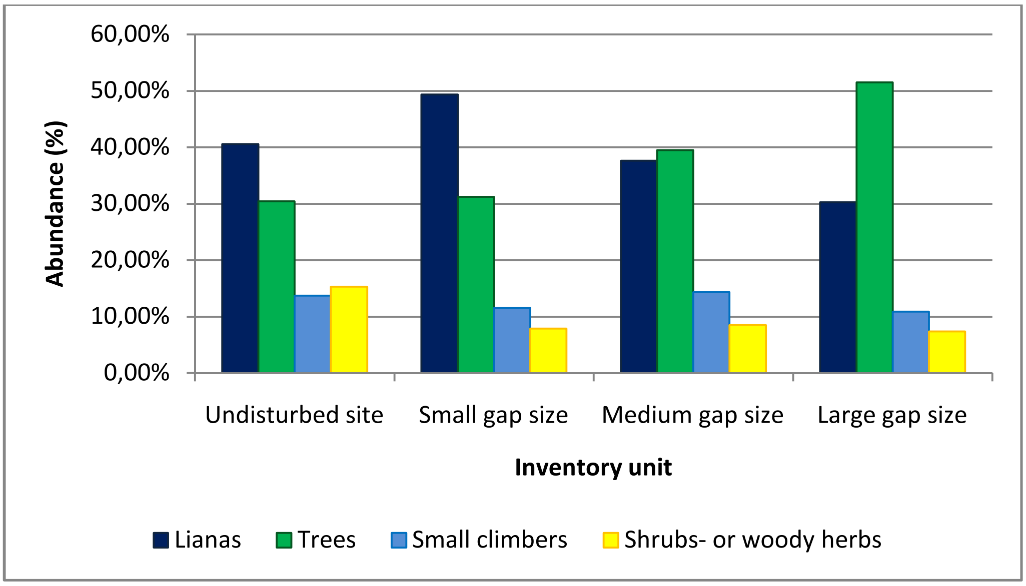


Figure 12: Abundance of growth form classes per inventory unit - seedling category. Growth form classes: [trees, shrubs- or large woody herbs, lianas and small climbers]. Inventory units: [Undisturbed site, Small gap size: ≤ 400 m², Medium gap size: 400-800 m², Large gap size: ≥ 800 m²]

7.5 REGENERATION OF COMMERCIAL CLASSES

According to the Ghanaian Timber Classification System, 30 species (14,5 %) of the natural regeneration were classified as Commercial Class I, which represented 32,3 % of the totally recorded tree species in this study. The group of Commercial Class I species showed an average abundance of 24,2 % (1.140 stems/ha) over all inventory units in the sapling category and 17,2 % (4.897 stems/ha) in the seedling category.

Table 21: Most abundant Commercial Class I spp. in the sapling category, over all inventory units

Species	Abundance (%)	Stem density (stems/ha)
Strombosia glaucescens	9,32	439,8
Celtis mildbraedii	6,38	300,9
Nesogordonia papaverifera	2,75	129,6

Table 22: Most abundant Commercial Class I spp. in the seedling category, over all inventory units

Species	Abundance (%)	Stem density (stems/ha)
Celtis mildbraedii	10,66	3.035,1
Strombosia glaucescens	1,51	429,8
Nesogordonia papaverifera	1,29	368,4

The abundance of Commercial Class I species in the sapling category straightly decreased with ascending gap size class, having the highest mean abundance in undisturbed forest sites. The two-way *ANOVA* without replication showed a significant difference between the abundance of Commercial Class I species and non-commercial species within each inventory unit with $p \leq 0,05$. The abundance of Commercial Class I species was significantly lower in the large gap size- and medium gap size class compared to the small gap size class and undisturbed forest sites [US] using the two-tailed *t-test* for equal respectively unequal variances with $p \leq 0,05$.

Table 23: Abundance of Commercial Class I per inventory unit - sapling category

Commercial Class	US	Small gap size	Medium gap size	Large gap size
Commercial Class I	30,5 %	26,9 %	20,3 %	15,4 %
non-commercial	69,5 %	73,1 %	79,7 %	84,6 %

In the seedling category the abundance of Commercial Class I species increased with ascending gap size class, showing the highest abundance in the large gap size class. The two-way *ANOVA* without replication showed a significant difference between the abundance of Commercial Class I species and non-commercial species within each inventory unit with $p \leq 0,05$. There were no significant differences in the abundance of Commercial Class I species between the different inventory units, using the two-tailed *t-test* with $p \leq 0,05$ although the mean abundance was markedly higher in the large gap size compared to the other inventory units.

Table 24: Abundance of Commercial Class I per inventory unit - seedling category

Commercial Class	US	Small gap size	Medium gap size	Large gap size
Commercial Class I	14,4 %	12,7 %	16,4 %	27,2 %
non-commercial	85,6 %	87,3 %	83,6 %	72,8 %

Figure 13: Abundance of Commercial Class I species per inventory unit - sapling category. Inventory units: [Undisturbed site, Small gap size: ≤ 400 m², Medium gap size: 400-800 m², Large gap size: ≥ 800 m²]

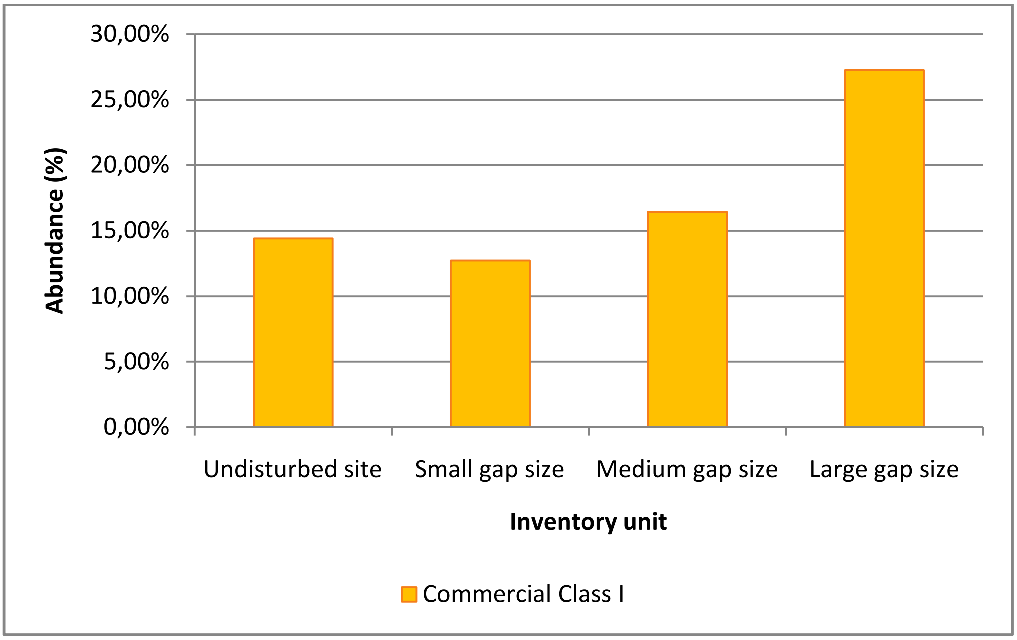


Figure 14: Abundance of Commercial Class I species per inventory unit - seedling category. Inventory units: [Undisturbed site, Small gap size: ≤ 400 m², Medium gap size: 400-800 m², Large gap size: ≥ 800 m²]

7.6 Regeneration of star categories

In presented study, 14 species (6,76 %) were classified as Pink Star species, 10 species (4,83 %) were classified as Red Star species and 9 species (4,35 %) were classified as Scarlet Star species. In total 100 % of the Red- and Scarlet Star species [High Priority species] and 57 % of the Pink Star species belonged to Commercial Class I. In addition, 29 % of the Pink Star species were classified as Commercial Class II. Over all inventory units, Red Star species represented 3,04 % (143 stems/ha) of the recorded plants in the sapling category and 1,05 % (299 stems/ha) in the seedling category. Scarlet Star species occurred with an abundance of 1,18 % (56 stems/ha) in the sapling- and 0,99 % (281 stems/ha) in the seedling category.

Table 25: Most abundant Red Star spp. in the sapling category, over all inventory units

Species	Abundance (%)	Stem density (stems/ha)
Guarea cedrata	0,88	41,7
Ceiba pentandra	0,69	32,4
Antiaris toxicaria	0,59	27,8

Table 26: Most abundant Red Star spp. in the seedling category, over all inventory units

Species	Abundance (%)	Stem density (stems/ha)
Guarea cedrata	0,37	105,3
Ceiba pentandra	0,18	52,6
Antiaris toxicaria	0,15	43,9

Table 27: Most abundant Scarlet Star spp. in the sapling category, over all inventory units

Species	Abundance (%)	Stem density (stems/ha)
Pterygota macrocarpa	0,39	18,5
Aningeria altissima	0,20	9,3
Triplochiton scleroxylon	0,20	9,3

Table 28: Most abundant Scarlet Star spp. in the seedling category, over all inventory units

Species	Abundance (%)	Stem density (stems/ha)
Entandophragma angolense	0,31	87,7
Guibourtia ehie	0,31	87,7
Aningeria altissima	0,18	52,6

In the sapling category, premium timber species like *Entandophragma angolense* (Welw.)DC., *Khaya ivorensis* A.Chev. and *Milicia excelsa* (Welw.)C.C.Berg were very rare with only one individual for each of those species recorded within all inventory plots (0,1 %, 4,6 stems/ha). For the Red- and Scarlet Star species there was no obvious trend for the abundance in relation to the different inventory units. In general, Scarlet Star species were scarce in the medium- and large gap size class. Red Star species showed their highest abundance in the small- to medium gap size class. There was no significant difference between Red- and Scarlet Star species within each inventory unit, using the two-way *ANOVA* without replication with $p \leq 0,05$. The two-tailed *t-test* showed no significanct differences for the abundance of Red- and Scarlet Star species between the different inventory units, using a significance level of $p \leq 0,05$.

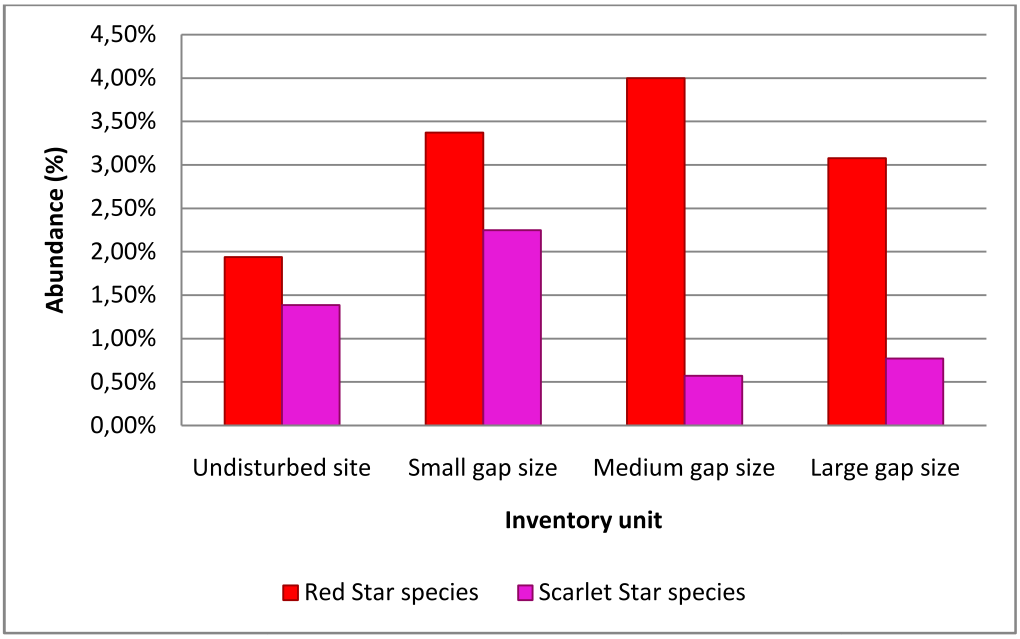
Table 29: Abundance of High Priority species per inventory unit - sapling category

Star category	US	Small gap size	Medium gap size	Large gap size
Red Star	1,94 %	3,37 %	4,00 %	3,08 %
Scarlet Star	1,39 %	2,25 %	0,57 %	0,77 %

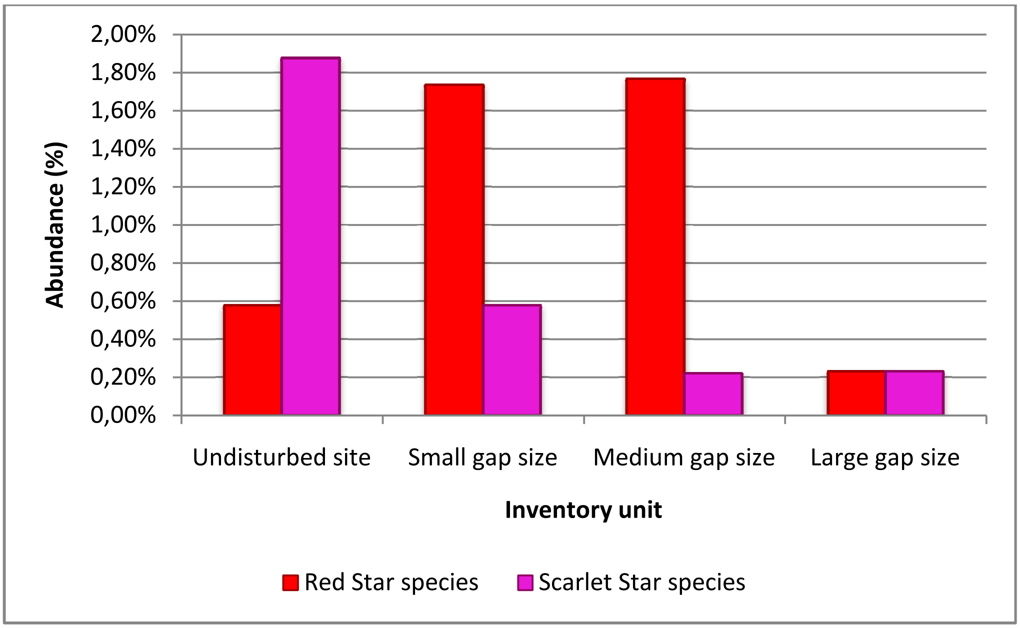
In the seedling category, premium timber species like *Khaya ivorensis* A.Chev. and *Milicia excelsa* (Welw.)C.C.Berg, were very rare with only one recorded individual for each of those species within all inventory plots (0,03 %, 8,8 stems/ha). Over the different inventory units the abundance of Scarlet Star species decreased with ascending gap size class. The abundance of those species was very low in medium- and large sized logging gaps. Red Star species showed their highest abundance in the small- and medium gap size class. There was no significant difference in the abundance of Red- and Scarlet Star species within each inventory unit, using the two-way *ANOVA* without replication with $p \leq 0,05$. The two-tailed *t-test* for equal respectively unequal variances of Scarlet- and Red Star species between the different inventory units showed a significant difference for the abundance of Red Star species between undisturbed forest sites and the small gap size class, as well as between the large gap size class and medium- respectively small sized gaps with a significance level of $p \leq 0,05$.

Table 30: Abundance of High Priority species per inventory unit - seedling category

Star category	US	Small gap size	Medium gap size	Large gap size
Red Star	0,58 %	1,73 %	1,77 %	0,23 %
Scarlet Star	1,87 %	0,58 %	0,22 %	0,23 %



<u>Figure 15</u>: Abundance of High Priority species per inventory unit - sapling category. Inventory units: [Undisturbed site, Small gap size: ≤ 400 m², Medium gap size: 400-800 m², Large gap size: ≥ 800 m²]



<u>Figure 16</u>: Abundance of High Priority species per inventory unit - seedling category. Inventory units: [Undisturbed site, Small gap size: ≤ 400 m², Medium gap size: 400-800 m², Large gap size: ≥ 800 m²]

8 DISCUSSION

8.1 GENERAL SCOPE OF THIS STUDY

The gap age that has been defined for the selection of logging gaps in this study presents a very initial phase of natural regeneration within logging gaps but involves about two complete periods of vegetation- and seed development after the point of gap creation. During this stage of recovery, the tree density is still increasing (Schnitzer et *al.*, 2000). The invasion of new species continues for over five years after the start of succession (Gómez-Pompa et *al.*, 1991) which had been initiated in this context with the felling and extraction of the timber tree. Nevertheless, the main accession- and germination phase of pioneer species should be finished at the time of data collection since a low canopy of woody plants is normally established after one year of succession or even within a shorter period of time (Gómez-Pompa et *al.*, 1991). As the later species composition in a tropical tree community is largely influenced by chance (Denslow, 1987) this study only presents a moment in time of the whole successional process and the recovery of logging gaps through germination and growth of natural regeneration.

Although the regeneration in forest gaps depends on various different biotic and abiotic factors (Sapkota & Odén, 2009) like temperature (Godoi & Takaki, 2004), soil moisture, nutrient availability (Denslow, 1987), herbivory (Crawley, 1989; Nichols et *al.*, 1999) and the presence and spatial distribution of seed trees (Guariguata & Pinard, 1998) it has been reported that the light availability and therefore the gap size is the underlying factor which influences the natural regeneration in canopy gaps (Brokaw, 1985; Thompson et *al.*, 1998; Rose, 2000; Toledo-Aceves & Swaine, 2008). Based on that information, it has been assumed for this study that the characterization of natural regeneration in relation to gap size classes is a suitable method for the evaluation of the natural recovery of logging gaps. Consequently it has been reasoned that the mean size of felling gaps is usable as a parameter for the comparison of the ecological impact that is created by different logging practices [CM/CL]. The variant ecological impacts that go beyond the gap size were not particularly considered in this study. In case of the presented topic it can be expected that the ecological impact differs multifariously between chainsaw milling and conventional logging. The manual on-site processing of trees with the help of a chainsaw and the timber extraction through human portage, as it is conducted by chainsaw millers (Adam et *al.*, 2007), is estimated not to be associated with severe damage to the forest stand compared to the skidding measures of conventional logging which apply heavy machinery for the timber extraction (Revised Logging Manual, 2003). Additional differences between chainsaw milling and conventional logging like the felling intensity and spatial distribution of logging activities in the Nkrabia forest reserve (Krediet, 2009) had not been considered for the data collection and evaluation in this study. The presented results are in this context appropriate for the comparison of the two different logging practices on the basis of average logging gap size, particular gap size class and the related effects on structure and composition of natural regeneration within the logging gaps.

8.2 GAP CHARACTERISTICS

Logging activities are always associated with a disturbance of the forest stand (Thiollay, 1997). The felling of trees is known to have the largest impact on the area as it amounts for almost 60 % of the total logging damage (Agyeman et *al.*, 1999). Canopy gaps that have been created by logging operations are larger in average compared to those emerged from natural disturbances (Parren & Bongers, 2001; Sapkota & Odén, 2009). Natural canopy gaps are mostly a result of the collapse of small- to medium sized trees while logging for timber production generally focuses on the extraction of dominant individuals with large boles and fully developed crowns (Van Gemerden, 2004).

The results of presented study show a broad range for the size of logging gaps [<200 m² to >1.500 m²] in the Nkrabia forest reserve but conform in average to other studies about logging gaps that have been carried out in Ghana and other parts of western- and central Africa. Agyeman et *al*. (1999) reports a gap size of 200 to 900 m² for conventional logging operations in Ghana. In the study of Nuys & Wijers (1992) the size of logging gaps ranged between 150 and 900 m² in Compartment 17 of the Nkrabia forest reserve for gaps that had been created by single tree fall, with an average size of 606 m². In the Republic of Congo a mean size of logging gaps of 719 m² has been reported with a dimension from zero to 2.769 m² (Brown et *al.*, 2008). As the results of previously mentioned reports are based on different gap definitions it is not possible to directly compare the numbers with the results of this study (Van der Meer et *al*., 1994). Nevertheless it can be stated that the outcomes of the presented study fall into a realistic amplitude of gap size which was caused by the felling of trees during logging operations. The gap definition that has been applied in this study (Runkle, 1992) offers objectivity and a high measuring precision for the gap size on the forest floor (Van der Meer et *al*., 1994). The size of logging gaps was positively correlated with the diameter at breast height [DBH] of the Gap maker. The comparative weakness of this correlation [coefficient of correlation r=0,56] can be explained with the importance of the particular tree allometry. Agyeman et *al*. (1999) describes the relevance of the species specific proportion between bole- and crown volume of the Gap maker for the size of created logging gap. However it can be confirmed with the results of this study that the size of the felled tree, expressed by the DBH, is an important determinant for the resultant logging gap size.

It has been reported in several studies that chainsaw operators [CM] tend to harvest trees that are below the cutting limit which is obligatory for conventional logging operations in Ghana (Adam et *al*., 2007; Adam & Dua Gyamfi, 2009). In fact 75 % of the trees that had been felled by chainsaw milling ranged below this species specific diameter limit in this study. Based on the mean size of trees that had been felled by both logging practices, the average size of gaps created by chainsaw milling was significantly smaller compared to the gap size emerged from conventional logging operations. Logging gaps created by chainsaw operators mainly were small- to medium sized, while the gaps created by conventional logging belonged to the medium- and large gap size class. Despite other factors that are crucial for the overall evaluation of different logging practices like felling intensity, rotation length and the spatial distribution of logging activities, it can be stated that on the basis of single logging gaps, the impact of chainsaw milling is smaller in average compared to the disturbance that is created by conventional logging in the Nkrabia forest reserve.

8.3 STATUS AND SPECIES COMPOSITION OF NATURAL REGENERATION

Generally it has been assumed that the natural regeneration throughout the High Forest zone in Ghana is sufficient or even more than adequate to replace the existing forest canopy (Hall & Swaine, 1976; Hawthorne, 1995). Especially in forests that are utilized for timber production the occurrence of sufficient natural regeneration is essential for the sustainability of forest management (Poorter et *al.*, 1996). The results of this study present a high overall stem density of natural regeneration both in the seedling and sapling category. The average stem density in the sapling category [4.717,6 stems/ha] was similar to the results that have been reported by Nuys & Wijers (1992) for Compartment 17 of the Nkrabia forest reserve and can therefore be seen as confirmation of existing data about the sapling regeneration in this forest reserve. The mean stem density in the seedling category [28.464,9 stems/ha] was approximately four times higher than the numbers of Nuys & Wijers (1992) which resulted from the deviant definition of the seedling category and considered growth forms.

Canopy gaps provide adequate environmental conditions and high availability of resources for the growth and survival of natural regeneration (Denslow, 1980). The stem density of plants however is not necessarily higher in gaps compared to sites within the interior forest (De Carvalho et *al.*, 2000). In presented study, the stem density of natural regeneration was in average lower within logging gaps compared to undisturbed forest sites, especially in the seedling category. The high stem density in the undisturbed forest can be explained with the substantial overall abundance of woody plant species that are able to tolerate shade during their early stage of life. The reduced stem density of regeneration in logging gaps might be a result of the felling impact. It is known that logging operations remove and damage high proportions of the established regeneration (Makana & Thomas, 2005). This assumption can be supported with the height class distribution of the sapling category in this study since the stem density of large saplings and consequently their mean height was markedly higher in undisturbed forest sites compared to the natural regeneration within the logging gaps.

The overall species composition of the natural regeneration in this study generally conformed to the results of Nuys & Wijers (1992). The main tree species that regenerate in the Nkrabia forest reserve were *Baphia nitida* Lodd., *Celtis mildbraedii* Engl., *Microdesmis puberula* J.Léonard and *Strombosia glaucescens* Oliv. which all are classified as Shade-bearers and reported to be typical species of the Moist Semi-deciduous forest formation in Ghana (Hall & Swaine, 1981). *Celtis mildbraedii* Engl. is one of the principal tree species throughout the High Forest zone (FAO, 2007b) and has been reported to be well abundant in all diameter classes in the Nkrabia forest reserve (Nuys & Wijers, 1992). *Celtis mildbraedii* Engl. also was the most abundant Gap border tree species in presented study. The highly abundant species of the group of climbing plants, *Griffonia simplicifolia* (Vahl ex DC.)Baill. and *Calycobolus africanus* (G.Don.)Heine are also typical indicator plants for the Moist Semi-deciduous forest formation (Hall & Swaine, 1981; Addo-Fordjour et *al.*, 2009). Other species that were frequently recorded in this study like *Acacia kamerunensis* Gand., *Chlamydocarya macrocarpa* A.Chev ex Hutch.&Dalziel and *Smilax kraussiana* Willd. are widely distributed throughout the forests in southern Ghana (Hall & Swaine, 1981). In general, the biodiversity of the natural regeneration of woody plants was high in presented study and heterogeneous over all inventory units as well as within each inventory unit. The main plant species however were highly abundant and frequent over all assessed inventory plots within logging gaps and undisturbed forest sites.

8.4 REGENERATION OF SUCCESSIONAL CLASSES IN RELATION TO GAP SIZE

Plant species can generally be classified according to their light requirement into distinct successional classes (Swaine & Whitmore, 1988) namely Shade-bearers, Non-pioneer Light-demanders and Pioneers (Hawthorne, 1993). As the light availability in canopy gaps increases with the extension of gap size (Wong, 2001) it can be expected that the abundance of different successional classes differs between logging gaps and undisturbed forest sites respectively between different gap size classes. Shade-intolerant species [Pioneers] are generally more abundant in large sized canopy gaps (Whitmore, 1990) while the regeneration of shade-tolerant species seems to be rather constant throughout different gap size classes (Brokaw, 1985; Denslow, 1987) and especially high in the interior forest (Kyereh et *al.*, 1999).

The results of this study support those assumptions as the abundance of Shade-bearers and Non-pioneer Light-demanders was relatively constant over the different gap size classes in the sapling category. The abundance of Shade-bearers however was significantly higher in undisturbed forest sites which can be explained with the capability of those species to accumulate under shadily conditions in the forest understory (Mwavu & Witkowski, 2009). The abundance of Non-pioneer Light-demanders was considerably lower in the sapling category over all inventory units. Although those species generally possess the ability to germinate and grow under forest shade they mostly die before attaining the sapling category, what prevents further accumulation within closed forest (Hawthorne, 1993). In the seedling category they were therefore similarly abundant as Shade-bearers. The abundance of Pioneers in the sapling category increased with ascending gap size class and even was significantly higher in medium- and large size logging gaps compared to undisturbed forest sites. This can be explained with their dependence on high solar radiation for germination and growth (Swaine & Whitmore, 1988) which is rather available under canopy gap conditions (Wong, 2001). In general it is known that small sized gaps are mostly recovered by the growth of established regeneration, whereas the regeneration in large gaps is strongly influenced by the seed rain and seed bank of Pioneer species (Gómez-Pompa et *al.*, 1991; Sapkota et *al.*, 2009). Nevertheless, Pioneers were also present below undisturbed canopy. That might indicate the overall light conditions of the Nkrabia forest reserve as a result of the former timber exploitation (De Vries, 2008). This phenomenon can further be related to the applied definition of undisturbed forest site [US] since small canopy openings due to branch fall and broken crowns were included as naturally occurring forest disturbances in this inventory unit.

The high abundance of Shade-bearers in large size logging gaps in the seedling category was mainly caused by the copious regeneration of the shade-bearing tree species *Celtis mildbraedii* Engl. which occurred as very small, recently germinated individuals in this gap size class. The abundance of Pioneer species in the seedling category was generally lower compared to the sapling category but showed similar tendencies over the different inventory units. It can be assumed that the natural regeneration in the seedling category is more affected by the rapid closure of the canopy gap in course of succession through the upward growth and proliferation of plants that immediately start to cover and shade the ground level of the area and prevent further germination of Pioneer species. This might explain the lower abundance of light demanding species in this category and therefore support the assumption that the time frame for the establishment of Pioneers in logging gaps is closed after a period of approximately two years from the point of gap creation.

8.5 REGENERATION OF LIANAS AND SMALL CLIMBERS IN RELATION TO GAP SIZE

In tropical forests lianas can account for over 20 % of the total stem density of the natural regeneration of woody plants (Putz, 1984). Especially the western African rainforests, although relatively species poor compared to the Neotropics (Huston, 1994), show a much higher liana density than the forests of all other continents (Reitsma, 1988). Particularly in Ghana, lianas can contribute for up to 31 % of the total species richness (Hall & Swaine, 1981). The importance of lianas for the natural regeneration is underlined with the results of presented study. Lianas made up a considerable proportion of the total biodiversity of woody plants and formed the most important class of natural regeneration, both in total abundance [39,7 %] and stem density [11.325 stems/ha] in the seedling category. Although they were relatively species poor, small climbers also markedly contributed to the regeneration over all inventory units in the Nkrabia forest reserve.

Lianas and small climbers have been reported to be particularly abundant in disturbed forest areas such as tree fall gaps (Parren, 2003). The abundance of lianas might initially be low but heavily increases during the first year of succession and remains on high level for several years after gap formation (Parren, 2003). Past four years, lianas can present 30 % of the stem density of woody plants within the canopy gap (Uhl et *al.*, 1981). In this study, climbing plants were abundant in logging gaps as well as within undisturbed forest sites. The abundance of lianas distinctly decreased with increasing gap size and even was significantly higher in the small- compared to the large gap size class. These results are unusual as it has been reported that the liana density in large canopy gaps can be as much as twice the density in the interior forest (Thompson et *al.*, 1998). The high abundance of lianas in undisturbed forest sites can be explained with the light requirement of the most abundant species in this class. *Griffonia simplicifolia* (Vahl ex DC.)Baill., *Calycobolus africanus* (G.Don.)Heine and *Acacia kamerunensis* Gand. are known as typical Shade-bearers or NPLD and therefore capable to form part of the seedling bank below closed canopy conditions (Hawthorne, 1993). Liana- and climber species that follow a typical Pioneer strategy were scarce in this study throughout all inventory units.

Generally it can be assumed that the established seedling bank of shade tolerant liana species starts to proliferate after gap creation due to increased light availability which rises the competition for other above- and below ground resources (Parren, 2003) and physical suppression between the individual plants (Neil, 1984). The competition between species that are similar in habit, constitution and structure is always severe (Simberloff & Dayan, 1991). It can further be supposed that this might lead to an increased mortality of climbing plants under gap conditions that goes along with the enhanced growth of single individuals. As the germination of shade-bearing species is not particularly triggered within canopy gaps, the stem density and abundance of lianas is unlikely to increase if there is no invasion and enhanced germination of aggressive Pioneer species. The results of this study were strongly influenced by the method for the inventory of natural regeneration since all stems that were rooted at the same place and all shoots connected by a single runner were counted as one individual. In fact, many of the assessed logging gaps in the Nkrabia forest reserve were visually dominated by lianas, small climbers and herbaceous vegetation. In general, it has been reported that canopy gaps are susceptible to infestation with pioneer vegetation in such an extent that succession seems to be totally repressed (Uhl et al., 1981). This however can not be ascribed to an increased abundance of lianas according to the results of presented study.

8.6 REGENERATION OF ECONOMIC TIMBER SPECIES IN RELATION TO GAP SIZE

Especially in forests that are managed for timber production the regeneration of economic timber species is crucial to sustain the yields and compensate for the extraction through logging operations (Poorter et *al.*, 1996). The classification of species according to their marketability as a result of timber properties, demand and frequency of distribution does not particularly consider the species ecological requirements. Those defined classes therefore present ecologically heterogeneous entities as they incorporate different successional classes.

It is a broadly accepted fact that the growth and survival of natural tree regeneration increases with higher light availability (Makana & Thomas, 2005). Since the extraction of timber through selective logging operations creates canopy gaps and thus increases the light availability (Cannon et *al.*, 1994) it has often been assumed that selective logging would positively influence natural regeneration (Makana & Thomas, 2005). In general, seedlings and saplings of many species that are dominant in the canopy layer of a forest are virtually absent in the understory (Poorter et *al.*, 1996). Those species are dependent on large gaps for successful regeneration (Denslow, 1980). As the forests in West Africa show a considerable abundance of big- and long-lived Pioneers and relatively light demanding climax species (Gómez-Pompa et *al.*, 1991) with many of them classified as highly economic timber species (Hawthorne, 1993) it could be reasoned that the gap creation through logging is likely to promote the natural regeneration of those desired timber species in the Nkrabia forest reserve and serves as a tool for sustainable forest management.

But in fact, the natural regeneration of the highly economic timber species [Red- and Scarlet Star species] *Entandophragma angolense* (Welw.)DC., *Khaya ivorensis* A.Chev., *Milicia excelsa* (Welw.)C.C.Berg, *Terminalia superba* Engl.&Diels and *Triplochiton scleroxylon* K.Schum was scarce in this study although they generally find suitable ecological conditions in the Semi-deciduous forest formation (Parren & De Graaf, 1995). Similar results have previously been reported by Nuys and Wijers (1992) for the Nkrabia forest reserve. As the majority of those species is dependent on increased solar radiation for successful regeneration (Hawthorne, 1993) they should particularly be abundant in canopy gaps. It has been reported for *Entandophragma* species to perform well under small- to medium gap size conditions and to develop best under 25 % of full sunlight (Hall et *al.*, 2003). Seedlings of *Khaya* species are able to establish in the forest understory but require canopy openings to gain larger size (Hawthorne, 1993). The endangered timber species *Milicia excelsa* requires over 40 % of full solar irradiance for optimum growth (Nichols et *al.*, 1999). *Terminalia superba* and *Triplochiton scleroxylon* are even considered to be large-gap specialists (Denslow, 1980; Hall & Swaine, 1981; Hawthorne, 1993). As the seeds of those species are rather easily dispersed (Poorter et *al.*, 2004) and a wide range of environmental conditions were considered for the inventory of natural regeneration in this study, namely undisturbed forest as well as different sized canopy gaps, the overall low abundance of Red- and Scarlet Star species is likely to be resultant from a lack of appropriate seed trees. As a matter of fact, it has been reported that the former timber exploitation in the Nkrabia forest reserve had strongly focused on the extraction of those High Priority species which consequently led to an accumulation of low-value species in the mature forest stand (De Vries, 2008). The decline of seed production through the removal of reproductive trees (Makana & Thomas, 2005) goes along with an overall change in the population structure and composition of the forest (Bongers et *al.*, 1988).

With respect to the different inventory units, Red Star species were most abundant in the small- and medium gap size class. Scarlet Star species were almost absent in medium- to large sized logging gaps. This can be explained with the previously mentioned scarceness of light-demanding High Priority species and the consequently higher proportion of shade-tolerant natural regeneration in the Nkrabia forest reserve. The most abundant Red- and Scarlet Star species over all inventory units were *Guarea cedrata* (A.Chev.)Pellegr., *Pterygota macrocarpa* K.Schum. and *Entandophragma angolense* (Welw.)DC. which are known to be rather shade-tolerant for germination and early growth (Poorter et *al.*, 2004). The species *Guarea cedrata* (A.Chev.)Pellegr. which was the most abundant Red Star species both in the seedling- and sapling category is reported to be capable of profuse regeneration even in deep forest shade (Kyereh et *al.*, 1999). As the category of Red- and Scarlet Star species therefore mainly consists of Shade-bearers and Non-pioneer Light-demanders, it can be reasoned that the creation of large sized logging gaps does not promote the overall abundance of High Priority species in the Nkrabia forest reserve. This was further demonstrated with the abundance of those species over the different inventory units. A detailed evaluaton of single timber species with focus on their particular gap dependence for regeneration was not conducted in this study due to the small sampling coverage and the rarity of many relevant species.

In general, commercial timber species [Commercial Class I] were highly abundant in presented study, compared to the single abundance of Red- and Scarlet Star species. The Moist and Dry Semi-deciduous forest formation in Ghana show a great stock of commercial timber species and therefore amount together with the Moist-evergreen forest type to the main timber production area in Ghana (Parren & De Graaf, 1995). The abundance of the natural regeneration of Commercial Class I species clearly decreased with ascending gap size class in the sapling category as the most important species were classified as Shade-bearers. The species with the highest overall abundance were *Strombosia glaucescens* Oliv., *Celtis mildbraedii* Engl. and *Nesogordonia papaverifera* (A.Chev.)R.Capuron, which are lower-value timber species but nevertheless form an important item of the national timber production and export market, due to their high production volume in Ghana (Oteng-Amoako, 2002). The dominance of Commercial Class I species in the large gap size class within the seedling category resulted from the copious regeneration of *Celtis mildbraedii* Engl. in form of very small, recently germinated individuals. Due to the significantly lower abundance of Commercial Class I species in the large- and medium gap size class compared to the small gap size and undisturbed forest sites in the sapling category, it can be approved that the creation of large sized logging gaps is counterproductive to the promotion of commercial timber species in the Nkrabia forest reserve since the major proportion of this class is formed by typical Shade-bearers. Contrary to the prior argumentation for the abundance of Red- and Scarlet Star species, a sufficient number of appropriate seed trees for Commercial Class I species can be expected in the Nkrabia forest reserve. The main species of this class have been reported to be frequently abundant in the mature forest stand of the reserve (Nuys & Wijers, 1992; De Vries, 2008) and were highly abundant as Gap border trees in presented study.

8.7 COMPARISON OF CHAINSAW MILLING AND CONVENTIONAL LOGGING

It has been assumed in this study that the mean gap size is usable as a parameter for the comparison of the ecological impact of different logging practices [CM/CL]. For this purpose, the reported gap characteristics of each logging practice have to be linked to the results of the evaluation of the natural regeneration according to the different gap size classes.

Although there was a significant difference in mean gap size between chainsaw milling and conventional logging, the average of both practices fell into the same gap size class, namely the class of medium size logging gaps [400-800 m^2]. Based on this, it has to be stated that there is no difference in natural regeneration between gaps that had been created by chainsaw milling and those emerged from conventional logging in the Nkrabia forest reserve. Nevertheless, it has become clear in this study that logging gaps created by chainsaw milling mainly belonged to the small- and medium gap size class while a relevant proportion of canopy gaps caused by conventional logging were assigned to the large gap size class. As it has been discussed in the previous chapters, it can be concluded with the results of presented study that large size logging gaps are rather inappropriate for the promotion of the natural regeneration of economic timber species in the Nkrabia forest reserve due to the species composition of the mature forest stand. Under this aspect it can be stated that the logging gaps which had been created by chainsaw operators are often more favourable for the recovery of Commercial- and High Priority timber species in this reserve than the gaps created by conventional logging.

This however solely applies on the basis of single logging gaps and with gap size as the only parameter for the comparison of both logging practices. In a broader context that does not mean that chainsaw operations are generally a supportive factor for sustainable forest management. Although the on-site conversion of logs into lumber and the extraction of processed trees by human portage (Adam et *al.*, 2007) are commonly estimated to be of little physical damage, there are several reasons why chainsaw milling is nowadays recognized as one of the main threats to the forests in Ghana (Marfo, 2010). The fact that chainsaw milling is not conducted under any official and regulated mandate leads to over-exploitation of timber resources and logging in areas that are not suitable for timber exploitation. The felling intensity of chainsaw milling exceeds, with up to seven trees per hectare, by far the restricted felling intensity of the formal timber production sector in Ghana (Marfo, 2010). As CM is mostly conducted in the surrounding of settlements and access roads (Krediet, 2009; Marfo, 2010) there is often a high concentration of logging activities in single areas. Additionally it has been reported that chainsaw milling shows a high selective nature and focuses only on the most valuable timber species [Red- and Scarlet Star species] and the best log quality (Hansen & Treue, 2008). Especially the designated forest reserves in Ghana serve as a source for those desired timber species for chainsaw operators (Chainsaw Logging and Milling in Ghana - Background study report). This negatively influences the stand structure and composition and leads to an accumulation of low-value timber species in the mature forest stand and its natural regeneration. As chainsaw milling is mostly conducted in areas that had been previously logged by conventional operations (Marfo, 2010) it is likely that chainsaw operators extract trees that have been left standing in the forest as future crop trees or reproductive seed trees. This additionally affects the prospective exploitable timber volume (Marfo, 2010). Overall it can be stated that the sustainably exploitable timber volume is exceeded by far if chainsaw milling is carried out in addition to conventional logging operations in Ghana.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

The conclusions of this research are based on the discussion of the results and follow the previously defined research questions. The main research questions for this study were:

(1) What are the differences between logging gaps that had been created by chainsaw milling and conventional logging in the Nkrabia forest reserve?

(2) What are the overall conditions of natural regeneration in the Nkrabia forest reserve? What is the status of the natural regeneration, with respect to different ecological species groups and the abundance of economic timber species, within different sized logging gaps and undisturbed forest sites?

(3) Does the natural regeneration which occurs in logging gaps that had been created by chainsaw milling differ from the regeneration in gaps created by conventional logging?

Logging gaps that had been created by chainsaw milling were smaller in average compared to gaps created by conventional logging operations. They mostly were assigned to small- and medium sized gaps while the canopy gaps created by conventional logging were limited to the medium- and large gap size class. The mean size of trees that had been felled by chainsaw operators was significantly below the size of trees that had been extracted by conventional logging operations. The main proportion of logs that were related to chainsaw activities in the Nkrabia forest reserve fell below the species specific cutting diameter which is the binding lower limit for the logging operations of the formal timber production sector in Ghana.

There was profuse natural regeneration of woody plants over all inventory units in the Nkrabia forest reserve. The regeneration was dominated by trees and lianas in the number of species, abundance and stem density. Shade-bearers generally were the most abundant successional class of natural regeneration in this study and were particularly present in undisturbed forest sites and small-sized logging gaps. Non-pioneer Light-demanders were infrequent in the sapling category as they are hardly able to grow to larger size under shadily conditions. The higher proportion of Pioneers in medium- and large sized logging gaps did not reflect the abundance of the growth form classes and economic timber classes over the different inventory units. The abundance of lianas decreased with ascending gap size class due to the high proportion of shade-tolerant species within this growth form class. Similar trends applied for the Commercial Class I species and High Priority species in presented study.

Natural regeneration of commercial timber species was not generally scarce in the Nkrabia forest reserve but rather deficient in High Priority species [Red- and Scarlet Star species]. This might be related to a lack of adequate seed trees which had been caused by the former timber exploitation which strongly had focused on the extraction of this high-value timber species. Taking this into consideration it can be assumed with reasonable certainty that the timber exploitation so far has been unsustainable regarding the recovery and promotion of High Priority species in the Nkrabia forest reserve.

Although the differences were not always significant, it can be concluded that the creation of large sized logging gaps is counterproductive to the promotion of desired timber species in the Nkrabia forest reserve due to structure and composition of the mature forest stand. Therefore, logging gaps that had been created by chainsaw milling featured frequently more suitable gap-size conditions for the natural regeneration of economic timber species in the Nkrabia forest reserve compared to the logging gaps created by conventional operations. In a broader context however, chainsaw milling is known to be an important agent of forest disturbance and destruction in Ghana.

9.2 RECOMMENDATIONS

The recommendations of this study follow the previously discussed results and conclusions. They focus on logging measures in the Nkrabia forest reserve with respect to the sustainable promotion of economic timber species through future interventions.

- The creation of large sized logging gaps has to be avoided in the Nkrabia forest reserve to prevent a further decline in the abundance of the natural regeneration of desired timber species and to minimize the area of felling disturbance within the forest reserve.

- The felling of large sized timber trees has to be avoided to prevent the creation of large sized logging gaps. The processing and skidding of timber has to be conducted in a manner that a further extension of the felling gap is limited.

- The creation of small- to medium sized logging gaps has to be fostered in the Nkrabia forest reserve for the promotion of the natural regeneration of economic timber species [Commercial Class I] and High Priority species [Red- and Scarlet Star species].

- Adequate seed trees of desired timber species have to be retained and carefully managed in the Nkrabia forest reserve to provide a sufficient base for the natural regeneration inside closed forest and within the created logging gaps. The seed trees of High Priority species should be retained in close range to canopy gaps to promote their natural regeneration.

- If there is a further decline in the abundance of High Priority species in the Nkrabia forest reserve it should be considered to conduct enrichment planting of desired timber species into logging gaps as a method to support the occurrence of those species in this forest reserve. Many high-value timber species have been reported to find suitable environmental conditions for natural regeneration within canopy gaps.

- Although it is associated with smaller ecological impact compared to conventional logging in the Nkrabia forest reserve, chainsaw milling needs to be controlled by official mandate and should be embedded into the sustainable Annual Allowable Cut to minimize its negative effects on the forest stand as a whole.

10. List of References

Adam, A. R. (1999) Timber Yield Determination and Allocation in Selective Logging System in Ghana. Forestry Research Institute of Ghana, Kumasi, Ghana.

Adam, A. R., Pinard, M. A., Cobinnah, J. R., Damnyag, L., Nutakor, E., Nketiah, K. S., Kyere, B. and Nyarko, C. (2007) Socio-economic impact of chainsaw milling and lumber trade in Ghana. *Chainsaw milling and lumber trade in West Africa*. Report No. 1. FORIG/Tropenbos International, Ghana.

Adam, K. A. and Dua-Gyamfi, A. (2009) Environmental impacts of chainsaw milling. Ghana case study of illegal chainsaw milling. Developing alternatives to illegal chainsaw milling through multi-stakeholder dialogue in Ghana and Guyana project. *FORIG Research Report* (CSIR-FORIG).

Addo-Fordjour, P., Obeng, S., Anning, A. K. and Addo, M. G. (2009) Floristic composition, structure and natural regeneration in a moist semi-deciduous forest following anthropogenic disturbances and plant invasion. *International Journal of Biodiversity and Conservation* Vol. 1(2) pp. 021-037.

Agyeman, V. K., Abu-Juam, M. and Hawthorne, W. D. (1999) Towards better forest harvesting. *Forestry Research Programme*, Project R 6716.

Agyarko, T. (2001) Forestry Outlook Study for Africa (FOSA) - Ghana. 2nd draft.

Asner, G. P., Keller, M., Pereira, R., Zweede, J. C. and Silva J. N. M (2004) Canopy Damage and Recovery after Selective Logging in Amazonia: Field and Satellite Studies. *Ecological Applications* 14(4) Supplement, 2004, pp. S.280-S.298.

Baker, J. G. (1913) Flora of Tropical Africa. Vol. 6, part 1. Page 441.

Baker, J. G. and Rendle, A. B. (1905) Flora of Tropical Africa. Vol. 4 Part 2, page 62.

Barton, A. M., Fetcher, N. and Redhead, S. (1989) The relationship between treefall gap size and light flux in a Neotropical Rain Forest in Costa Rica. *Journal of Tropical Ecology* (1989) 5:437-439.

Bongers, F., Pompa, J., Del Castillo, L. and Carabias, J. (1988) Structure and floristic composition of the lowland rain forest of Los Tuxtlas, Mexico. *Vegetatio* 74:55-80.

Brack, D. (2005) Controlling Illegal Logging and the Trade of Illegally Harvested Timber, The EU´s Forest Law Enforcement, Governance and Trade Initiative. *RECIEL* 14(1).

Brenan, J. P. M. (1959) Flora of Tropical East Africa. Vol.1.

Broadbent, E. N. (2005) Post-Harvest Recovery of Forest Structure and Spectral Properties after Selective Logging in Lowland Bolivia. *Master of Science-thesis*, University of Florida 2005.

Brokaw, N. V. L. (1985) Gap-phase regeneration in a tropical forest. *Ecology Letters* 66: 682-7.

Brown, S., Pearson, T., Moore, N., Parveen, A., Ambagis, S. and Shoch, D. (2008) Impact of selective logging on the carbon stocks of tropical forests: Republic of Congo as a case study. Deliverable 6: Logging impacts on carbon stocks.

Burkill, H. M. (1985) The Useful Plants of West Tropical Africa. Vol. 1.

Cannon, C. H., Peart, D. R., Leighton, M. and Kartawinata, K. (1994) The structure of lowland rain forest after selective logging in West Kalimantan, Indonesia. *Forest Ecology and Management* 67, 49-68.

Chainsaw Logging and Milling in Ghana - Background study report. [online] Available from: http://www.illegal-logging.info/.

Climate Chart-Kumasi (2007) [online] Available from: http://www.klimadiagramme.de/.

Crawley, M. J. (1989) Insect Herbivores and Plant Population Dynamics. *Annual Review of Entomology*, Vol. 34: 531-562.

De Carvalho, L. M. T., Fontes, M. A. L. and Oliveira-Filho, A. T. (2000) Tree species distribution in canopy gaps and mature forest in an area of cloud forest of the Ibitipoca Range, south-eastern Brazil. *Plant Ecology* 149: 9–22, 2000.

Denslow, J. S. (1980) Gap partitioning among Tropical Rainforest Trees. *Biotropica* Vol. 12, No. 2, Supplement: Tropical Succession pp. 47-55.

Denslow, J. S. (1987) Tropical Rainforest Gaps and Tree Species Diversity. *Annual Review of Ecology*, 1987, 18: 431-51.

De Vries, J. (2008) The Influence of the Declining Wood Availability on the Ghanaian Timber Industry-A Case Study in the Nkrabia Forest Reserve. *Bachelor Thesis*. University of Applied Sciences Van Hall Larenstein.

Donkor, B. N. (2003) Evaluation of government interventions in Ghana´s forest product trade: A post-intervention impact assessment and perceptions of marketing implications.

EIA (2002) Environmental Investigation Agency. Illegal Logging and The International Trade in Illegally Sourced Timber: How CITES can Help and Why it Should. A Briefing of the 12th Conference of the Parties to CITES.

FAO (1995) Food and Agriculture Organization: Forestry Paper 107. Conservation of genetic resources in tropical forest management-Principles and concepts. Part 2: Case studies.

FAO (2007a) Food and Agriculture Organization: World Soil Resources Report 103. World reference base for soil resources 2006. First update 2007.

FAO (2007b) Food and Agriculture Organization: Forest Health & Biosecurity Working Papers. Overview of Forest Pests. Ghana. January 2007.

Garnica, J. G. F., Gonzalez, D. A. M. and Dios Benavides Solorio, J (2006) Geostatistical Evaluation of Natural Tree Regeneration of a Disturbed Forest. Centro de Investigaciones del Pacífico Centro. INIFAP. Parque Los Colomos S/N, Col. Providencia. Guadalajara, Jal.isco. México.

GFIP (1989) Ghanaian Forest Inventory Project. Seminar proceedings, Editor: Wong, J. L. G., Accra, March 1989. Ghana Forestry Department and Overseas Development Administration of the United Kingdom 101p.

Glastra, R. (1999) Cut and Run - Illegal logging and timber trade in the tropics.

Godoi, S. and Takaki, M. (2004) Effects of light and temperature on seed germination in *Cecropia hololeuca* Miq. (Cecropiaceae). *Brazilian Archives of Biology and Technology*, Vol. 47, No. 2, Curitiba, June 2004.

Gómez-Pompa, A., Whitmore, T. C. and Hadley, M. (1991) Rainforest regeneration and management. *Man and the Biosphere Series*-Volume 6.

Guariguata, M. R. and Pinard, M. A. (1989) Ecological knowledge of regeneration from seed in neotropical forest trees: Implications for natural forest management. *Forest Ecology and Management*, Vol. 112, Issue 1-2.

Hall, J. B. and Swaine, M. D. (1976) Classification and Ecology of Closed-Canopy Forest in Ghana.

Hall, J. B. and Swaine, M. D. (1981) Distribution and Ecology of Vascular Plants in A Tropical Rainforest-Forest Vegetation in Ghana.

Hall, J. B., Medjibe, V., Berlyn, G. P. and Ashton, P. M. S. (2003) Seedling growth of three co-occurring *Entandophragma* species (Meliaceae) under simulated light environments: implications for forest management in central Africa. *Forest Ecology and Management* 179 (2003) 135-144.

Hansen, C. P. and Treue, T. (2008) Assessing Illegal Logging in Ghana. *International Forest Review* Vol. 10 (4), 2008.

Hawthorne, W. D. (1993) FROGGIE-Forest Reserves of Ghana Graphical Information Exhibitor. Forest Inventory and Management Project. Planning Branch, Forestry Department, Kumasi, Ghana. Part 2 (first draft).

Hawthorne, W. D. (1995) Ecological Profiles of Ghanaian Forest Trees. *Tropical Forestry Papers* 29, Oxford Forestry Institute, Oxford, UK.

Hawthorne, W. D. and Abu-Juam, M. (1995) Forest protection in Ghana: With particular reference to vegetation and plant species. *IUCN Forest Conservation Programme* 14.

Hawthorne, W. D. and Gyakari, N. (2006) Photoguide for the Forest Trees of Ghana: A Tree-spotter´s Field Guide for Identifying Large Trees. Oxford Forestry Institute.

Hemsley, J. H. (1968) Flora of East Africa. Royal Botanical Gardens, Kew.

Huston, M. A. (1994) Biological diversity. The coexistence of species on changing landscapes. Cambridge University Press, Cambridge.

Karsenty, A. and Gourlet-Fleury, S. (2006) Assessing Sustainability of Logging Practices in the Congo Basin´s Managed Forests: the Issue of Commercial Species Recovery.

Krediet, G. (2009) A case and field study in the Nkrabia forest reserve. *Internship report* 3rd year. University of Applied Sciences Van Hall Larenstein.

Kyereh, B., Swaine, M. D. and Thompson, J. (1999) Effect of light on the germination of forest trees in Ghana, *Journal of Ecology* 1999, 87, 772-783.

Makana, J. R. and Thomas, S. C. (2005) Effects of Light Gaps and Litter Removal on the Seedling Performance of Six African Timber Species. *Biotropica* 37(2): 227-237, 2005.

Marfo, E. (2010) Chainsaw Milling in Ghana, Context, Drivers and Impacts; Tropenbos International, Wageningen, the Netherlands. Xii + 64 pp.

Mwavo, E. N. and Witkowski, E. T. F. (2009) Seedling regeneration, environment and management in a semi-deciduous African tropical rain forest. *Journal of Vegatation Science* 1-14, 2009.

Neil, P. E. (1984) Climber problems in Solomon Islands forestry. *Commonwealth Forestry Review* 63: 27-34.

Nichols, J. D., Agyeman, V. K., Agurgo, B. F., Wagner, M. R. and Cobbinah, J. R. (1999) Patterns of Seedling Survival in the Tropical African Tree *Milicia excelsa*. *Journal of Tropical Ecology*, Vol. 15, No. 4, pp. 451-461.

Nuys, G. J. and Wijers, R. G. (1992) Wood residues and logging damage in Nkrabia forest reserve, Ghana. ITTO-Project PD 74/90: Better utilization of tropical timber resources in order to improve sustainability and reduce negative ecological impacts.

Oduru, K. A. and Gyan, K. (2007) Draft Document on the Definition of Legal Timber in Ghana.

Oteng-Amoako, A. A. (2002) Timber Trees from Ghana. KNUST-Kumasi, 2002.

Parren, M. (2003) Lianas and Logging in West Africa. Tropenbos International Wageningen, the Netherlands 2003. *Tropenbos-Cameroon Series* 6, 2003.

Parren, M. and Bongers, F. (2001) Does climber cutting reduce felling damage in southern Cameroon? *Forest Ecology and Management* 141, 175-188.

Parren, M. and De Graaf, N. R. (1995) The quest for natural forest management in Ghana, Côte d´Ivoire and Liberia. *Tropenbos series* 13, 1995.

Poorter, L., Bongers, F., Rompaey, R. S. A. R. and De Klerk, M. (1996) Regeneration of canopy tree species at five sites in West African moist forest. *Forest Ecology and Management* 84 (1996) 61-69.

Poorter, L., Bongers, F., Kovainé, F. N. and Hawthorne, W. D. (2004) Biodiversity of West African Forests – An ecological Atlas of Woody Plant Species, 2004.

Procedures Manual (2003) Competitive Bidding for Timber Utilisation Contracts. Ghana Forestry Commission, June 2003.

Putz, F. E. (1984) The natural history of lianas on Barro Colorado Island, Panama. *Ecology* 65: 1713-1724.

Reitsma, J. M. (1988) Forest vegetation of Gabon. *Tropenbos Technical Series* No 1. Tropenbos Foundation, Ede, The Netherlands, 142 p.

Revised Logging Manual for Ghana (2003) Guidance for Companies operating Timber Utilisation Contracts in the High Forest in Ghana. Ghana Forestry Commission, March 1998 with later revisions, March 2003.

Rose, S. (2000) Seed, seedlings and gaps - size matters: a study in the tropical rain forest of Guyana, Tropenbos-Guyana Series 9; *Tropenbos-Guyana Programme*, Georgetown, Guyana.

Runkle, J. R. (1992) Guidelines and Sample Protocol for Sampling Forest Gaps. United States Department of Agriculture, General Technical Report PNW-GTR-283.

Sapkota, I. P. and Odén, P. C. (2009) Gap attributes and their impact on dominance, regeneration and early growth of woody species. *Journal of Plant Ecology* 2: 21-29.

Saaka, S. O., Iddrisu, A. and Telly, E. M. (1999) Republic of Ghana – National report to the third session of the conference of the parties to the United Nations conventions to combat desertification.

Schnitzer, S. A., Dalling, J. W. and Carson, W. P. (2000) The impact of lianas on tree regeneration in tropical canopy gaps: evidence for an alternative pathway of gap phase regeneration. *Journal of Ecology*, 2000, 88, 655-666.

Simberloff, D. and Dayan, T. (1991) The Guild Concept and the Structure of Ecological Communities. *Annual Review of Ecology and Systematics*. Volume 22 (1991), 115-143.

Swaine, M. D. and Hall, J. B. (1983) Succession on Cleared Forest Land in Ghana. *Journal of Ecology*, Vol. 71, No. 2, pp. 601-627.

Swaine, M. D. and Whitmore, T. C. (1988) On the Definition of Ecological Species Groups in Tropical Rain Forests. *Vegetatio* 75, 81-86.

Tacconi, L. (2007) Illegal Logging: Law Enforcement, Livelihoods and Timber Trade. *Earthscan*, London, United Kingdom, 301 pp.

Thiollay, J. M., (1997) Disturbance, selective logging and bird diversity: A Neotropical Forest Study. *Biodiversity and Conservation* 6, 1155-1173.

Thompson, J., Proctor, J., Scott, D. A., Fraser, P. J., Marrs, R. H., Miller, R. P. and Viana, V. M. (1998) Rain forest on Maraca Island, Roraima, Brazil: artificial gaps and plant response to them. *Forest Ecology and Management 102*: 305-321.

Thullin, M. (2008) Flora Somalia. Vol. 2. (1999). Updated 2008.

Toledo-Aceves, T. and Swaine, M. D. (2008) Effect of lianas on tree regeneration in gaps and forest understorey in a tropical forest in Ghana. *Journal of Vegetation Science* 19: 717-728, 2008.

Toyne, P., O´Brien, C. and Nelson, R. (2002) The Timber Footprint of the G8 and China. *WWF International*, Gland, Switzerland 40 pp.

Uhl, C., Clark, K., Clark, H. and Murphy, P. (1981) Early plant succession after cutting and burning in the Upper Rio Negro region of the Amazon Basin. *Journal of Ecology*, 69,631-649.

Van Gemerden, B. S. (2004) Disturbance, diversity and distributions in Central African rain forest. *Wageningen University Dissertation* 2004.

Van der Meer, P. J., Bongers, F., Chatrou, L. and Riéra, B. (1994) Defining canopy gaps in a tropical rainforest: effects on gap size and turnover time. *Acta Ecologica*, 1994, 15 (6), 701-714.

Whitmore, T. C. (1990) An Introduction to Tropical Rain Forests. Oxford, U.K. Claredon Press, pp.

Wong, C. M. (2001) Species Regeneration Response to Clearing Size: A *Swietenia macrophylla* King. harvested forest in Northern Belize. Nicholas School of Environment of Duke University.

11. ANNEXES

ANNEX 01: SPECIES DESCRIPTION

Description of the most important species presented in this study. The species are arranged in alphabetical order, including species of trees, shrubs- or large woody herbs, lianas and small climbers. Importance of species according to stated Results and Discussion.

Acacia kamerunensis Gand.	
Synonym:	*Acacia pennata* (L.) Willd.
Family:	Leguminosae - Mimosoideae
Species information:	Large woody climber to tall liana (Hall & Swaine, 1981)
	Widespread in Africa, from French Guinea and Sierra Leone to Cameroon, Dem. Republic of Congo and Uganda, southwards to Angola (Brenan, 1959)
	Seedlings are found in forest shade, show rapid growth in canopy gaps (Hall & Swaine, 1981)
	Non-pioneer Light-demander (Hawthorne, 1993)
	Green Star species (Hawthorne, 1993)

Aningeria altissima (A.Chev.)Baehni	
Synonym:	*Pouteria altissima* (A.Chev.)Baehni
Family:	Sapotaceae
Local name(s):	Asanfena
Trade name(s):	Aningeria, Aningeria blanc
Species information:	Tall, deciduous tree, up to 50 m height, with clean straight cylindrical bole (Hemsley, 1968)
	Ranges from Guinea, Ghana to Cameroon, Sudan and Ethiopia (Hemsley, 1968)
	Seedlings under forest shade (Hall & Swaine, 1981)
	Non-pioneer Light-demander (Hawthorne, 1993)
	Scarlet Star species (Hawthorne & Gyakari, 2006)
	Commercial Class I, very high production and frequent export (Oteng-Amoako, 2002)

Antiaris toxicaria (Rumph.ex Pers.)Leschen.	
Synonym:	*Antiaris kerstingii* Engl.
Family:	Moraceae
Local name(s):	Kyenkyen, Akede, Ako
Trade name(s):	Antiaris
Species information:	Large tree up to 51 m height with a maximum DBH of 130 cm (Poorter et *al*., 2004)
	Distributed from Guinea, Ghana to Central Africa (Poorter et *al*., 2004)
	Strong light-demander, seedlings common in shade but require exposure to sun for further growth, rapid growth under light conditions (Poorter et *al*., 2004)
	Non-pioneer Light-demander (Hawthorne, 1993)
	Red Star species (Hawthorne & Gyakari, 2006)
	Commercial Class I, very high production and regular export (Oteng-Amoako, 2002)

Baphia nitida Lodd.	
Synonym:	*Baphia barombiensis* Taub. *Delaria pyrifolia* Desv.
Family:	Leguminosae - Papilionoideae
Common name(s):	Camwood
Species information:	Small shrub or tree of 10 m height with a DBH up to 45 cm, in the forest understory (Burkill, 1985)
	Western Africa, from Guinea, Côte d´Ivoire, Ghana to Cameroon (Burkill, 1985)
	Shade-bearer (Hawthorne, 1993)
	Green Star species (Hawthorne, 1993)
	Commercial Class III

Bussea occidentalis Hutch.	
Family:	Leguminosae - Caesalpinioideae
Common name(s):	Samanta
Species information:	Evergreen tree with a height of up to 45 m and DBH of maximum 100 cm (Poorter et *al.*, 2004)
	West Africa, Sierra Leone, Liberia, Côte d´Ivoire and Ghana
	Seedlings are common in shade but benefit from increased light level in small to medium sized canopy gaps (Poorter et al. 2004)
	Non-pioneer Light-demander (Hawthorne, 1993)
	Green Star species (Hawthorne, 1993)
	Commercial Class III

Calycobolus africanus (G.Don)Heine	
Synonym:	*Calycobolus alternifolia* Planch.
Family:	Convolvulaceae
Species information:	Climbing shrub (Baker & Rendle, 1905) or large woody climber (Hall & Swaine, 1981)
	Western Africa, from Guinea to Cameroon, Dem. Republic of Congo and Angola (Burkill, 1985)
	Profuse regeneration under forest shade (Hall & Swaine, 1981)
	Green Star species (Hawthorne, 1993)

Ceiba pentandra (L.)Gaertn.	
Synonym:	*Ceiba thonningii* A.Chev. *Bombax pentandrum* L.
Local name(s):	Ceiba
Trade name(s):	Ceiba, Fuma
Family:	Malvaceae
Species information:	Large deciduous tree with straight trunk (Thullin, 2008) up to 65 m height with a DBH of 300 cm (Burkill, 1985)
	Common in all tropics, in West Africa from Guinea Bissau, Côte d´Ivoire, Ghana, Nigeria to Cameroon (Burkill, 1985)
	Extreme light demander, regenerates only in canopy gaps and along roadsides (Hall & Swaine, 1981)
	Pioneer (Hawthorne, 1993)
	Red Star species (Hawthorne & Gyakari, 2006)
	Commercial Class I, very high production (Oteng-Amoako, 2002)

Celtis mildbraedii Engl.	
Synonym:	*Celtis compressa* A. Chev. *Celtis soyauxii* Engl.
Local name(s):	Esa-Biri, Esa-Fufu, Ohia
Trade name(s):	Celtis
Family:	Ulmaceae
Species information:	Mostly evergreen forest tree up to 54 m height (Poorter et *al*., 2004), straight trunk with over 100 cm DBH (Burkill, 1985)
	Western Africa to Sudan, southwards to Angola, Tanzania, Zimbabwe and South Africa (Burkill, 1985)
	Regenerates freely under forest shade (Hall & Swaine, 1981)
	Shade-bearer (Hawthorne, 1993)
	Pink Star species (Hawthorne & Gyakari, 2006)
	Commercial Class I, very high production and regular export (Oteng-Amoako, 2002)

Chlamydocarya macrocarpa A.Chev. Ex Hutch.&Dalziel	
Family:	Icacinaceae
Species information:	Woody climber (Burkill, 1985), closely related to *Chlamydocarya soyauxii* Engl. from Cameroon to Gabon (Hemsley, 1968)
	Western Africa, Côte d´Ivoire to Ghana (Hall & Swaine, 1981)
	Regenerates abundantly in forest shade (Hall & Swaine, 1981)
	Shade-bearer (Hawthorne, 1993)
	Green Star species (Hawthorne, 1993)

Entandophragma angolense (Welw.)DC.	
Synonym:	*Entandrophragma macrophyllum* A.Chev.
Local name(s):	Edinam
Trade name(s):	Tiama, Esaka, Lifuma, Mountain Mahagony
Family:	Meliaceae
Species information:	Large deciduous forest tree up to 50 m height with long straight trunk (Burkill, 1985), DBH up to over 180 cm (Poorter et *al*., 2004)
	Western Africa, Guinea, Ghana to Sudan, Uganda, Angola and Dem. Republic of Congo (Brenan, 1959)
	Germination occurs in shade but saplings establish best in small gaps (Hall & Swaine, 1981), seedlings are common in gaps of all sizes (Poorter et *al*., 2004)
	Non-pioneer Light-demander (Hawthorne, 1993)
	Scarlet Star species (Hawthorne & Gyakari, 2006)
	Commercial Class I, high production and regular export (Oteng-Amoako, 2002)

Griffonia simplicifolia (Vahl ex DC.)Baill.	
Synonym:	*Schotia simplicifolia* Vahl ex DC.
Family:	Leguminosae - Caesalpinioideae
Species information:	Large woody climber (Hall & Swaine, 1981)
	Western Africa, from Liberia to southern Nigeria (Burkill, 1985)
	Regenerates abundantly in forest shade (Hall & Swaine, 1981)
	Non-pioneer Light-demander (Hawthorne, 1993)
	Green Star species (Hawthorne, 1993)

Guarea cedrata (A.Chev.)Pellegr.	
Synonym:	*Trichilia cedrata* A Chev.
Local name(s):	Bosassa, Bosse, Diambi
Trade name(s):	Guarea, Pink Mahagony, Pink African Cedar
Family:	Meliaceae
Species information:	Large evergreen forest tree up to 55 m height with heavy buttresses and fluted bole, up to over 100 cm DBH (Burkill, 1985)
	From Sierra Leone to southern Nigeria, Cameroon and Zaire (Burkill, 1985)
	Regenerates profusely in deepest forest shade (Hall & Swaine, 1981), regeneration not successful in light (Poorter et *al*., 2004)
	Shade-bearer (Hawthorne, 1993)
	Red Star species (Hawthorne & Gyakari, 2006)
	Commercial Class I, moderate production and irregular export (Oteng-Amoako, 2002)

Microdesmis puberula Hook.f. ex Planch.	
Synonym:	*Microdesmis keayana* J.Léonard
Local name(s):	Diola
Family:	Pandaceae
Species information:	Evergreen bush, shrub or understory tree about 3 to 6 m height (Baker, 1913)
	Western Africa, from Guinea, Côte d´Ivoire, Ghana, southern Nigeria to Congo (Baker, 1913)
	Common understory species in primary and secondary forests (Baker, 1913)
	Shade-bearer (Hawthorne, 1993)
	Green Star species (Hawthorne, 1993)
	Commercial Class III

Nesogordonia papaverifera (A.Chev.)R.Capuron	
Synonym:	*Cistanthera papaverifera* A. Chev.
Local name(s):	Danta
Trade name(s):	Danta, Kotibe
Family:	Malvaceae
Species information:	Large (mostly) evergreen forest tree up to 45 m height with clean straight trunk, 150 cm DBH (Poorter et *al*., 2004), with small, sharp buttresses (Burkill, 1985)
	From Sierra Leone, Côte d´Ivoire, Togo to Nigeria and Dem. Republic of Congo (Burkill, 1985)
	Regenerates profusely in forest shade (Hall & Swaine, 1981), not light demanding but common in forest gaps (Poorter et *al*., 2004)
	Shade-bearer (Hawthorne, 1993)
	Pink Star species (Hawthorne & Gyakari, 2006)
	Commercial Class I, moderate production and regular export (Oteng-Amoako, 2002)

Smilax kraussiana Willd.	
Synonym:	*Smilax morsaniana* Kunth.
Family:	Smilacaceae
Species information:	Small climber (Hawthorne, 1993)
	Widespread in tropical- and South Africa (Burkill, 1985)
	Often in secondary forests (Burkill, 1985)
	Pioneer (Hawthorne, 1993)
	Green Star species (Hawthorne, 1993)

Sphenocentrum jollyanum Pierre	
Family:	Menispermaceae
Species information:	Erect and sparingly branched, evergreen shrub or treelet of maximum 1,40 m height (Burkill, 1985)
	Occurring from the Côte d´Ivoire to southern Nigeria (Burkill, 1985)
	Abundant in the forest undergrowth (Burkill, 1985)
	Shade-bearer (Hawthorne, 1993)
	Green Star species (Hawthorne, 1993)

Strombosia glaucescens Oliv.	
Synonym:	*Strombosia pustulata* Oliv.
Local name(s):	Afina
Trade name(s):	Afina, Itako
Family:	Olacaceae
Species information:	Evergreen forest tree up to 25 m height with long, straight trunk of maximum 50 cm DBH (Burkill, 1985)
	From Sierra Leone, Côte d´Ivoire over Cameroon to Congo and Angola (Burkill, 1985)
	Shade-bearer (Hawthorne, 1993)
	Pink Star species (Hawthorne & Gyakari, 2006)
	Commercial Class I, insignificant production and occasional export (Oteng-Amoako, 2002)

Triplochiton scleroxylon K.Schum.	
Synonym:	*Triplochiton nigericum* Sprague
Local name(s):	Wawa
Trade name(s):	Obeche, Abachi, African Whitewood
Family:	Malvaceae
Species information:	Very tall and often emergent, deciduous tree to 50–65 m height, deciduous with straight trunk with a DBH up to 200 cm (Burkill, 1985)
	From Guinea over Cameroon to Congo and Dem. Republic of Congo (Burkill, 1985)
	Regeneration naturally very scarce, able to regenerate under shade (Hall & Swaine, 1981) but mostly in canopy gaps (Poorter et *al*., 2004)
	Pioneer (Hawthorne, 1993)
	Scarlet Star species (Hawthorne & Gyakari, 2006)
	Commercial Class I, very high production and frequent export (Oteng-Amoako, 2002)

ANNEX 02: CHARACTERISTICS OF LOGGING GAPS

List and recorded characteristics of the selected logging gaps in the Nkrabia forest reserve. CL: Conventional logging and CM: Chainsaw milling. The presented gap size class conforms to chapter: 6.2 Classification of logging gaps.

Gap No.	Logging practice	Gap maker		Gap border-trees	Gap size	
		Species	**DBH** (cm)	**Number**	**Area** (m^2)	**Class**
1	CM	*Piptadeniastrum africanum*	76	18	264,20	small
2	CM	*Piptadeniastrum africanum*	110	12	732,87	medium
3	CM	*Nesogordonia papaverifera*	48	17	340,96	small
4	CM	*Nesogordonia papaverifera*	57	14	588,11	medium
5	CM	*Entandophragma candollei*	85	12	207,42	small
6	CM	*Entandophragma candollei*	95	13	628,01	medium
7	CM	*Petersianthus macrocarpus*	83	12	275,86	small
8	CM	*Entandophragma angolense*	119	15	540,96	medium
9	CM	*Nesogordonia papaverifera*	45	8	197,44	small
10	CM	*Triplochiton scleroxylon*	81	16	552,97	medium
11	CM	*Entandophragma angolense*	92	15	1.061,00	large
12	CM	*Terminalia superba*	74	11	225,72	small
13	CM	*Entandophragma angolense*	97	13	433,30	medium
14	CM	*Petersianthus macrocarpus*	110	12	441,46	medium
15	CM	*Entandophragma candollei*	64	13	254,89	small
16	CM	*Nesogordonia papaverifera*	49	13	340,00	small
17	CM	*Piptadeniastrum africanum*	82	14	759,84	medium
18	CM	*Piptadeniastrum africanum*	77	12	628,04	medium
19	CM	*Petersianthus macrocarpus*	65	12	259,93	small
20	CM	*Petersianthus macrocarpus*	62	10	406,16	medium
21	CL	*Entandophragma cylindricum*	161	21	819,32	large
22	CL	*Celtis mildbraedii*	87	16	864,19	large
23	CL	*Celtis mildbraedii*	100	17	436,80	medium
24	CL	*Entandophragma cylindricum*	122	18	866,04	large
25	CL	*Pterygota macrocarpa*	100	17	1.128,01	large
26	CL	*Cylicodiscus gabunensis*	120	22	737,72	medium
27	CL	*Nesogordonia papaverifera*	71	18	763,70	medium
28	CL	*Piptadeniastrum africanum*	100	16	577,85	medium
29	CL	*Cylicodiscus gabunensis*	104	17	699,34	medium
30	CL	*Celtis mildbraedii*	77	20	1.013,45	large
31	CL	*Celtis mildbraedii*	67	18	404,55	medium
32	CL	*Khaya ivorensis*	94	16	531,06	medium
33	CL	*Triplochiton scleroxylon*	134	17	699,05	medium
34	CL	*Cylicodiscus gabunensis*	127	18	584,69	medium
35	CL	*Entandophragma cylindricum*	152	18	953,99	large
36	CL	*Cylicodiscus gabunensis*	112	17	947,85	large
37	CL	*Khaya ivorensis*	135	22	1.503,70	large
38	CL	*Khaya ivorensis*	89	21	663,92	medium
39	CL	*Antiaris toxicaria*	101	16	571,60	medium
40	CL	*Entandophragma cylindricum*	131	18	613,60	medium

ANNEX 03: GPS COORDINATES OF LOGGING GAPS / INVENTORY SPOTS

List of the GPS coordinates of all selected logging gaps in Compartment 17 & 38 of the Nkrabia forest reserve. CL: Conventional logging and CM: Chainsaw milling. The Gap No. corresponds to Annex 02: Characteristics of logging gaps. The GPS coordinates represent the location of the survey plot center according to the defined gap center. GPS coordinates in decimal degrees.

Gap No.	Logging practice	GPS Coordinates	
1	CM	N 06°01´074´´	W 001°35´516´´
2	CM	N 06°01´082´´	W 001°35´324´´
3	CM	N 06°01´070´´	W 001°35´248´´
4	CM	N 06°00´971´´	W 001°35´325´´
5	CM	N 06°00´992´´	W 001°35´349´´
6	CM	N 06°00´988´´	W 001°35´372´´
7	CM	N 06°00´969´´	W 001°35´342´´
8	CM	N 06°01´064´´	W 001°35´533´´
9	CM	N 06°01´069´´	W 001°35´327´´
10	CM	N 06°00´920´´	W 001°35´345´´
11	CM	N 06°00´859´´	W 001°35´364´´
12	CM	N 06°00´888´´	W 001°35´362´´
13	CM	N 06°00´884´´	W 001°35´388´´
14	CM	N 06°00´805´´	W 001°35´362´´
15	CM	N 06°00´811´´	W 001°35´379´´
16	CM	N 06°00´774´´	W 001°35´359´´
17	CM	N 06°00´745´´	W 001°35´341´´
18	CM	N 06°00´755´´	W 001°35´300´´
19	CM	N 06°00´752´´	W 001°35´294´´
20	CM	N 06°00´776´´	W 001°35´280´´
21	CL	N 05°59´978´´	W 001°32´968´´
22	CL	N 05°59´964´´	W 001°32´945´´
23	CL	N 05°59´953´´	W 001°32´955´´
24	CL	N 05°59´938´´	W 001°33´043´´
25	CL	N 05°59´912´´	W 001°33´023´´
26	CL	N 05°59´962´´	W 001°33´125´´
27	CL	N 05°59´958´´	W 001°32´986´´
28	CL	N 05°59´953´´	W 001°33´075´´
29	CL	N 05°59´878´´	W 001°33´194´´
30	CL	N 05°59´894´´	W 001°33´145´´
31	CL	N 05°59´888´´	W 001°33´105´´
32	CL	N 05°59´923´´	W 001°32´929´´
33	CL	N 05°59´897´´	W 001°32´873´´
34	CL	N 05°59´819´´	W 001°32´926´´
35	CL	N 05°59´811´´	W 001°32´944´´
36	CL	N 05°59´795´´	W 001°32´998´´
37	CL	N 05°59´832´´	W 001°33´014´´
38	CL	N 05°59´785´´	W 001°33´065´´
39	CL	N 05°59´793´´	W 001°33´141´´
40	CL	N 05°59´795´´	W 001°33´176´´

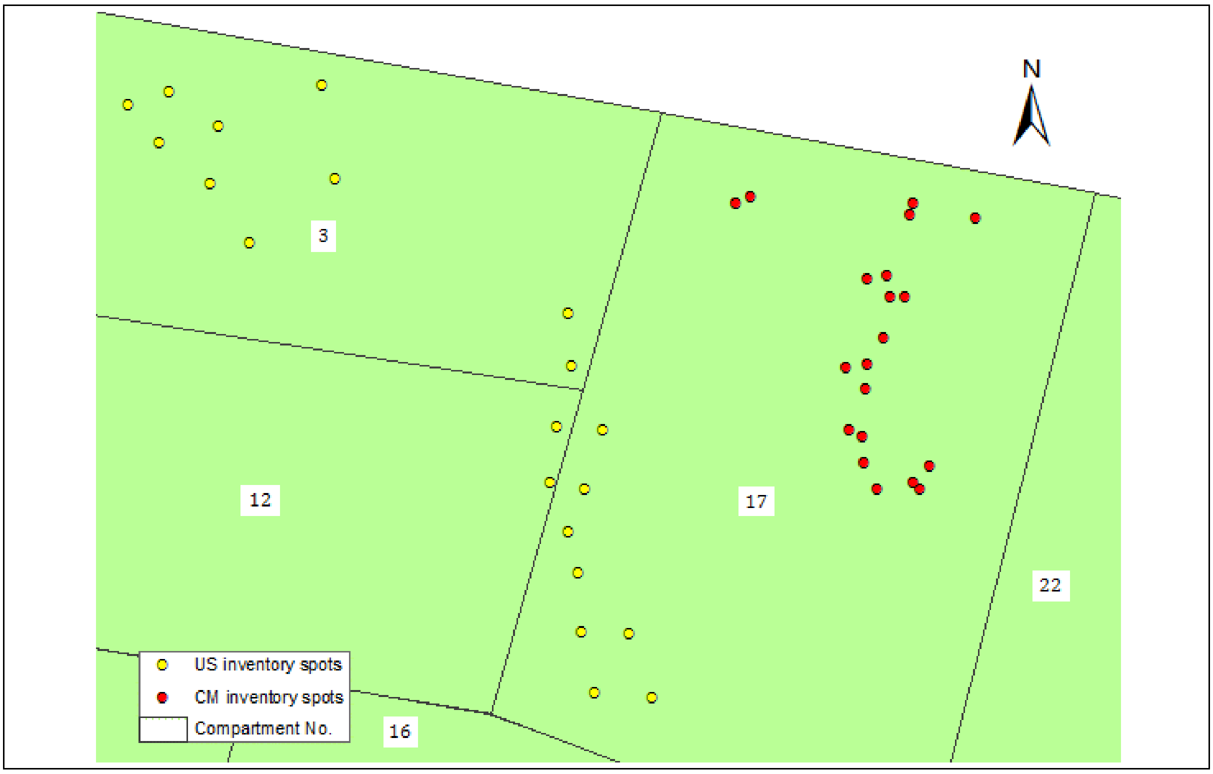
ANNEX 04: GPS COORDINATES OF UNDISTURBED SITES / INVENTORY SPOTS

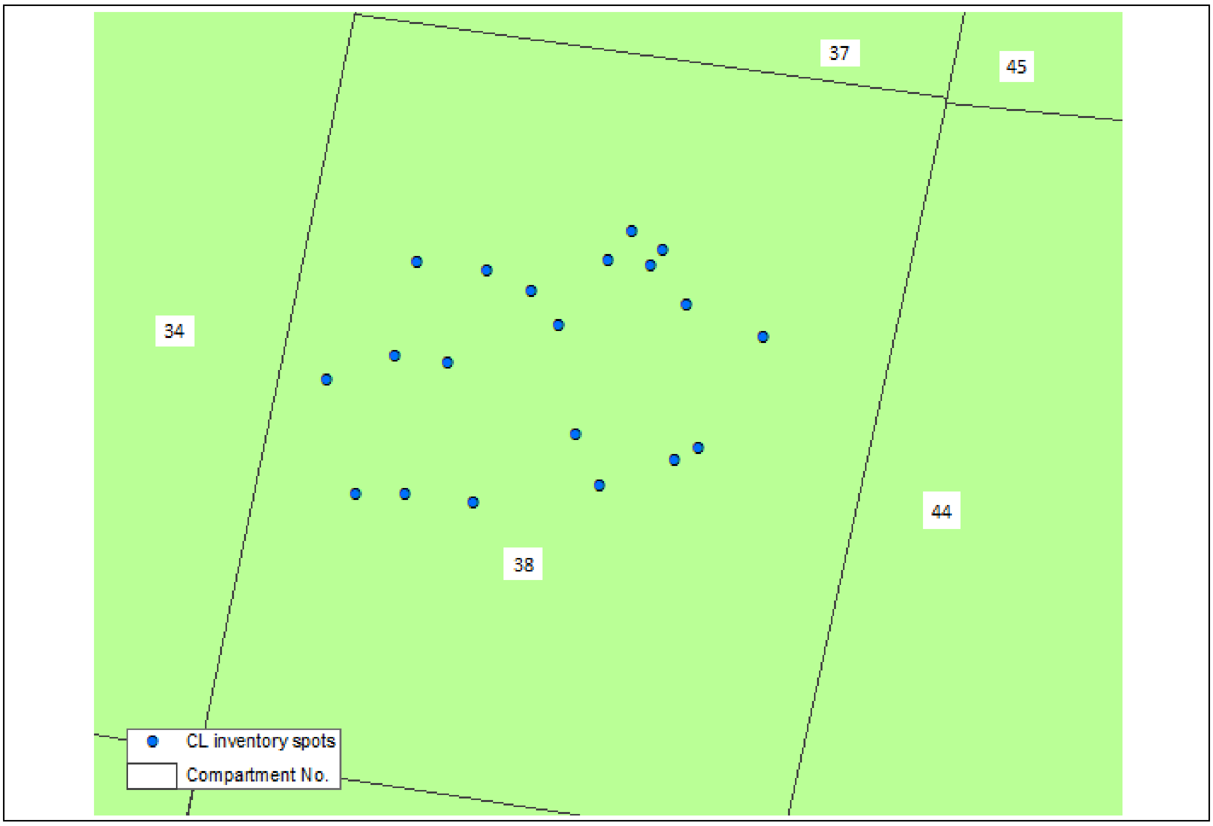
List of the GPS coordinates of all survey plots in undisturbed forest sites in the Nkrabia forest reserve. US: Undisturbed site. The Plot No. is in continuation of the Gap No. of Annex 03: GPS coordinates of logging gaps / inventory spots. The GPS coordinates represent the defined plot centers according to the defined inventory spot [US]. GPS coordinates in decimal degrees.

Plot No.		**GPS Coordinates**	
41	US	N 06°00´916´´	W 001°35´711´´
42	US	N 06°00´857´´	W 001°35´677´´
43	US	N 06°00´791´´	W 001°35´699´´
44	US	N 06°00´730´´	W 001°35´711´´
45	US	N 06°00´674´´	W 001°35´692´´
46	US	N 06°00´560´´	W 001°35´683´´
47	US	N 06°00´494´´	W 001°35´669´´
48	US	N 06°00´486´´	W 001°35´602´´
49	US	N 06°00´556´´	W 001°35´624´´
50	US	N 06°00´627´´	W 001°35´680´´
51	US	N 06°00´722´´	W 001°35´670´´
52	US	N 06°00´784´´	W 001°35´644´´
53	US	N 06°01´171´´	W 001°36´190´´
54	US	N 06°01´125´´	W 001°36´155´´
55	US	N 06°01´077´´	W 001°36´096´´
56	US	N 06°01´010´´	W 001°36´055´´
57	US	N 06°01´077´´	W 001°35´948´´
58	US	N 06°01´186´´	W 001°35´954´´
59	US	N 06°01´142´´	W 001°36´083´´
60	US	N 06°01´177´´	W 001°36´146´´

ANNEX 05: LOCATION OF INVENTORY SPOTS

Location of the inventory spots [CM, CL & US] within the Compartments of the Nkrabia forest reserve. CM: Chainsaw milling (*red*), US: Undisturbed site (*yellow*) [Scale: 1 : 18.750] and CL: Conventional logging (*blue*) [Scale: 1 : 12.500].





ANNEX 06: SPECIES LIST OF GAP BORDER TREES

Species list of recorded Gap border trees; Species arranged in alphabetical order. The 10 most abundant species in total are highlighted. CL: Conventional logging [Compartment 38, Nkrabia forest reserve] and CM: Chainsaw milling [Compartment 17, Nkrabia forest reserve].

Species	**Abundance CL [Comp. 38]**	**Abundance CM [Comp. 17]**	**Abundance total**
	(%)	(%)	(%)
Aidia genipiflora	0,83 %	0,38 %	0,64 %
Albizia ferruginea	0,55 %	-	0,32 %
Albizia glaberrima	0,28 %	0,38 %	0,32 %
Albizia zygia	-	0,38 %	0,16 %
Allanblackia floribunda	0,28 %	-	0,16 %
Alstonia boonei	0,83 %	1,53 %	1,12 %
Amphimas pterocarpoides	0,55 %	0,38 %	0,48 %
Aningeria altissima	0,55 %	1,91 %	1,12 %
Antiaris toxicaria	0,55 %	-	0,32 %
Baphia pubescens	0,28 %	-	0,16 %
Blighia sapida	3,86 %	0,38 %	**2,40 %**
Bombax brevicuspe	-	0,38 %	0,16 %
Calpocalyx brevibracteatus	0,28 %	1,15 %	0,64 %
Canarium schweinfurthii	0,28 %	0,38 %	0,32 %
Ceiba pentandra	0,83 %	0,38 %	0,64 %
Celtis adolfi-friderici	0,55 %	1,15 %	0,80 %
Celtis mildbraedii	27,55 %	31,30 %	**29,12 %**
Celtis zenkeri	0,83 %	1,15 %	0,96 %
Chrysophyllum perpulchrum	-	0,38 %	0,16 %
Cleistopholis patens	-	0,38 %	0,16 %
Cola nitida	1,38 %	0,38 %	0,96 %
Copaifera salikounda	0,28 %	-	0,16 %
Corynanthe pachyceras	-	0,76 %	0,32 %
Craterispermum caudatum	-	0,38 %	0,16 %
Cylicodiscus gabunensis	3,86 %	2,29 %	**3,20 %**
Dacryodes klaineana	6,06 %	-	**3,52 %**
Daniellia ogea	0,28 %	0,38 %	0,32 %
Diospyros soubreana	-	0,38 %	0,16 %
Diospyros viridicans	0,28 %	0,38 %	0,32 %
Discoglypremna caloneura	-	0,76 %	0,32 %
Distemonanthus benthamianus	0,28 %	-	0,16 %
Duboscia macrocarpa	-	0,38 %	0,16 %
Duboscia viridiflora	-	0,38 %	0,16 %
Elaeis guineensis	0,28 %	0,38 %	0,32 %
Enantia polycarpa	0,28 %	-	0,16 %
Entandophragma angolense	1,65 %	1,91 %	1,76 %
Entandophragma candollei	0,28 %	-	0,16 %
Erythrina mildbraedii	0,28 %	-	0,16 %
Ficus exasperata	-	1,53 %	0,64 %
Funtumia africana	2,48 %	1,15 %	1,92 %
Funtumia elastica	-	0,38 %	0,16 %
Greenwayodendron oliveri	0,55 %	-	0,32 %
Guarea cedrata	0,28 %	1,15 %	0,64 %

Hannoa klaineana	1,38 %	0,76 %	1,12 %
Hexalobus crispiflorus	0,55 %	-	0,32 %
Homalium letestui	0,55 %	-	0,32 %
Hymenostegia afzelii	3,58 %	-	2,08 %
Khaya ivorensis	0,83 %	-	0,48 %
Klainedoxa gabonensis	0,28 %	-	0,16 %
Lannea welwitschii	0,28 %	0,38 %	0,32 %
Lecaniodiscus cupanioides	0,28 %	-	0,16 %
Macaranga barteri	0,28 %	-	0,16 %
Maesopsis eminii	0,28 %	-	0,16 %
Mammea africana	-	0,38 %	0,16 %
Milicia excelsa	0,28 %	0,38 %	0,32 %
Monodora myristica	1,10 %	0,38 %	0,80 %
Musanga cecropioides	1,38 %	0,38 %	0,96 %
Myrianthus arboreus	0,55 %	-	0,32 %
Myrianthus libericus	1,38 %	1,53 %	1,44 %
Nesogordonia papaverifera	1,93 %	5,73 %	**3,52 %**
Ongokea gore	0,28 %	0,38 %	0,32 %
Panda oleosa	0,55 %	-	0,32 %
Parinari excelsa	-	0,38 %	0,16 %
Parkia bicolor	0,28 %	-	0,16 %
Pentaclethra macrophylla	1,10 %	-	0,64 %
Petersianthus macrocarpus	2,48 %	1,53 %	2,08 %
Phyllocosmus africanus	0,28 %	-	0,16 %
Piptadeniastrum africanum	2,48 %	2,29 %	**2,40 %**
Pleiocarpa mutica	0,28 %	-	0,16 %
Pterocarpus santalinoides	0,55 %	-	0,32 %
Pterygota macrocarpa	1,38 %	1,53 %	1,44 %
Pycnanthus angolensis	0,83 %	-	0,48 %
Ricinodendron heudelotii	2,20 %	2,67 %	**2,40 %**
Scottellia klaineana	0,55 %	-	0,32 %
Sterculia oblonga	1,65 %	3,82 %	**2,56 %**
Sterculia rhinopetala	0,55 %	2,67 %	1,44 %
Sterculia tragacantha	0,83 %	0,38 %	0,64 %
Strombosia glaucescens	0,55 %	6,11 %	**2,88 %**
Terminalia superba	0,28 %	0,38 %	0,32 %
Tetrapleura tetraptera	0,28 %	-	0,16 %
Tetrorchidium didymostemon	-	1,53 %	0,64 %
Treculia africana	0,28 %	-	0,16 %
Tricalysia discolor	0,28 %	0,38 %	0,32 %
Trichilia monadelpha	1,65 %	3,44 %	2,40 %
Trichilia prieureana	1,93 %	0,38 %	1,28 %
Trichilia tessmannii	0,28 %	0,76 %	0,48 %
Trilepisium madagascariense	0,28 %	1,15 %	0,64 %
Triplochiton scleroxylon	1,10 %	4,58 %	**2,56 %**
Uapaca guineensis	3,86 %	-	2,24 %
Xylia evansii	0,28 %	-	0,16 %
Xylopia villosa	0,28 %	-	0,16 %
Zanthoxylum gilletii	0,28 %	-	0,16 %
Zanthoxylum leprieurii	-	0,38 %	0,16 %
Zanthoxylum parvifoliolum	-	0,38 %	0,16 %

Annex 07: Species list and classification

Species list and classification of all recorded plant species; Species arranged in alphabetical order. Included: Natural regeneration in survey plots, Gap makers and Gap border trees. L = liana, SC = small climber, SH = shrub- or large woody herb, T = tree. NPLD = Non-pioneer Light-demander, P = Pioneer and SB = Shade-bearer.

Species	**Author**	**Growth *Class***	**Succ. *Class***	**Star *Category***	**Commercial *Class***
Acacia kamerunensis	Gand.	L	NPLD	Green	-
Acacia pentagona	(Schumach.&Thonn.)Hook.f.	L	NPLD	Green	-
Acridocarpus alternifolius	(Schumach.&Thonn.)Niedenzu.	SC	NPLD	Green	-
Acridocarpus longifolius	(G.Don)Hook.f.	L	NPLD	Green	-
Adenia rumicifolia	Engl.&Harms	L	P	Green	-
Afrosersalisia afzelii	(Engl.)A.Chev.	T	SB	Green	III
Agelaea nitida	(Lam.)Baill.	L	SB	Green	-
Agelaea paradoxa	Gilg	L	NPLD	Green	-
Aidia genipiflora	(DC.)Dandy	T	SB	Green	III
Alafia barteri	Oliv.	L	NPLD	Green	-
Albizia adianthifolia	(Schumach.)W.F.Wight	T	NPLD	Green	III
Albizia ferruginea	(Guill.&Perr.)Benth.	T	NPLD	Scarlet	I
Albizia glaberrima	(Schumach.&Thonn.)Benth.	T	NPLD	Green	III
Albizia zygia	(DC.)J.F.Macbr.	T	NPLD	Pink	I
Allanblackia floribunda	A.Chev.	T	SB	Pink	III
Alstonia boonei	DeWild.	T	P	Green	I
Amphimas pterocarpoides	Harms	T	NPLD	Green	I
Aningeria altissima	(A.Chev.)Baehni	T	NPLD	Scarlet	I
Anthonotha macrophylla	P.Beauv.	T	SB	Green	III
Antiaris toxicaria	(Rumph.ex Pers.)Leschen.	T	NPLD	Red	I
Baissea baillonii	Hua	SC	SB	Green	-
Baphia nitida	Lodd.	T	SB	Green	III
Baphia pubescens	Hook.f.	T	P	Green	III
Berlinia tomentella	Keay.	T	SB	Green	I
Blighia sapida	Konig	T	NPLD	Green	II
Blighia unijugata	Baker	T	SB	Green	II
Blighia welwitschii	(Hiern.)Radlk.	T	NPLD	Green	III
Bombax brevicuspe	(Sprague)Roberty	T	P	Red	I
Bridelia atroviridis	Müll.Arg.	T	P	Green	III
Bussea occidentalis	Hutch.	T	NPLD	Green	III
Caloncoba echinata	(Oliv.)Gilg.	T	SB	Green	III
Calpocalyx brevibracteatus	Harms	T	SB	Green	II
Calycobolus africanus	(G.Don)Heine	L	SB	Green	-
Canarium schweinfurthii	Engl.	T	P	Red	I
Carapa procera	DC.	T	SB	Green	III
Carpolobia alba	G.Don	SH	SB	Green	-
Carpolobia lutea	G.Don	SH	SB	Green	-
Ceiba pentandra	(L.)Gaertn.	T	P	Red	I
Celtis adolfi-friderici	Engl.	T	P	Pink	II
Celtis mildbraedii	Engl.	T	SB	Pink	I
Celtis zenkeri	Engl.	T	NPLD	Pink	I
Cercestis afzelii	Schott	SC	SB	Green	-

Species	Author	Growth *Class*	Succ. *Class*	Star *Category*	Commercial *Class*
Chlamydocarya macrocarpa	A.Chev. Ex Hutch.&Dalziel	SC	SB	Green	-
Chrysophyllum perpulchrum	Mildbr.exHutch.&Dalziel	T	NPLD	Pink	II
Chrysophyllum pruniforme	Pierre ex Engl.	T	SB	Pink	II
Chytranthus carneus	Radlk.	T	SB	Green	III
Cissus aralioides	(Welw. ex Baker)Planch.	SC	SB	Green	-
Cissus producta	Afzel.	SC	SB	Green	-
Cleidion gabonicum	Baill.	T	SB	Green	III
Cleistopholis patens	(Benth.)Engl.&Diels	T	P	Green	III
Cnestis ferruginea	Vahl ex DC.	SC	P	Green	-
Cola caricifolia	(G.Don)K.Schum.	T	P	Green	III
Cola gigantea	A.Chev.	T	NPLD	Green	II
Cola millenii	K.Schum.	T	NPLD	Green	III
Cola nitida	(Vent.)Schott.&Endl.	T	SB	Pink	III
Cola verticillata	(Thonn.)Stapf ex A.Chev.	T	SB	Green	III
Combretum oyemense	Exell.	L	non	Green	-
Combretum racemosum	P.Beauv.	L	P	Green	-
Combretum smeathmannii	Schumach.	L	P	Green	-
Combretum zenkeri	Engl.&Diels	L	P	Green	-
Copaifera salikounda	Heckel	T	SB	Red	I
Corynanthe pachyceras	K.Schum.	T	NPLD	Green	II
Craterispermum caudatum	Hutch.	T	SB	Green	III
Culcasia angolensis	Welw. ex Schott.	SH	NPLD	Green	-
Culcasia striolata	Engler.	SH	SB	Green	-
Cylicodiscus gabunensis	Harms	T	SB	Pink	I
Dacryodes klaineana	(Pierre)H.J.Lam	T	SB	Green	III
Dactyladenia barteri	(Hook.f. ex Oliv)Prance&White	T	SB	Green	III
Dalbergia adamii	J.Berhaut	L	non	Green	-
Dalbergia afzeliana	G.Don	L	NPLD	Green	-
Dalbergia saxatilis	Hook.f.	SC	non	Green	-
Daniellia ogea	(Harms)Holland	T	P	Red	I
Deinbollia pinnata	Schumach.&Thonn.	T	NPLD	Green	III
Dialium dinklagei	Harms	T	NPLD	Green	III
Dichapetalum pallidum	(Oliv.)Engl.	SC	SB	Green	-
Dichapetalum toxicarium	(G.Don)Baill.	L	NPLD	Green	-
Dioscorea praehensilis	Benth.	SC	NPLD	Green	-
Diospyros ferrea	(Willd.)Bakh.	T	SB	Green	III
Diospyros gabunensis	Gürke	T	SB	Green	III
Diospyros monbuttensis	Gürke	T	SB	Green	III
Diospyros piscatoria	Gürke	T	SB	Green	III
Diospyros soubreana	F.White	T	SB	Green	III
Diospyros viridicans	Hiern	T	SB	Green	III
Discoglypremna caloneura	(Pax)Prain	T	P	Green	III
Distemonanthus benthamianus	Baill.	T	NPLD	Red	I
Dorstenia kameruniana	Engl.	T	non	Green	III
Dracaena ovata	Ker-Gawl.	SH	non	Green	-
Dracaena phrynioides	Hook.	SH	SB	Green	-
Dracaena surculosa	Lindl.	SH	SB	Green	-
Duboscia macrocarpa	Bocq.	T	NPLD	Green	III

Species	**Author**	**Growth *Class***	**Succ. *Class***	**Star *Category***	**Commercial *Class***
Elaeis guineensis	Jacq.	T	P	Green	III
Enantia polycarpa	(A.DC.)Van Setten&Maas	T	SB	Green	III
Entandophragma angolense	(Welw.)DC.	T	NPLD	Scarlet	I
Entandophragma candollei	Harms	T	NPLD	Scarlet	I
Entandophragma cylindricum	(Sprague)Sprague	T	NPLD	Scarlet	I
Eremospatha macrocarpa	(Mann&Wendl.)Wendl.	L	NPLD	Green	-
Erythrina mildbraedii	Harms	T	P	Blue	III
Euadenia eminens	Hook.f.	SH	SB	Green	-
Ficus exasperata	Vahl	T	P	Green	II
Flagellaria guineensis	Cav.	SC	SB	Green	-
Funtumia africana	(Benth.)Stapf	T	NPLD	Green	III
Funtumia elastica	(Preuss)Stapf	T	non	Green	III
Glyphaea brevis	(Spreng.)Monachino	T	SB	Green	III
Gongronema latifolium	Benth.	L	non	Green	-
Greenwayodendron oliveri	(Engl.)Verdc.	T	SB	Green	III
Grewia mollis	Juss.	T	P	Green	III
Griffonia simplicifolia	(Vahl ex DC.)Baill.	L	NPLD	Green	-
Guarea cedrata	(A.Chev.)Pellegr.	T	SB	Red	I
Guibourtia ehie	(A.Chev.)J.Léonard	T	NPLD	Scarlet	I
Hannoa klaineana	Pierre&Engl.	T	P	Green	II
Heisteria parvifolia	Sm.	T	SB	Green	III
Hexalobus crispiflorus	A.Rich.	T	SB	Green	III
Hildegardia barteri	(Mast.)Kosterm.	T	non	Blue	III
Hippocratea vignei	Hoyle	L	non	Green	-
Homalium letestui	Pellegr.	T	NPLD	Green	II
Hoslundia opposita	Vahl	SH	P	Green	-
Hymenostegia afzelii	(Oliv.)Harms	T	SB	Green	III
Hypselodelphys poggeana	(K.Schum.)Milne-Redh.	SH	P	Green	-
Hypselodelphys triangulare	Jongkind ined.	SH	P	Green	-
Hypselodelphys violacea	(Ridl.)Milne-Redh.	SH	P	Green	-
Ixora laxiflora	Sm.	SH	SB	Green	-
Khaya ivorensis	A.Chev.	T	NPLD	Scarlet	I
Klainedoxa gabonensis	Pierre ex Engl.	T	NPLD	Pink	I
Laccosperma opacum	G.Mann&H.Wendl.	L	NPLD	Green	-
Landolphia hirsuta	(Hua)Pichon	L	non	Green	-
Landolphia macrantha	(A.Chev.)Pichon	L	NPLD	Green	-
Landolphia owariensis	P.Beauv.	L	non	Green	-
Lannea welwitschii	(Hiern)Engl.	T	P	Green	II
Lecaniodiscus cupanioides	Planch.ex Benth.	T	SB	Green	III
Leea guineensis	G.Don	SH	P	Green	-
Lepisanthes senegalensis	(Poir.)Leenhouts	T	SB	Green	III
Leptaspis cochleata	Thwaites	SH	SB	Green	-
Leptaulus daphnoides	Benth.	T	SB	Green	III
Leptoderris brachyptera	(Benth.)Dunn	L	non	Green	-
Lijndenia barteri	(Hook.f.)K.Bremer	SH	non	Green	-
Lovoa trichilioides	Harms	T	NPLD	Red	I
Lychnodiscus reticulatus	Radlk.	T	SB	Green	III
Macaranga barteri	Müll.Arg.	T	P	Green	III
Maesobotrya barteri	(Baill.)Hutch.	T	SB	Green	III

Species	Author	Growth *Class*	Succ. *Class*	Star *Category*	Commercial *Class*
Mallotus oppositifolius	(Geisel.)Müll.Arg.	T	SB	Green	III
Mammea africana	Sabine	T	SB	Blue	I
Manniophyton fulvum	Müll.Arg.	L	NPLD	Green	-
Marantochloa leucantha	(K.Schum.)Milne-Redh.	SH	P	Green	-
Mareya micrantha	(Benth.)Müll.Arg	T	SB	Green	III
Massularia acuminata	(G.Don)Bullock ex Hoyle	T	SB	Green	III
Memecylon spp.		T	SB	Green	III
Microdesmis puberula	Hook.f. ex Planch.	T	SB	Green	III
Milicia excelsa	(Welw.)C.C.Berg	T	P	Scarlet	I
Millettia chrysophylla	Dunn	L	NPLD	Green	-
Millettia zechiana	Harms	T	P	Green	III
Monodora myristica	(Gaertn.)Dunal	T	SB	Green	II
Monodora tenuifolia	Benth.	T	P	Green	III
Morinda morindoides	(Baker)Milne-Redh.	SC	NPLD	Green	-
Motandra guineensis	(Thonn.)A.DC.	SC	NPLD	Green	-
Musanga cecropioides	F.Br.	T	P	Green	III
Myrianthus arboreus	P.Beauv.	T	SB	Green	III
Myrianthus libericus	Rendle	T	SB	Green	III
Napoleonaea vogelii	Hook.&Planch.	T	SB	Green	III
Neostenanthera gabonensis	(Engl.&Diels.)Exell.	T	SB	Green	III
Nesogordonia papaverifera	(A.Chev.)R.Capuron	T	SB	Pink	I
Newbouldia laevis	(P.Beauv.)Seemann ex Bureau	T	P	Green	III
Nichallea soyauxii	(Hiern) Bridson	SC	non	Green	-
Olax gambecola	Baill.	SH	SB	Green	-
Ongokea gore	(Hua)Pierre	T	NPLD	Pink	II
Ouratea calophylla	(Hook.f.)Tiegh.	T	SB	Green	III
Panda oleosa	Pierre	T	SB	Green	II
Parinari excelsa	Sabine	T	NPLD	Green	III
Parkia bicolor	A.Chev.	T	NPLD	Green	III
Pentaclethra macrophylla	Benth.	T	NPLD	Green	III
Persea americana	Mill.	T	non	Green	III
Petersianthus macrocarpus	(P.Beauv.)Liben	T	P	Pink	I
Phyllocosmus africanus	(Hook.f.)Klotzsch	T	NPLD	Green	III
Piper guineensis	Schumach.&Thonn.	SC	SB	Green	-
Piptadeniastrum africanum	(Hook.f.)Brenan	T	NPLD	Red	I
Pleiocarpa mutica	Benth.	T	SB	Green	III
Psychotria ivorensis	DeWild.	SH	SB	Green	-
Pterocarpus santalinoides	DC.	T	non	Green	III
Pterygota macrocarpa	K.Schum.	T	NPLD	Scarlet	I
Pycnanthus angolensis	(Welw.)Warb.	T	NPLD	Red	I
Pycnocoma macrophylla	Benth.	SH	SB	Green	-
Raphia hookeri	G.Mann&H.Wendl.	T	non	Green	III
Rauvolfia vomitoria	Afzel.	T	P	Green	III
Rhaphiostylis beninensis	(Hook.f.)Planch ex Benth	L	SB	Green	-
Rhaphiostylis cordifolia	Hutch.&Dalziel	L	SB	Green	-
Rhaphiostylis preussii	Engl.	L	SB	Green	-
Ricinodendron heudelotii	(Baill.)Pierre ex Pax	T	P	Pink	II
Rinorea angustifolia	(Thou.)Baill.	T	SB	Green	III
Rinorea ilicifolia	Kuntze	SH	SB	Green	-

Species	**Author**	**Growth** ***Class***	**Succ.** ***Class***	**Star** ***Category***	**Commercial** ***Class***
Rothmannia longiflora	Salisb.	T	SB	Green	III
Rourea coccinea	(Thonn. ex Schumach.)Benth.	SC	P	Green	-
Salacia columna	N.Halle	L	SB	Green	-
Salacia elegans	Welw. ex Oliv.	L	NPLD	Green	-
Salacia owabiensis	(Sabine)Steud.	L	NPLD	Green	-
Salacia pallescens	Oliv.	SC	NPLD	Green	-
Scottellia klaineana	Pierre	T	SB	Pink	II
Smilax kraussiana	Willd.	SC	P	Green	-
Solanum anomalum	Thonning	SH	P	Green	-
Solanum erianthum	D.Don	T	P	Green	III
Sphenocentrum jollyanum	Pierre	SH	SB	Green	-
Stachyanthus occidentalis	(Keay&Miège)Boutique	SC	SB	Green	-
Sterculia oblonga	Mast.	T	NPLD	Pink	II
Sterculia rhinopetala	K.Schum.	T	NPLD	Pink	I
Sterculia tragacantha	Lindl.	T	P	Green	II
Strombosia glaucescens	Oliv.	T	SB	Pink	I
Strophanthus gratus	(Hook.)Franch.	L	P	Green	-
Strychnos afzelii	Gilg	L	SB	Green	-
Strychnos asterantha	Leeuwenberg	L	non	Green	-
Strychnos floribunda	Gilg	L	NPLD	Green	-
Tabernaemontana africana	A.DC.	T	SB	Green	III
Terminalia superba	Engl.&Diels	T	P	Red	I
Tetrapleura tetraptera	(Schumach.&Thonn.)Taub.	T	P	Green	III
Tetrorchidium didymostemon	(Baill.)Pax&K.Hoffm.	T	P	Green	III
Tiliacora dielsiana	(Scott-Eliott)Diels	L	NPLD	Green	-
Treculia africana	Decne.	T	NPLD	Green	II
Tricalysia discolor	Brenan	T	SB	Green	III
Tricalysia pallens	Hiern.	T	SB	Green	III
Trichilia monadelpha	(Thonn.)J.J.deWilde	T	NPLD	Green	III
Trichilia prieureana	A.Juss.	T	NPLD	Green	II
Trichilia tessmannii	Harms	T	NPLD	Green	II
Triclisia dictyophylla	Diels	L	P	Green	-
Triclisia patens	Oliv.	SC	non	Green	-
Trilepisium madagascariense	DC.	T	NPLD	Green	II
Triplochiton scleroxylon	K.Schum.	T	P	Scarlet	I
Uapaca guineensis	Müll.Arg.	T	NPLD	Green	III
Uvaria anonoides	Baker f.	L	NPLD	Green	-
Uvariodendron calophyllum	R.E.Fr.	T	SB	Green	III
Vitex grandifolia	Gürke	T	SB	Green	III
Warneckea guineensis	(Keay)Jacq.-Fél.	T	SB	Green	III
Xylia evansii	Hutch.	T	NPLD	Blue	III
Xylopia villosa	Chipp	T	SB	Green	III
Zanthoxylum gilletii	(DeWild.)Watermann	T	P	Green	II
Zanthoxylum leprieurii	Guill.&Perr.	T	P	Green	III
Zanthoxylum parvifoliolum	(A.Chev.exKeay)W.D.Hawthorne	T	P	Gold	III

Annex 08: Species abundance and frequency

Species list showing the abundance (%) and frequency (%) of all recorded plant species of natural regeneration in the seedling and sapling category; Species arranged in alphabetical order. Abundance and frequency over all inventory units. The most important species regarding abundance and frequency in the seedling- and sapling category are highlighted.

Species	Sapling category		Seedling category	
	Abundance (%)	Frequency (%)	Abundance (%)	Frequency (%)
Acacia kamerunensis	**-**	**-**	**3,91 %**	**26,67 %**
Acacia pentagona	-	-	1,76 %	8,33 %
Acridocarpus alternifolius	-	-	0,06 %	1,67 %
Acridocarpus longifolius	-	-	0,12 %	6,67 %
Adenia rumicifolia	-	-	0,09 %	6,67 %
Afrosersalisia afzelii	-	-	0,03 %	1,67 %
Agelaea nitida	-	-	1,11 %	23,33 %
Agelaea paradoxa	-	-	1,63 %	35,00 %
Aidia genipiflora	0,20 %	3,33 %	0,15 %	5,00 %
Alafia barteri	-	-	0,31 %	11,67 %
Albizia adianthifolia	-	-	1,14 %	13,33 %
Albizia glaberrima	-	-	0,37 %	3,33 %
Albizia zygia	0,10 %	1,67 %	0,09 %	5,00 %
Allanblackia floribunda	0,10 %	1,67 %	-	-
Alstonia boonei	0,29 %	5,00 %	0,06 %	3,33 %
Amphimas pterocarpoides	0,49 %	8,33 %	-	-
Aningeria altissima	0,20 %	3,33 %	0,18 %	5,00 %
Anthonotha macrophylla	0,49 %	6,67 %	0,09 %	5,00 %
Antiaris toxicaria	0,59 %	10,00 %	0,15 %	8,33 %
Baissea baillonii	-	-	1,48 %	45,00 %
Baphia nitida	**16,39 %**	**81,67 %**	**2,99 %**	**65,00 %**
Baphia pubescens	1,57 %	21,67 %	-	-
Berlinia tomentella	0,10 %	1,67 %	0,03 %	1,67 %
Blighia sapida	0,59 %	6,67 %	0,55 %	21,67 %
Blighia unijugata	0,49 %	8,33 %	0,12 %	6,67 %
Bridelia atroviridis	-	-	0,03 %	1,67 %
Bussea occidentalis	-	-	1,85 %	1,67 %
Caloncoba echinata	0,10 %	1,67 %	-	-
Calpocalyx brevibracteatus	0,59 %	10,00 %	0,34 %	5,00 %
Calycobolus africanus	**-**	**-**	**3,39 %**	**91,67 %**
Canarium schweinfurthii	0,10 %	1,67 %	-	-
Carapa procera	0,20 %	3,33 %	0,43 %	8,33 %
Carpolobia alba	0,20 %	3,33 %	0,09 %	5,00 %
Carpolobia lutea	0,10 %	1,67 %	0,09 %	5,00 %
Ceiba pentandra	0,69 %	6,67 %	0,18 %	6,67 %
Celtis mildbraedii	**6,38 %**	**56,67 %**	**10,66 %**	**80,00 %**
Celtis zenkeri	0,20 %	3,33 %	0,03 %	1,67 %
Cercestis afzelii	-	-	0,18 %	10,00 %
Chrysophyllum perpulchrum	0,10 %	1,67 %	-	-
Chrysophyllum pruniforme	-	-	0,03 %	1,67 %
Chytranthus carneus	0,29 %	5,00 %	0,03 %	1,67 %
Cissus aralioides	-	-	0,06 %	5,00 %
Cissus producta	-	-	0,09 %	5,00 %

Species	Sapling category		Seedling category	
	Abundance (%)	Frequency (%)	Abundance (%)	Frequency (%)
Cleidion gabonicum	-	-	0,03 %	1,67 %
Cleistopholis patens	0,39 %	6,67 %	-	-
Cnestis ferruginea	-	-	0,49 %	18,33 %
Cola caricifolia	1,28 %	20,00 %	0,12 %	6,67 %
Cola gigantea	0,10 %	3,33 %	0,12 %	3,33 %
Cola millenii	0,29 %	3,33 %	-	-
Cola nitida	0,59 %	8,33 %	0,09 %	5,00 %
Cola verticillata	0,79 %	13,33 %	0,03 %	1,67 %
Combretum oyemense	-	-	0,06 %	3,33 %
Combretum racemosum	-	-	0,03 %	1,67 %
Combretum smeathmannii	-	-	0,03 %	1,67 %
Combretum zenkeri	-	-	0,28 %	13,33 %
Copaifera salikounda	0,10 %	1,67 %	0,06 %	3,33 %
Culcasia angolensis	-	-	0,12 %	3,33 %
Culcasia striolata	-	-	2,65 %	25,00 %
Cylicodiscus gabunensis	0,10 %	1,67 %	0,03 %	1,67 %
Dacryodes klaineana	0,39 %	5,00 %	0,06 %	3,33 %
Dactyladenia barteri	1,18 %	8,33 %	0,74 %	16,67 %
Dalbergia adamii	-	-	0,06 %	3,33 %
Dalbergia afzeliana	-	-	0,09 %	5,00 %
Dalbergia saxatilis	-	-	0,06 %	1,67 %
Daniellia ogea	0,20 %	5,00 %	-	-
Deinbollia pinnata	0,79 %	13,33 %	0,09 %	3,33 %
Dialium dinklagei	0,10 %	1,67 %	-	-
Dichapetalum pallidum	-	-	1,08 %	36,67 %
Dichapetalum toxicarium	-	-	0,34 %	11,67 %
Dioscorea praehensilis	-	-	0,09 %	5,00 %
Diospyros ferrea	1,08 %	11,67 %	0,55 %	8,33 %
Diospyros gabunensis	0,10 %	1,67 %	-	-
Diospyros monbuttensis	0,29 %	5,00 %	-	-
Diospyros piscatoria	-	-	0,06 %	3,33 %
Diospyros soubreana	-	-	0,03 %	1,67 %
Diospyros viridicans	0,10 %	1,67 %	-	-
Discoglypremna caloneura	0,59 %	10,00 %	-	-
Dorstenia kameruniana	-	-	0,15 %	6,67 %
Dracaena ovata	-	-	1,26 %	30,00 %
Dracaena phrynioides	-	-	0,06 %	3,33 %
Dracaena surculosa	-	-	1,05 %	21,67 %
Entandophragma angolense	0,10 %	1,67 %	0,31 %	6,67 %
Entandophragma candollei	-	-	0,03 %	1,67 %
Entandophragma cylindricum	0,10 %	1,67 %	-	-
Eremospatha macrocarpa	-	-	0,03 %	1,67 %
Euadenia eminens	0,10 %	1,67 %	0,06 %	3,33 %
Ficus exasperata	0,10 %	1,67 %	0,03 %	1,67 %
Flagellaria guineensis	-	-	0,03 %	1,67 %
Funtumia africana	0,69 %	6,67 %	0,40 %	13,33 %
Glyphaea brevis	0,69 %	6,67 %	0,06 %	3,33 %
Gongronema latifolium	-	-	0,25 %	10,00 %
Greenwayodendron oliveri	1,47 %	18,33 %	0,37 %	15,00 %

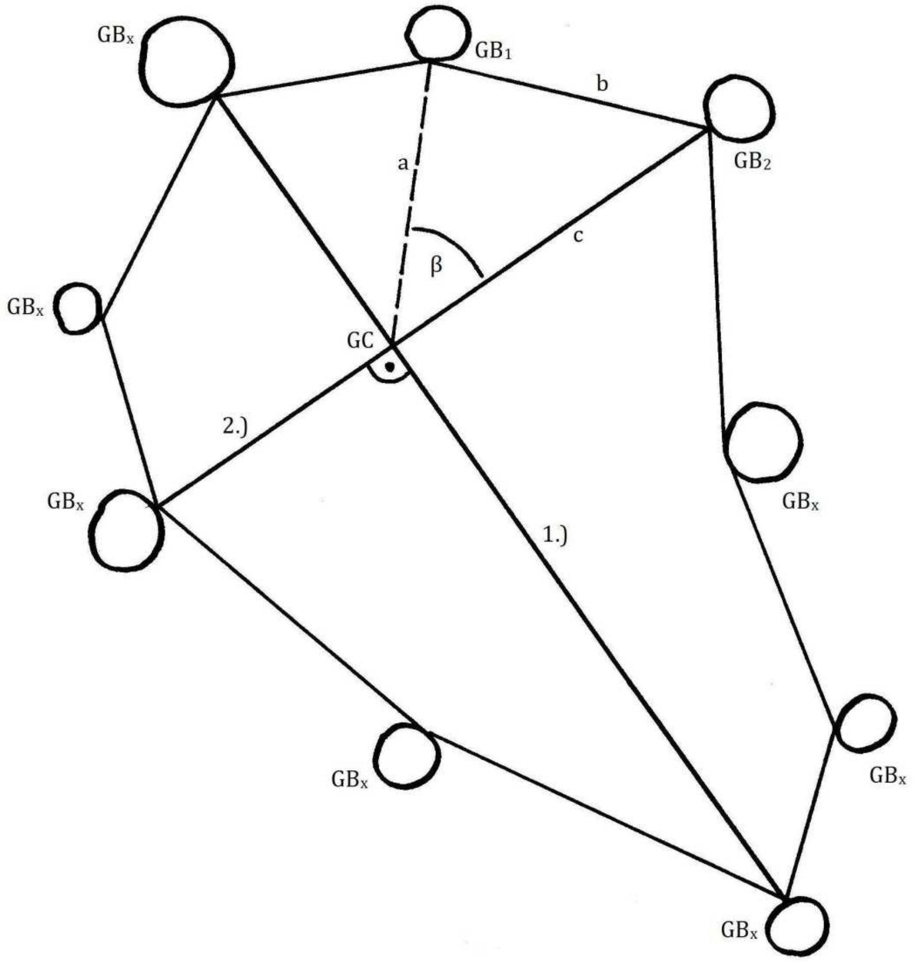
Species	Sapling category		Seedling category	
	Abundance (%)	Frequency (%)	Abundance (%)	Frequency (%)
Grewia mollis	-	-	0,03 %	1,67 %
Griffonia simplicifolia	**-**	**-**	**17,60 %**	**90,00 %**
Guarea cedrata	0,88 %	13,33 %	0,37 %	16,67 %
Guibourtia ehie	0,10 %	1,67 %	0,31 %	1,67 %
Hannoa klaineana	0,10 %	1,67 %	-	-
Heisteria parvifolia	0,69 %	8,33 %	0,22 %	8,33 %
Hildegardia barteri	-	-	0,18 %	5,00 %
Hippocratea vignei	-	-	0,52 %	26,67 %
Homalium letestui	0,10 %	1,67 %	-	-
Hoslundia opposita	0,20 %	3,33 %	-	-
Hymenostegia afzelii	1,67 %	11,67 %	1,51 %	11,67 %
Hypselodelphys poggeana	-	-	0,92 %	33,33 %
Hypselodelphys triangulare	-	-	0,15 %	5,00 %
Hypselodelphys violacea	-	-	0,22 %	5,00 %
Ixora laxiflora	0,10 %	1,67 %	-	-
Khaya ivorensis	0,10 %	1,67 %	0,03 %	1,67 %
Laccosperma opacum	-	-	0,12 %	6,67 %
Landolphia hirsuta	-	-	0,34 %	13,33 %
Landolphia macrantha	-	-	0,15 %	8,33 %
Landolphia owariensis	-	-	0,03 %	1,67 %
Lannea welwitschii	0,10 %	1,67 %	-	-
Lecaniodiscus cupanioides	0,39 %	5,00 %	0,09 %	5,00 %
Leea guineensis	-	-	0,06 %	3,33 %
Lepisanthes senegalensis	0,20 %	3,33 %	0,09 %	3,33 %
Leptaspis cochleata	-	-	0,49 %	5,00 %
Leptaulus daphnoides	-	-	0,03 %	1,67 %
Leptoderris brachyptera	-	-	0,09 %	3,33 %
Lijndenia barteri	-	-	0,09 %	5,00 %
Lovoa trichilioides	-	-	0,03 %	1,67 %
Lychnodiscus reticulatus	0,10 %	1,67 %	-	-
Macaranga barteri	0,10 %	1,67 %	-	-
Maesobotrya barteri	0,79 %	11,67 %	-	-
Mallotus oppositifolius	1,57 %	3,33 %	0,15 %	1,67 %
Manniophyton fulvum	-	-	0,22 %	10,00 %
Marantochloa leucantha	-	-	0,03 %	1,67 %
Mareya micrantha	0,20 %	1,67 %	-	-
Massularia acuminata	0,20 %	3,33 %	-	-
Memecylon spp.	-	-	0,03 %	1,67 %
Microdesmis puberula	**7,95 %**	**66,67 %**	**0,55 %**	**30,00 %**
Milicia excelsa	-	-	0,03 %	1,67 %
Millettia chrysophylla	**-**	**-**	**2,96 %**	**66,67 %**
Millettia zechiana	0,49 %	6,67 %	0,22 %	8,33 %
Monodora myristica	0,29 %	3,33 %	0,31 %	16,67 %
Monodora tenuifolia	0,29 %	5,00 %	0,25 %	11,67 %
Morinda morindoides	-	-	0,06 %	3,33 %
Motandra guineensis	-	-	1,45 %	41,67 %
Musanga cecropioides	0,69 %	11,67 %	0,06 %	3,33 %
Myrianthus arboreus	0,39 %	6,67 %	-	-
Myrianthus libericus	0,79 %	11,67 %	0,15 %	8,33 %

Species	Sapling category		Seedling category	
	Abundance (%)	Frequency (%)	Abundance (%)	Frequency (%)
Napoleonaea vogelii	2,45 %	31,67 %	0,46 %	21,67 %
Neostenanthera gabonensis	0,10 %	1,67 %	-	-
Nesogordonia papaverifera	**2,75 %**	**26,67 %**	**1,29 %**	**43,33 %**
Newbouldia laevis	0,39 %	6,67 %	0,03 %	1,67 %
Nichallea soyauxii	-	-	0,31 %	13,33 %
Olax gambecola	0,49 %	6,67 %	0,22 %	10,00 %
Ouratea calophylla	-	-	0,03 %	1,67 %
Persea americana	0,10 %	1,67 %	-	-
Petersianthus macrocarpus	0,29 %	5,00 %	0,37 %	8,33 %
Piper guineensis	-	-	0,31 %	11,67 %
Piptadeniastrum africanum	0,10 %	1,67 %	0,06 %	3,33 %
Pleiocarpa mutica	**3,83 %**	**25,00 %**	**0,49 %**	**20,00 %**
Psychotria ivorensis	0,20 %	1,67 %	0,15 %	8,33 %
Pterygota macrocarpa	0,39 %	6,67 %	0,06 %	3,33 %
Pycnanthus angolensis	0,20 %	3,33 %	0,12 %	6,67 %
Pycnocoma macrophylla	-	-	0,52 %	8,33 %
Raphia hookeri	-	-	0,03 %	1,67 %
Rauvolfia vomitoria	0,10 %	1,67 %	0,12 %	1,67 %
Rhaphiostylis beninensis	-	-	0,09 %	5,00 %
Rhaphiostylis cordifolia	-	-	0,71 %	21,67 %
Rhaphiostylis preussii	-	-	0,12 %	5,00 %
Ricinodendron heudelotii	1,77 %	13,33 %	0,12 %	5,00 %
Rinorea angustifolia	**5,20 %**	**41,67 %**	**1,54 %**	**31,67 %**
Rinorea ilicifolia	0,39 %	1,67 %	0,03 %	1,67 %
Rinorea oblongifolia	**3,34 %**	**25,00 %**	**1,05 %**	**23,33 %**
Rothmannia longiflora	0,59 %	10,00 %	0,06 %	3,33 %
Salacia columna	-	-	0,09 %	5,00 %
Salacia elegans	-	-	0,22 %	11,67 %
Salacia owabiensis	-	-	0,34 %	15,00 %
Salacia pallescens	-	-	0,28 %	8,33 %
Smilax kraussiana	**-**	**-**	**1,63 %**	**55,00 %**
Solanum anomalum	0,10 %	1,67 %	-	-
Solanum erianthum	0,39 %	3,33 %	-	-
Sphenocentrum jollyanum	**0,29 %**	**5,00 %**	**2,87 %**	**56,67 %**
Stachyanthus occidentalis	-	-	1,33 %	48,33 %
Sterculia oblonga	0,20 %	3,33 %	0,28 %	13,33 %
Sterculia rhinopetala	0,29 %	5,00 %	0,37 %	11,67 %
Sterculia tragacantha	0,29 %	5,00 %	0,12 %	5,00 %
Strombosia glaucescens	**9,32 %**	**55,00 %**	**1,51 %**	**41,67 %**
Strophanthus gratus	-	-	0,12 %	6,67 %
Strychnos afzelii	-	-	0,03 %	3,33 %
Strychnos asterantha	-	-	0,22 %	0,05 %
Strychnos floribunda	-	-	0,12 %	3,33 %
Tabernaemontana africana	0,39 %	6,67 %	0,03 %	1,67 %
Terminalia superba	0,20 %	3,33 %	0,06 %	3,33 %
Tetrorchidium didymostemon	0,29 %	3,33 %	-	-
Tiliacora dielsiana	-	-	0,22 %	6,67 %
Tricalysia discolor	-	-	0,03 %	1,67 %
Tricalysia pallens	-	-	0,12 %	5,00 %

Species	Sapling category		Seedling category	
	Abundance (%)	Frequency (%)	Abundance (%)	Frequency (%)
Trichilia monadelpha	0,29 %	5,00 %	0,83 %	18,33 %
Trichilia prieureana	**2,75 %**	**33,33 %**	**0,62 %**	**20,00 %**
Trichilia tessmannii	0,10 %	1,67 %	-	-
Triclisia dictyophylla	-	-	0,09 %	3,33 %
Triclisia patens	-	-	0,06 %	3,33 %
Triplochiton scleroxylon	0,20 %	3,33 %	0,03 %	1,67 %
Uvaria anonoides	-	-	0,09 %	5,00 %
Uvariodendron calophyllum	0,10 %	1,67 %	-	-
Vitex grandifolia	0,10 %	1,67 %	-	-
Warneckea guineensis	0,10 %	1,67 %	0,03 %	1,67 %
Xylopia villosa	0,49 %	8,33 %	0,09 %	5,00 %
Zanthoxylum gilletii	0,20 %	3,33 %	0,03 %	1,67 %

<u>ANNEX 09</u>: GAP SIZE ASSESSMENT AND DEFINITION OF THE GAP CENTER

Layout for the definition of the gap center [GC] with 1.) the longest straight distance that fits into the canopy gap [≙ the felling direction] and 2.) the longest distance that crosses the felling direction perpendicular. The GC marks the location spot for the survey plot within the logging gap. The area of single triangles within the gap was defined and calculated using the GC and two adjacent Gap border trees [GB_1 & GB_2, respectively for all GB_x] with b = distance between two adjacent Gap border trees [GB_1 & GB_2], a = distance from the GC to GB_1, c = distance from GC to GB_2 and β = enclosed angle (°). The Gap border trees were defined as the trees that surround the logging gap and have (1) a diameter breast height [DBH] of ≥ 20 cm and (2) a height of ≥ 20 meters.



Special thanks to my field team Jonathan Dabo (*upper picture, right*), Seth Kankam Nuamah (*lower picture, left*) and Phillip (*upper picture, left*) for their support during field work and their friendship during my wonderful and unforgettable time in Ghana, 2010.