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SOCIAL AND ECOLOGICAL IMPACTS OF LOGGING IN GHANA

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COVERING THE PERIOD 1ST SEPTEMBER 2000 TO 31ST AUGUST 2001

By

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# ACRONYMS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>dbh</td>
<td>Diameter at breast height</td>
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<tr>
<td>FAO</td>
<td>Food and Agriculture Organization of the United Nations</td>
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<tr>
<td>FD</td>
<td>Forestry Department</td>
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<tr>
<td>FIP</td>
<td>Forest Inventory Project</td>
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<tr>
<td>GHAFOSIM</td>
<td>Ghana Forest Simulation; a model developed to assist natural forest management in Ghana</td>
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<tr>
<td>GTMO</td>
<td>Ghana Timber Millers’ Organization</td>
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<td>IIED</td>
<td>International Institute for Environment and Development</td>
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<td>ITTO</td>
<td>International Tropical Timber Organization</td>
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<tr>
<td>MFD</td>
<td>Minimum Felling Diameter</td>
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<tr>
<td>NRCD</td>
<td>National Redemption Council Decree</td>
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<td>RWC</td>
<td>Research Working Cycle</td>
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<tr>
<td>TEDB</td>
<td>Timber Export Development Board</td>
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Terms of Reference

Ecological impacts of logging
- Help develop methodologies to:
  > determine forest recovery through time after logging;
  > determine the number of seed trees to be retained after logging for effective natural regeneration;
  > review minimum felling diameter limit for sustainable timber harvesting;
  > determine wood loss in standing trees due to logging wounds and identification of economically feasible methods of log preservation in forests.
- Provide direction and support to project staff in data analysis and reporting
- Provide support to the local project staff in the development of protocols for seed tree retention and yield allocation.

Social impacts of logging
- Help provide an adequate understanding of the social implications of logging to project staff
- Help develop methodologies to assess the impact of logging on the various user-groups of forests
- Propose mitigative actions necessary to restore the forest and maintain the community dependence on forest resources

ABSTRACT
The report is in two parts, the first dealing with social aspects of the project, the second with ecological and silvicultural issues.

The social implications of logging in Ghana’s forest reserves can be considered at both macro- and micro-levels. This project will focus on the micro-level impacts, particularly examining factors relevant to forest fringe communities. An examination of the socio-political context in which people living near forests is important for understanding how goods and services from forests support rural livelihoods and how forestry interacts with agriculture. Institutional arrangements governing access to resources and benefit-sharing agreements include both traditional and district government institutions. Conflicts have arisen over access to forest products because of lack of consultation in policy development and incompatibility of regulations requiring permitting and social understanding of rights of access.

We report on the project objectives to review application of minimum felling diameter limit in selective logging and assessing wood loss in standing trees due to logging wounds in Ghana. We do this first by reviewing the mechanisms used in regulating selective logging practices in Ghana from 1950 to 1990. Secondly we examine the ecological impacts of regulating selective logging through minimum felling diameter in a logging experiment. The third part of this report deals with assessment of wood loss in trees damaged by logging. The results of each study are discussed in relation to long-term impacts associated with minimum felling diameter and felling damage. This report does not include recommendations for the revision of the selective logging system in Ghana.

1.0 UNDERSTANDING THE SOCIAL IMPLICATIONS OF LOGGING

1.1 INTRODUCTION
Logging in Ghana’s forest reserves has both macro- and micro-level impacts on society. At the macro-level, activities in the reserves affect society through their contribution to the national economy, through the development of infrastructure (physical and institutional), and industrial processing capacity. Also, because logging can affect the ecological functions of forests, and contribute directly or indirectly to change in forest cover, they impact the environmental services that forests provide to society. At a micro-level, logging activities may impact people living near forests in a variety of ways. For example, in Ghana many rural people, particularly women, rely on non-timber forest products collected from the countryside, including the forest reserves (Falconer 1992). Logging activities within the reserves, and associated impacts adjacent to the reserves, may influence access to non-timber forest products and the quality and quantity of these products available in the landscape. Logging activities, with the associated influx of machinery and workers from outwith the area, may bring conflicts, for example in terms of disturbance (e.g., noise), risks to local people’s safety. Alternately, logging activities may bring short-term positive impacts such as temporary employment, improvements to road networks, and increases in economic activity (e.g., trade).

Attempts to manage Ghana’s forest resource have varied over time as social, economic and environmental changes have occurred in the country. These management practices have shown an evolutionary trend from the establishment or reservation phase, to the development of silvicultural and management systems. Although the forests are managed for many purposes logging is the most conspicuous activity in the forest.
It is clear that logging provides an important source of revenue in Ghana yet the socio-economic impacts of logging, particularly at the micro-level, are poorly known.

The aim of this component of the project is to contribute to the understanding of the social impacts of logging in forest reserves in Ghana. This aim is addressed through the following objectives: 1) to examine the issues through a review of policy, project experience and Environmental Impact Assessments; 2) to determine the impacts of logging on various user-groups, particularly from the perspective of the forest service, timber contractors and local communities; 3) to develop methodologies to assess the impact of logging on various user-groups; 4) to identify potential conflicts between timber management and the provision of goods and services valued by people living near forests; and, 5) to propose mitigative actions necessary to restore forest values that have been compromised, and to maintain the provision of goods and services to people living near the forest resources. In the first year report, the focus will be on the first objective.

1.2 BACKGROUND

Ghana's reserve forests (Appendix I) were demarcated for management as permanent forest estates for the preservation of soil and water resources, conservation of biological diversity and sustainable production for domestic and commercial use. Production reserves constitute almost 45% of the total forest estate, and from these forests the bulk of the nation's timber is produced.

The unreserved forest area is currently estimated by the Forestry Department to be 0.5 million ha. These areas were largely forested at the turn of the century but are rapidly disappearing as the forestland is giving way to other land uses. The unreserved forest patches lie within a matrix of bush fallows and active agricultural areas.

The intact forests, mostly located in the Western Region of the country, have substantial canopy cover with composition similar to the reserved areas. The bush fallows are secondary growth from abandoned farms with high potential for maturing into high forest if adequately managed. The agricultural lands are characterised by a relatively high density of trees on farms. Results from a forest inventory conducted by the Forestry Department of Ghana with the support of the Overseas Development Administration (ODA), UK, revealed that off-reserve forest areas have about 268 million m$^3$ of standing tree volume of suitable form to be classified as timber. About 101 million m$^3$ of the total volume is in trees greater than the minimum felling limits (FD undated).

There has been a rapid loss of forest resources from both reserved and off-reserved areas probably because of increasing population pressure. At the turn of the last century, the forest zone of Ghana covered about 34% of the total land area. However, by 1987 over 75% of the land area originally covered by forests had been cleared (Forestry Department, 1987). This corresponds to an annual deforestation rate of 0.84% (684 km$^2$). FAO (1988) estimated annual deforestation between 1981-1985 in Ghana to be 220 km$^2$. If these figures are reliable, they suggest that the deforestation rate is decreasing. This trend may be a reflection of the small forest area outside reserves that remains to be felled (Agyeman 1994).

The total volume of timber extracted in Ghana between 1986-1992 was 7.8 million m$^3$ (7.5% of standing volume) of round wood (IIED et al. 1993). Increasing population pressures and its resulting impact on forest degradation has been one of the most important factors influencing the evolution of policies, silvicultural techniques and forest management practices in Ghana.

2.0 METHODOLOGY

2.1 Literature review of forest harvesting in the tropics

A review of literature, project documents, and environmental impact assessments was conducted to determine established knowledge in relation to social implications of logging. This review was supplemented by field visits to timber extraction areas in Ghana. Results from the review were used to guide the creation of a checklist of factors of interest to consider during field surveys. The review and field visits also were used to inform the formulation of a questionnaire for use with various user-groups. A review of policies and legislation that have bearing on the exploitation and management of timber resources was conducted. The history of forest management in the country was also reviewed.

2.2 Check list for field surveys

The following check list was developed based on literature and experiences gathered from Environmental Impact Assessment studies of a number of natural resource management projects.
2.2.1 General Land-use Characteristics of the Study Area
Land-use in Ghana is the direct result of the interaction of many factors related to the country's physical and human geography. The land-use zones relate to vegetation formations and are closely related to climatic conditions. Identification of the major land-use categories and determination of their relative importance for natural resources, including biodiversity, will inform project formulation.

2.2.2 Primary Stakeholders in the Forestry Sector
From the occupational characteristics, the nature of households and land-use patterns in the study area, people that depend on or benefit directly from the extraction or utilization of the forest resources must be identified and their characteristics described.

2.2.3 Socio-economic Characteristics of Forest Fringe Communities
The social and economic characteristics of the communities around a study area, provides an understanding of the extent of dependency of the various identified social groups (stakeholders) on the forest resources. It also presents an opportunity to assess the impact of the increased harvesting of timber in general and specific species in particular on the various social groups in the study area.

2.2.4 Population Growth
According to the 1984 population census report, the populations of many rural communities in the forest zone are growing at 3.4%, which outstrips the national average of 2.6%. A rapidly growing population has implications for the maintenance of natural resources in these areas. Knowledge of migration and emigration patterns are also crucial for understanding change in local demands on the forest.

2.2.5 Labour
Rural Ghana has an agrarian economy with about 92% of adults being actively engaged in small-scale agriculture. The present study could explore current opportunities for rural employment in the forestry sector, and the interest within forest fringe communities in gaining employment in forestry. The field visits suggest that, in general, logging activities bring very little job creation to rural areas as contractors rely on their own workers and tend not to recruit locally.

2.2.6 Household Economy
Most rural households derive their monetary income through farming especially cultivation of cocoa and food crops. Nevertheless, forest products may play a significant role as a source of supplementary and subsistence income. It is common across the tropics for forest products to serve as a safety net, providing income during periods of unemployment or resources during periods of scarcity. It will be interesting to determine to what extent this pattern holds true in Ghana.

2.2.7 Income Distribution
The average annual household income should be estimated and compared with the national average. Patterns of inequality in the study areas should be highlighted.

2.2.8 Ethnicity
The migrant community normally has socio-economic characteristics quiet different from indigenous population. The migrants may have limited access to land. Although they can gain access to land for farming through various arrangements there are still limitations, that may force them to adopt forest based livelihoods. Such livelihoods may either be facilitated by commercial logging come into conflict with it.

2.2.9 Social Services
Social Services are recognized as an important prerequisite for development. Services accessible to forest fringe communities must be determined. Equally important is the quality and source of such facilities, therefore it will be important to determine if any of them have come as a result of forest exploitation.

2.3.0 Traditional Administration
Traditional forms of administration are the responsibility of the chiefs and elders. The chief, who is the traditional head of the community, and his elders are responsible for the day to day administration of the communities, organization of communal labour, revenue raising, ensuring environmental cleanliness, and the implementation and monitoring of self help projects among others. The Chiefs in the communities hold the lands in trust for the people in the area. Therefore they receive royalties accruing from timber that have of late become source of conflict between many traditional authorities and their subjects.
With regards to legislative and executive functions, the Chiefs with the assistance of sub-chiefs pass and enforce laws that they think are in the interest of the development of the traditional area. In addition to this, they also enforce bans that are backed by traditional beliefs. It will be interesting to know how the management of timber royalties is affecting the relationship between traditional authorities and their subjects as well as the ability to make and enforce laws in the communities.

2.3.1 District Administration
The District Assemblies (DAs) are the pivot of administrative, planning, developmental decision-making and rating authorities at the district levels. Members of the DAs are the District Chief Executive (DCE), the governments appointed political head, one elected person from each electoral area in the district, the member(s) of Parliament and other nominated persons not exceeding 30% of the total membership of the Assembly appointed by the President in consultation with the traditional authorities and other interest groups in the district. Each DA has a Presiding Member (PM) who is also elected by the Assembly. For the purposes of planning, each Assembly has established a Planning Authority called the District Planning Coordinating Unit (DPCU). These units are made up of such professional staff that the District Planning Authorities in consultation with the National Development Planning Commission (NDPC) agree upon (Local Government Act 1993, Act 462). The DAs collect all royalties including those from timber accruing to the district administration. The perceptions and aspirations of the DA members on the current role of logging in local council development agenda need to be captured.

2.3.2 Community Common Rights
Community accessibility to natural resources depends on the nature and extent of common rights that prevail in the area. An understanding of the common rights therefore will indicate the extent of dependency and accessibility of natural resources to the people in the study area. The team should study the following common rights likely to be found in the study area:

2.3.3 Rights to Water Resources
All the people in the communities, irrespective of status should have the rights to water from streams, rivers and ponds except when it is the product of someone's personal effort or creation. In most rural areas, water from streams, rivers and ponds is considered as 'free gift of nature' and constitute the main potable water for domestic use. Local processing industries depend very much on water from these sources for their operation. Other end-uses of rural water are irrigation and aquaculture. Forest reserves provide watershed to most of the streams and rivers and their logging will therefore impact on rural water availability.

2.3.4 Rights to fishing
People living close to watercourses have the right to fish in them without trespass. River fishing is basically a non-commercial activity in the forest area. Fishes caught are mostly used to supplement domestic protein intake and therefore constitute a very important activity in rural economies. The intensity of fishing operations depends on the seasonality of the rivers, which to a greater extent are influenced by the state of the forest. To this effect logging may affect people's ability to fish efficiently.

2.3.5 Rights to hunting
Wildlife laws require that hunting is done with official permits. Nevertheless, people still follow the traditional ways and hunt anywhere including forest reserves with impunity. Hunting for bush meat is both a commercial and non-commercial activity. Bush meat constitutes a very important protein intake of most people in rural areas. The hunting expedition depends on the state of the forest. Most hunters spoke to now hunt from the forest reserves since the off-reserves are degraded. The positive and negative impacts of logging on hunting can be assessed through hunter interviews and discussions with local food sellers who mostly serve as clients to the hunters.

2.3.6 Community dependence on commercial timber species
In Ghana, the forest is an integral part of the rural economy providing subsistence goods and services as well as trade (Falconer, 1991). The forests provided food, fodder, fuel, medicine, building materials, materials for various households items as well as intangible benefits such as cultural symbols and ritual artifacts before the central government took control over their management and user rights. This study should examine the foregone benefits to communities as a result of their inability to remove timber species for traditional or domestic usage.

2.3.7 Rights to gather Non-timber Forest Products (NTFPs)
According to forest laws local communities have the right to collect non-timber forest products from forest reserves for domestic uses with permission from the Forest Service Division. The NTFPs are very important for household use and are mostly gathered, hunted or harvested from the outside reserves. However, with
the recent levels of land degradation, more NTFPs especially the traded ones like cane, chewstick and medicinal plants are collected from the forest reserves. During one of our rounds some NTFP collectors complained that a number of their commodities have become unavailable due to logging in the forest reserves. It is also possible that for the “light demanding” NTFPs logging will enhance their abundance. We should determine the influence of logging on NTFPs availability, quality, and sustainability.

2.3.8 Communal Accessibility to Forest Resources
Forest reserves are fully vested in the State through the Forest Ordinance of 1927. Although the ownership of land did not alter at the time of reservation the traditional owners have no right of access to the trees or land in the reserve except on permit from the competent government authority (Forestry Department). The management of trees, the right to own, plant, use and dispose of trees within the forest reserves is controlled by the state, through the Forest Protection Decree, 1974 (NRCD 243).

Under the working plans of all forest reserves, the following communal rights are usually admitted in forest reserves by permit.

- Communal rights to hunting, fishing, collecting of fuelwood, snails, medicinal plants.
- Farming rights to admitted or allowed farms. Admitted farms are portions of land inside the forest reserves which had been farmed at the time of reservation and allowed to continue as such. These lands do not constitute part of the reserves even though they are situated inside them. These communal rights have been the subject of several disputes between the Government Forest Service (Forestry Department) and the communities.

Forest tenure within what used to be the protected forest (now forest reserves) is also controlled by the state. Government regulated the use of trees within these forests through its Protected Timber Lands Act of 1959, which prohibited farming in concession areas until exploitation had ended.

Concessions did not interfere with the customary rights of hunting, trapping, collection of firewood or natural produce other than timber. The tenure on protected forests is less restrictive than that in the forest reserves and the emphasis is on the type/species and use of the individual trees. Another type of forest tenure is through the purchase of timber rights. This is controlled by the Concessions Act of 1952, which regulates the granting of timber felling and harvesting rights. This tenurial system is restricted to farms and the Protected forest areas which have good stocking of timber trees. The traditional land owners, in this case the various Stool heads, are paid compensation or royalties through the Forestry Department. The local community, however, have the right of access to other non-timber trees and their produce in the concession areas outside forest reserves.

Forest reservation by communities was usually on communal land in the form of Sacred grooves. No individual has the right to plant, use and inherit trees and tree products in most of these traditional forests or grooves. In some cases the “Okomfo” or fetish priest of the community who is the care-taker of these sacred grooves is accorded limited rights to sell tree products, but not the land. No individual has the right to dispose of such lands. Customary law does not encourage the reservation of communal or family land as forest by individuals if another member of the community or family needs it to farm.

2.3.9 Increased Collaboration in Forest Management.
A lackadaisical attitude of communities to the protection of the forest resources coupled with the inability of the Forestry Department to properly manage the forest led to increasing illegal harvesting of timber, which contributes to deforestation and loss of biodiversity. However with increasing harvesting of timber, the need for collaboration in forest management has become more apparent. A new concept of community forest management committees to deal with illegal logging and other forms of forest abuses has emerged in Ghana. Initial observations suggest that these committees are prevalent and active in timber rich areas. The piloting of collaborative forest management systems in some of the study areas has increased community access to forest resources especially the harvesting of non-timber forest products through free community access to NTFPs for domestic purposes. The role that logging plays in bringing different stakeholders together for a common purpose is worth investigating.

3.0 CONCLUDING REMARKS
The review has provided insight into the possible socio-economic impact of logging on local forest users/fringe communities. However, the issues are complex and variable across the study area. The historical lack of dialogue between the forest stewards (forestry commission) and local populations has contributed to the development of ignorance and apathy among forest fringe communities. Special effort
must therefore be made at the beginning of the study to win the confidence and trust of the respondents, and to explore with them the potential importance of the study and also its limitation in terms of direct impact of their lives.
4.1 Introduction

Sustainable forest management is to ensure forest productivity through ecologically sound practices (i.e., silviculture and logging). In this respect the maintenance of good forest structure after logging is of major concern.

Forest structure is controlled by four main variables namely, (a) amount of growing stock (b) diameter distribution within stand, (c) species composition, and (d) cutting cycle lengths (e.g., Smith, 1962; Oliver and Larson, 1996). It is generally said that these variables or attributes for regulating uneven-aged forest structure are more of forest art than science (Leuschner, 1990). However, mathematical models and guidelines, describing and directing foresters how to achieve balanced structure in uneven-aged forests are based on these variables (Leak et al., 1987). For instance, diameter distributions of individual species examined on fairly homogeneous tracts are found to follow either negative exponential or rotated sigmoid pattern (Muller, 1982; Lorimer and Frelich, 1984). However, these population structures depend on species and site (Leak, 1998). These variables are usually applied in combination to achieve a balanced structure (Leuschner, 1990), especially during the initial cutting period or first felling cycle referred to as adjustment period (Recknagel, 1913; Dewight, 1965).

In tropical countries, the most common variable for controlling forest structure are minimum felling diameter (MFD) and felling cycle (Dykstra et al., 1996; Dawkins and Philip, 1998). Since diameter (at breast height = 1.3m) is convenient to measure and closely correlates with stem volume, it has become a convenient variable used in forestry. For instance, diameter class models are used to generate future diameter distribution and product yield based on initial distribution and known growth rates (Gadow and Hui, 1999). The knowledge of the structure of diameter distribution in a stand is also considered very vital in the design of felling system and silvicultural treatments especially, as they vary greatly with forest type and status of advance growth regeneration (Dawkins and Phillips, 1998). Stand structure, specifically diameter distribution and species composition, is thus an important variable for monitoring stand development after harvesting.

In Ghana, various mechanisms to control exploitation with the aim of maintaining good residual forest and ensuring sustainable production of timber have been used since 1907. These selective logging controls relate to species categorization, Minimum felling Diameter (MFD), Felling cycle lengths, and annual allowable cuts (Ghartey, 1989; Francais, 1988; Boakye-Dapaah, 1990; Anon, 1995; Aninakwa, 1998).

Because sustainable forest management is seen as one way to reduce the loss of bio-diversity and forest degradation, there is a pressing need to assess the consequences of these regulatory mechanisms on the forest structure and dynamics (Pelissier et al., 1998), especially when there is no post logging silvicultural treatment.

It is believed that the negative impacts of logging on residual forest can be reduced through effective planning, tree selection procedures, and good logging practices (Hendrison, 1990). A current approach to reducing negative effects of selective logging in the tropics is through Reduced Impact Logging (RIL) practices (Bertault and Sist, 1997; Sist et al., 1998). RIL techniques are built on strict rules that guide the planning and control of logging operations (Dykstra and Henrich, 1996; Pinard et al., 1998). These include pre-logging forest inventories, topography survey and layout plans for skid trails. However, significant impediments remain to the widespread application of RIL technologies in the tropics (Putz et al., 2000; Dykstra, 2001). Apart from the cost and training needs identified as general problems (Sarre and Efransjah, 2001), successful application of RIL requires adequate input of specific local information such as how many trees to be felled, which species to be harvested, and which trees are to be retained (Agyeman et al., 1999).

The effects of timber harvesting on forest health and ecological stability depend on logging intensity and prevailing physical, and biological conditions (Hendrison, 1990). In the same manner, the future value of any previously logged forest for timber production and biodiversity conservation depends to a great extent on how much damage was done during the previous harvesting (Gullison and Hardner, 1993). On these bases we review the past regulatory practices in the light of current forest conditions.

4.2 Review of felling controls

4.2.1 Introduction

To understand the effect of felling controls on forest exploitation and residual forest stand, seven forest reserves were selected for study (Appendix 1). At least one forest in each of the five regional forest administrations in the high forest zone (i.e., Ashanti, Brong-Ahafo, Eastern, Central, and Western regions) was selected for study. For each selected Forest Reserve (FR) the past and present forest management
plans (where available) were studied to find the control mechanisms applied since it was first logged. Controls searched for were:

- Minimum felling diameters (MFD) for various species
- Cutting cycle lengths
- Methods of selecting trees for felling and retention as seed trees or residual stand

In each FR, timber exploitation records for at least two compartments logged between the periods 1951-1960; 1961-1970; 1971-1980; and 1981-1990 were compiled. For each compartment, the number of trees prescribed for felling and the actual numbers of trees felled for a period were compiled from the compartment register so as to determine the prescribed and actual harvest intensity and relate these to the control mechanisms during the periods.

4.2.2 Results and discussion

Forest management regulatory mechanisms applied between 1910 and 1990 included 4 versions of minimum felling diameters, 3 different felling cycle lengths, and 3 different methods for selecting the permissible number of trees to be felled per compartment. There have also been species groupings based on silvicultural or commercial considerations. The classified economic species constitutes the exploited group.

(a) Minimum Felling Diameter (MFD)

Application of felling diameter limits in Ghana commenced with the passing of Timber Protection Ordinance in 1907 that sought to protect the felling of immature trees (Taylor, 1960). Since then, there have been revisions of these felling limits in 1910, 1958, 1972 and 1989 (Ghartey, 1989) and recently in 1997 (Ofosu-Asiedu et al. 1997). A comparative table of the felling diameter schedules for 1907-1989 is provided as Appendix (2) and a summary of the limits of the various schedules is given below (Table 1).

<table>
<thead>
<tr>
<th>Period</th>
<th>Minimum Felling Diameter (MFD) limits (cm. dbh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1907-1949a</td>
<td>58, 68, 87</td>
</tr>
<tr>
<td>1950-1971b</td>
<td>70, 90, 110</td>
</tr>
<tr>
<td>1972-1988c</td>
<td>70, 110</td>
</tr>
<tr>
<td>1989d</td>
<td>50, 70, 90, 110</td>
</tr>
</tbody>
</table>

Sources: a = Logan (1947); b = FD (1955); c = FD (1972); d = François (1989).

Felling limits between 50 cm and 110 cm dbh are being used in Ghana. The bases for fixing the previous limits are not known. However, since 1989, they are supposed to indicate a point in the species diameter distribution where the average national stocking shows a sharp decline. The latest revision also adopted diameter ranges similar to that of 1989, but classified some species into lower or higher limits based on additional variables such as average diameter increment of different DBH classes, ten-year average annual exploited volume, stocking km² above 40 cm dbh, and prevalence of decay in exploited stems of respective species (Ofosu-Asiedu et al., 1997). We observed that, since 1972, Ghana has adopted felling diameter limits that are higher than in many countries in West-Central Africa. For example the Ghanaian MFD are 10-40 cm higher than that of Cameroon, 10-60 cm higher than in Côte d’Ivoire and ± 10 cm of that in Liberia (Parren and de Graaf, 1995; Dykstra et al., 1996).

(b) Felling Cycle Lengths

Between 1950 and 1989 three different lengths of felling cycles were instituted in the management of reserved forests in Ghana. A felling cycle of 26 years was started in the 1960s, when working plans for some forest reserves were first produced and the respective forests were opened for timber exploitation and silvicultural treatment. In 1972, when the first cycle was only 12 years old, a management operation termed “salvage felling” was introduced to remove so-called over-mature trees. It was explained that the then ongoing enumeration surveys had shown a preponderance of large diameter trees that were dying and or losing their timber value because of defects. It was believed necessary to remove them through commercial logging before they were lost to natural mortality. Under this operation, all reserved forests with or without management plans were to be logged within 15 years. The records indicate that the salvage felling, which should have ended in 1987, continued until 1990 in the absence of an alternative yield regulation method. Salvage felling offered an unprecedented chance for second cycle felling in some forest reserves earlier than
expected. In 1990, a forty year felling cycle was introduced based on the average time of passage (TOP) estimated as the time for most of the high value species to grow from the next lower diameter class to the mature class (Boakye-Dapaah, 1990). This review does not discuss the rationale of the 40-year felling cycle, as its effect cannot be seen in the present stocking data.

(c) Determination and selection of permissible cut trees.
In Ghana, two broad approaches have been used for determining permissible cut. They are the formula and direct diameter methods. Between 1950 and 1971 three formula methods developed by Jack, Kinloch, and Kandambi, all colonial foresters were introduced (Anon, 1962). They were all derivatives of the Brandis method (Osmaston, 1968), used in the Teak forests of the Far East, and the classical European methods (Brasnett, 1953). The Jack, Kinloch and Kandambi formulae determined the permissible cut in basal area recruitment (Anon, 1962), but the cut was prescribed in number of stems for each economic species per annual coupe. The yield was selected from stems within the felling diameter classes and usually the bigger stems were chosen first. When the total calculated yield was not obtainable from the available stock of exploitable trees, the deficit could not be taken from the lower diameter class.

Between 1972 and 1989 and alongside the salvage felling regime, only the Minimum Felling Diameter (MFD) was used as the means to determine the permissible cut. By this method all stems of a given species recorded to be above the MFD during a 100% timber inventory in a compartment were selected for felling (Anon, 1972; Anon, 1995).

After the 1989 national forest inventory, another formula method was introduced. This formula is based on the population of the stems above the MFD and those in the next lower dbh class. It also seeks to provide between 40% to 60% retention of trees above MFD for canopy structure, seed production and bio-diversity conservation (Anon, 1995). The current form of the formula is given as

\[ Z = 0.5Y + 0.2X \] for the moist forest, and
\[ Z = 0.25Y + 0.2X \] for the dry forest.

where:
- \( Z \) = total permissible number of stems,
- \( Y \) = the number of stems of a given species above the MFD, and
- \( X \) = the number of stem of a given species in the next lower diameter class to the MFD.

The formula is applied at the compartment (128 ha.) level and the \( Y \) and \( X \) estimates are obtained from a 100% timber inventory of all commercial class 1 trees. Species that are exploited at dbh \( \geq 70 \) cm are inventoried down to 50 cm dbh. Those exploited at 50 cm are inventoried down to 30 cm.

According to Vanclay (1993) the yield prescribed by this formula, if considered against diameter recruitment and stem mortality over a 40 year felling cycle, can be sustainable only when the ratio of \( X:Y \) is 3:1, a situation that is rare in the TMF. Adam (1999) also points out that the 40-60 percent retention envisaged by the above formula cannot be attained, because the algebraic equation for the retention input was incorrect. For instance when the value of \( Y \) equals \( X \), it means 70% and 45% of the mature commercial stems will be cut in a moist or dry forest, and the respective retention will become 30 and 55% instead of 40 and 60% respectively. As the ratio of \( X \) to \( Y \) increases the retention value diminishes, but that is not what is intended. The continued use of this formula therefore makes sustained timber production doubtful.

A simulation model (GHAFOSIM) was developed by Alder (1989), but has not yet been used to determine the permissible cut at forest reserve level. This is due to the limited number of species for which increment data were available at the time of developing the model. However, it has been used at the planning level to provide estimates of stand mortality, species group time of passage, and national annual allowable cut, all variables used as inputs for the current yield regulation formula (Anon, 1995).

(d) Exploitation Intensity
Although the forest reserves were available for exploitation in the late 1950s, full-scale entry appeared to have occurred in the 1970s (Figure 1) or at the onset of the Salvage felling regime. The Forestry Department records for the 7 Forest Reserves examined show a gradual increase in both the numbers of trees selected for felling (i.e. prescribed yield) and the actual trees removed over the years (Figure 1). The levels, however, vary with Forest Reserve. While prescriptions varied between 80 and 780 stems per compartment, actual removals were between 25 to 320 stems (i.e. less than 50% was exploited).

The number of stems prescribed for felling depends mainly on the list of commercial species of the period, species richness and the number of trees above the MFD in the compartments due for exploitation. Thus
there was the tendency to select more trees for exploitation when there were many stems above the MFD. Similarly, more stems would be exploited if the selected yield was composed of many high value species. For instance, the selected trees at Atewa Forest were made up of mainly high value species (Meliaceae) and they were all exploited despite the low number (Figure 1). At Draw River Forest, one high-value species (*Heritiera utilis*), constituted over 40% of selected trees, and because over 72% of this species was exploited, it finally made up 54% of the total exploited number (Table 2). Again, because *Heritiera* is gregarious in this forest, there were many trees above the MFD (70 cm dbh), and an average of 156 stems were selected per compartment, for exploitation, resulting in high felling intensity (Figure 1). In the moist semi-evergreen forest where *Triplochiton scleroxylon* also dominates, similar selection and removal trends were observed. For instance, at Offin shelterbelt, Tano Suhien and Mamang Forests, *Triplochiton scleroxylon* constituted 47%, 26% and 18% of selected tree whiles it made up 43%, 31% and 29% of removals in the respective forests (Table 2). The over-reliance on MFD as a criterion for selecting trees for felling results in high felling intensity, especially, when there is a higher stocking of stems ≥ MFD. It was observed in this study that, the amount of trees removed, was influenced more by the concession holders' preference, than by the forest managers' selection.
Figure 1. Histograms showing number of trees selected for harvesting (PR) and actual number of trees removed (RM) per compartment (128 ha.) during logging in the respective Forest Reserves at various periods of their exploitation history. Due to hilly terrain at Atewa Range, tree selection there, was based on yield marking of a few valuable species that were all removed.

Table 2. Comparative numbers of trees selected for felling and actual numbers removed for some major species per compartment (128 ha.). Removal was 25-54% of total number selected.

<table>
<thead>
<tr>
<th>FR</th>
<th>Species Selected</th>
<th>Selected Trees</th>
<th>Trees Exploited</th>
<th>% Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No.</td>
<td>%</td>
<td>No.</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Draw</td>
<td>Hertetiera utilis</td>
<td>156</td>
<td>40.3</td>
<td>112</td>
</tr>
<tr>
<td></td>
<td>Khaya ivorensis</td>
<td>21</td>
<td>5.4</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Piptadeniastrium a</td>
<td>24</td>
<td>6.2</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Other species (36)</td>
<td>186</td>
<td>48.1</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>387</td>
<td>100</td>
<td>209</td>
</tr>
<tr>
<td>Wawahl</td>
<td>Antiaris toxicaria</td>
<td>96</td>
<td>17.2</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Triplochiton s.</td>
<td>45</td>
<td>8.1</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Nesogordonia p.</td>
<td>51</td>
<td>9.1</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Other species (52)</td>
<td>387</td>
<td>65.6</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>559</td>
<td>100</td>
<td>149</td>
</tr>
<tr>
<td>Subim</td>
<td>Triplochiton s.</td>
<td>96</td>
<td>17.8</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Entandrophragma u.</td>
<td>35</td>
<td>6.5</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Pericopsis elata</td>
<td>21</td>
<td>3.9</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Other species (32)</td>
<td>388</td>
<td>71.9</td>
<td>68</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>540</td>
<td>100</td>
<td>138</td>
</tr>
<tr>
<td>Mamang</td>
<td>Triplochiton s.</td>
<td>23</td>
<td>17.6</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Terminalia superba</td>
<td>16</td>
<td>12.2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Entandrophragma c.</td>
<td>9</td>
<td>6.9</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Other species (30)</td>
<td>83</td>
<td>63.4</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>131</td>
<td>100</td>
<td>57</td>
</tr>
<tr>
<td>Tano</td>
<td>Triplochiton s.</td>
<td>108</td>
<td>26.3</td>
<td>46</td>
</tr>
<tr>
<td>Suhien</td>
<td>Piptadeniastrium a</td>
<td>45</td>
<td>10.9</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Khaya ivorensis</td>
<td>13</td>
<td>3.2</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Other species (40)</td>
<td>245</td>
<td>59.6</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>411</td>
<td>100</td>
<td>146</td>
</tr>
<tr>
<td>Offin</td>
<td>Triplochiton s.</td>
<td>137</td>
<td>46.8</td>
<td>68</td>
</tr>
<tr>
<td>Shelterbelt</td>
<td>Entandrophragma u.</td>
<td>10</td>
<td>3.4</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Khaya anthotheca</td>
<td>12</td>
<td>4.1</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Other species (25)</td>
<td>134</td>
<td>45.7</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>293</td>
<td>100</td>
<td>157</td>
</tr>
</tbody>
</table>

Note: High value species (Entandrophragma, Khaya & Pericopsis) were always removed in preference to others even when stems allocated were fewer. At Draw River FR stems of Khaya removed were more than allocated. Source: Data compiled from Compartment Registers of respective Forest Reserves at Forest District offices in Ghana.

A further examination of the Forest Reserve felling records showed that, between 1960 and 1989, removals in six of the seven sites, were below 200 trees per compartment (128 ha.) which agrees with the threshold level of 182 trees per compartment or 1.5 trees hectares\(^1\) that has been suggested by Hawthorne (1993). It will be important to examine the influence of these felling intensities on the residual stand against the background of reported forest degradation during these regimes of selective logging.
4.2.3 Conclusion
Repeated cutting targeted mainly at larger trees or all mature trees of relatively few species, offers little or no chance for distributing tree removal in a balanced way across all size classes for individual species. Exploitation control mechanisms (most notably Minimum Felling Diameter, tree selection methods, and cutting cycle lengths) used in the previous management regimes in Ghana, can not be seen to have aimed to maintain a balanced species mix in the residual stands especially because removals were influenced by market demand.

Cutting cycle lengths of 25 and 15 years were used mainly to remove larger diameter trees but not to transform the diameter distribution into a balanced structure at the end of the second cycle in 1987. This is demonstrated by the stand structure in 1989 (FRIP, 1989). The yield formula introduced in 1990 seeks to address the diameter distribution by retaining a certain percentage of the exploitable trees, but the retention percent was not based on any prior ecological or silvicultural studies. It is not clear whether the retention of 40-60% stem numbers above the MFD will give adequate density of canopy trees to prevent creation of large gaps especially in the partly degraded and the dry forests. Minimum felling diameters are an important aspect of the regulation mechanisms but the rationale is influenced more by economic, than ecological or silvicultural considerations.

4.3 Impacts of regulating logging through MFD
4.3.1 Introduction
Injection of investment capital into the timber processing industry in 1983, as part of Ghana's Economic Recovery programme (ERP) and trade liberalisation policies, has contributed to the expansion of processing capacity, which TEDB (1996) estimated at 2.7 million m$^3$ per annum. The current annual cut prescribed by the Forestry Department is one million m$^3$ (Aninakwa, 1996), insufficient to meet the increased national processing capacity. Therefore, there is mounting pressure from the timber industry for increasing harvest intensity (GTMO, 2001). The industry has strong bargaining power because of its immense contribution to the general economy (Banahene, 2001). The government is thus under immense political pressure to assist the timber industry as an important component of the national economy, as well as protect the forest resources as a national heritage. Forest resource managers are meeting these requests from industry and their obligations to the government with recommendations for the increased use of under-exploited species.

The viability and implications for increasing exploitation of additional species need to be investigated. Some examples of questions that could be raised are as follows:

- Can the harvesting intensity be increased if more species are removed?
- How much loss in terms of stem stocking, species composition, and future timber yield can be expected if felling intensity is increased and more species are harvested, under the current selective logging practice?
- Can the forests absorb more disturbances than they have already taken?

4.3.2 Objectives of Study
It was assumed that large diameter trees are usually associated with large crowns and when felled, will cause more damage, by creating larger canopy gaps which favour regeneration of pioneer and non-pioneer light demanding species. Alternatively, selection of more smaller diameter trees will cause less damage but create smaller canopy gaps which favour shade tolerant timber species. The research objectives were:

1. To compare logging damage (ground area disturbed, stem damage, and canopy loss) in areas harvested at felling intensities equivalent to current annual allowable cut (26.3m$^3$ ha$^{-1}$) prescribed by Ghana forest service & two times as much (52.6m$^3$ ha$^{-1}$) in combination with two stem size selection criteria (small and large diameter stems).
2. To explore the implications of stem diameter as a criterion for tree selection to reduce logging damage.

4.3.3 Method of study
We examined the ecological implications of increasing harvest intensity by testing two levels of felling intensities and tree selection criteria and comparing treatment effects on numbers and size of felling gaps, canopy loss, skid trail density, and proportion of trees damaged.

These objectives were to test the hypothesis that logging damage (stem damage, ground disturbance, and canopy loss) is positively related to felling intensity and size of tree felled. The study was conducted at Pra-
Anum Forest Reserve between January and September 2000. A description of study site and methodology is provided in Appendix 3.

4.3.4 Results and Discussion

(a) Felling intensity and area disturbed

Over an area of 32 hectares each, extraction of 1600 m$^3$ and 840 m$^3$ of timber (equivalent to 53 m$^3$ and 26 m$^3$ ha$^{-1}$ respectively) resulted in 5.5 km and 3.9 km of skid trail network respectively. In terms of area, skid trails in the high intensity site disturbed 2 ha (i.e. 12.5 m$^2$ m$^{-2}$) and 1.3 ha (i.e. 15.5 m$^2$ m$^{-2}$) in the low intensity harvesting site. These areas disturbed by the skidder (D7 crawler tractor), were equivalent to 6.25% and 4% of the area of the high and low intensity logging sites respectively. Vegetation was completely destroyed and soils compacted or turned over by the tracks and logs dragged along the soil surface.

The skid-trail length increased by doubling the felling intensity, but the increase was only 40%. This may indicate that proportionately less damage will result to forest from skidding a given harvest volume if the harvest intensity is increased. In fact it is unlikely that the relationship between ground area disturbed and harvest intensities are linear (Panfil and Gullison, 1998). Some logging simulation models also suggest that damage could be reduced further if skid trails are made linear. For instance Gullison and Hardner (1993) achieved a 25% reduction in logging damage by requiring main roads and skid trail to be linear in a simulation model. Several studies also show that pre-planned skid trails do reduce logging damage (e.g. Johns et al., 1996; Bertault and Sist, 1997). For instance Johns et al. (1996) found that for a tree harvested, unplanned logging affected a ground area that was more than 100 m$^2$ greater than planned operations. Jackson et al. (2002) also reports 25% ground area disturbance in the form of skid trails, logging roads and log landings in a Bolivian forest at a harvest intensity of 12.1 m$^2$ ha$^{-1}$ and attributed the high level of ground area disturbed to unnecessarily long skid trails.

The devastating effect of skidding was also partly due to the wide trail widths that were created as a result of frequent manoeuvring of the crawler tractor. This usually occurred when the trail meandered and caused the log to swing over the trail edges. In this study it became obvious that felling intensity and size of the log extracted had the effect of increasing the width of skid trail and consequently disturbing larger ground area. On average, the trails in the high intensity treatment sites were 0.9m wider than those in the low intensity site, and it was 0.5m wider in the sites with larger trees than that with smaller trees felled.

Although the sizes of the trees felled did not show any significant effect on tree fell-gaps, it seemed to have influenced the skid trail width and sizes of log-yards. In the high intensity treatment the site with large stems had a log yard that was 50% larger than the one with smaller stems. In the low intensity treatment the difference was 26% greater for the large stems. It thus appeared that larger log yards were needed in respect of larger trees, possibly for machine manoeuvre.

The harvested volumes gave a stem felling intensity of 5-6 trees ha$^{-1}$ and 2-3 trees ha$^{-1}$ for the high and low intensities respectively. The results indicated significant differences in ground area disturbed by felling at low and high intensities. Obviously areas disturbed through tree felling in high intensity harvest (median 242.3 m$^2$, N = 32) were larger than those in low intensity harvest (median =138.8 m$^2$) sites.

However, felling gap areas created by felling large diameter trees (median =151.9 m$^2$, N = 32) appeared smaller than those created by felling many smaller trees (median = 217.1, N =32). Statistical analysis, however, did not show the differences to be significant. The results suggest that, overall, felling many smaller trees create gaps similar to felling fewer large size trees. This is true especially as felling clusters of trees do result in creating large gaps. Cluster felling was more frequent in the study sites where many smaller trees were felled (Figure 2). However it may be cautioned that the results could have been biased due to the narrow range of diameter sizes selected for felling in the two tree size treatments.

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Figure 2. Ground areas (m²) of plots disturbed by felling and skidding operations in two felling intensity and stem selection treatments. Low felling intensity = 26m² ha⁻¹, High felling intensity = 53m² ha⁻¹. Large stems = fewer number but larger diameter stems, Small stems = more stems but smaller diameter.

As anticipated, the forest canopy loss due to logging was higher in the high intensity treatment (Mean loss = 20.8% ± 1.3 SE, n = 129) than in the low intensity treatment (Mean loss = 41.65% ± 1.2 SE, n = 107). This effect is similar to the ground area disturbed for the reason that twice the felling intensity did not produce twice as much effect on canopy loss. However, the result does corroborate other studies showing that there is a negative correlation between tree harvesting intensity and post logging forest canopy cover (Webb, 1997; Whitman et al., 1997) in other words, there is a strong linear relationship between canopy loss and harvest volume (Pereira Jr et al., 2002).

(b) Residual tree damage

The study failed to reject the null hypothesis that there are no differences in the number of stems damaged (injured or killed) in a high and low felling intensity. Some studies have reported positive correlation between harvest intensity and proportion of residual stem damage (e.g. Webb, 1997; Sist et al., 1998). In this study it did not appear that the number of stems damaged (i.e. injured or killed) during logging does necessarily relate to the volume harvested.

Figure 3. Correlation between forest area disturbed during tree felling and skidding and numbers of trees damaged.

This result corroborates the observations of Johns et al. (1995) who did not find any correlation between the number of harvested trees and the amount of damage. It was not feasible to do a correlation analysis between felling intensity and numbers of damaged stems as the investigation was dealing with variation between only two intensities. However, it was observed that between the two felling intensities, it was the area disturbed that had more influence on the number of trees damaged (Figure 3).

The area disturbed through tree felling varied significantly between the two harvest intensities and was higher in the high intensity treatment sites. This indicates a positive association between felling intensity and area disturbed during tree felling and consequently numbers of trees damaged. However, as discussed above, doubling the harvest intensity did not double the area of skid trail, for example, nor the number of damaged stems. Therefore, it can be expected that increased harvest intensity may not increase stem damage significantly.

The overall effect of felled tree size on number of stems damaged in felling gaps was also not significant in this study (N = 256, F = 3.56, df = 1, P = 0.06). In single-tree felling-gaps the number of stems damaged are reported to show positive correlation with the dbh of felled trees (e.g. Jackson et al., 2002). However, over a
larger area, as in this study, the association may become weaker due to overlapping of felling gaps and resultant reduction in average number of stems damaged per tree felled. For instance, Panfil and Gullison (1998) observed in a logging experiment in Bolivia that as harvest intensity increased, trees tended to fall at least partially on existing gaps so that per tree damage declined. They concluded that the area of vegetation damaged by logging was a quadratic increasing function of harvest intensity.

For the two logging operations examined (tree felling and log skidding), skidding appeared the more destructive (Figure 4). This was because many live trees had to be removed, to clear a trail in order to reach each felled tree. The natural instinct for the skidder operator to avoid large trees and water-logged terrain also increased the skid trail length, resulting in more fatality, especially to smaller diameter stems that the crawler tractor could easily drive over. Skidding thus resulted in killing more smaller size trees (i.e. the advance regeneration = 5-19 cm dbh) than felling in the two treatments. Comparatively, felling operations also killed more medium diameter trees (> 20-49 cm dbh) than skidding (Figure 4). This was mainly because fellers lack skills in directional felling and could not effectively prevent felling onto nearby large trees. These observations support the recommendations that if unnecessary skid trails can be avoided, for instance by planning trail layouts, and logging undertaken when soils are dry, and if tree fellers are trained to apply directional felling, logging damage to residual trees could be greatly reduced (Jackson et al., 2002).

![Figure 4. Box-plot for DBH distribution of trees killed by felling (A) and skidding (B) operations in sample plots at Pra-Anum Logging study site.](image)

No significant differences were observed in the proportion of stand stem stocking damaged in the two felling intensities. However, the proportions varied with diameter class (Figure 5). In the high intensity site the percentage damage (felling+ skidding) ranged from 9% ± 2(SE) to 20% ± 4 (N = 32) and in the low intensity it ranged from 11% ± 2(SE) to 16% ± 3 (N = 32) with the higher dbh class (50+ cm) always recording the least. This means that distribution of damage across dbh classes was similar in the two felling intensities and the proneness to logging damage was more dependent on the size of the residual stems. Similar trends are reported from many logging studies in the tropics (e.g. Readhead, 1960; Mensah, 1968; Bertault and Sist, 1997). In forests of Indonesia, Bertault and Sist (1997) observed 40% damage to residual stems (> 10 cm dbh) under higher felling intensities (> 80 m³ ha⁻¹) and when trees of diameter > 50 cm dbh were felled.

The management implication here is that the influence of logging on the residual forest diameter distribution will vary depending on the stand diameter composition at the time of logging and the severity of damage. Therefore, it would be unwise to prescribe high harvest intensity for example, if there was also a high density of small individuals of commercial species that would be killed during extraction.
4.4 Wood Loss Due to Decay Associated with Logging Wounds

4.4.1 Introduction

Dying economic timber trees or live hollow trees constitute a major source of timber production loss when they are felled and have to be abandoned because of wood degradation or hollowness resulting from decay. Another disadvantage of harvesting hollow trees is the extent of damage as compared with log volume recovery. For some species and stem sizes, the volume obtainable will not worth the residual damage left behind (Imayabir et al., 2000).

Injuries to standing trees, especially wounds extending beneath the sapwood zone, render trees more vulnerable to pathogen infestation that may lead later to decay (Strouts and Winter, 1994; Greif and Archibold, 2000; Whitford, 2002). Other micro-organisms, arthropods and birds may further break down the decaying wood so that finally a cavity or hollow is formed (Strouts and Winter, 1994) culminating in loss of commercial volume. Decay caused by fungi make stems of trees less commercially useful and in some cases completely useless for manufacture into lumber or veneer (Tainter and Baker, 1996). Nicholson (1958) drew attention to logging damage such as bark and wood injuries in the tropical forests that favour the entry of pathogens which are likely to reduce tree survival rate or cause bole distortion making the timber commercially unsuitable (cf Sist and Nguyen-Thé, 2002). Logging wounds also account for high mortality rate immediately after logging. For instance, Sist and Nguyen-Thé (2002) found a significantly higher stand annual mortality of 2.6% in logged forest as against 1.5% in unlogged Dipterocarp forest of East Kalimantan within 4-5 years after logging. They noted that the increased mortality in the logged forest was mainly amongst injured trees.

Most logging damage studies provide quantitative or qualitative assessment of residual tree damage including percentage of stems or basal area of trees killed or injured (e.g. ITTO project PD79/90). For example, in the logging damage study conducted at Pra-Anum, between 8 and 11% of stems > 5 cm dbh were estimated killed and 5-6% left injured and standing. But post-logging conditions of wounded trees have not been studied in managed tropical forests in order to estimate potential commercial wood loss and to develop measures for preventing wood degradation and timber loss. Techniques to identify degradation in standing trees in order to exclude them from production and prevent loss of production time are limited in the tropics. Most loggers rely on the experience of tree fellers who either use the "knock on wood" method or 90° sawing with chainsaw into a suspected wound to identify presence of hollows and cavity size in trees (Bell, 1971; Trockenbrodt et al., 2002). These methods were found unreliable for preventing harvesting of hollow trees in Sabah, Malaysia (Trockenbrodt et al., 2002).
The extent and severity of logging damage is highly dependent on harvest intensity and mode of conducting skidding operations. This study aims to provide additional information to support the implementation of appropriate felling and skidding practices in order to improve residual tree conditions.

The objectives of this study were:
- To assess the incidence of healed and unhealed loggings wounds among different timber species and different stem sizes in compartment RWC1-3 of Pra-Anum forest five years after logging damage.
- To assess the incidence of wood decay and discoloration in unhealed wounds in order to estimate the potential loss of commercial timber due to decay in association with mechanical damage to trees during logging.

4.4.2 Methodology
The study was conducted through field observation of wound conditions on wounded trees and measurement of wound surface area and decay depth at Pra-Anum forest. Full methodology is provided in Appendix 4.

4.4.3 Results and Discussion

(a) Unhealed logging wounds among timber species
A total of 390 wounds were found on the lower bole of 359 trees of 15 selected timber species in compartments RWC1-3 of Pra-Anum forest. Amongst the wounds encountered, 264 were completely covered with regenerated bark and were assumed healed. The other 126 had no regenerated bark and out of these 103 had decay. Most trees had single wounds but 31 had two wounds each in different condition. Three tree species Celtis, Turreanthus and Sterculia dominate the sample because they dominate current stock of timber species at the site.

The results showed that the distribution of the healed and unhealed wounds among the sample trees was dependent on species. Species with low numbers of unhealed wounds were those that appeared capable of rapid bark regeneration after wounding. The converse may be true for those with higher occurrence of wound decay. This agrees with other observations (Harmon et al., 1986) and Spies et al., 1988) cf. Franklin et al. (2002) that wood decay following wounding is related to species.

![Figure 6. Box plot showing decay depths measured in wounds assumed due to logging damage incurred on lower boles of trees (selected species) 5 years prior to sampling.](image)

Regenerated bark is essential for preventing further infestation (Philips and Burdenken, 1992) and for restoration of cambial activity around the full circumference of the bole (Thomas et al., 1995). The anatomy and chemistry of the bark tissues of the sampled species, which are not well known, may explain part of the
variation. Field description of the tree bark showed that all the species that had over 70% healed wounds were those with thick, fleshy, soft or firm bark (e.g. *Entandrophragma angolense*, *Ceiba pentandra*, *Turreanthus africana*, and *Sterculia rhinopetala*). Decay in wounds (Figure 6) occurred mostly in species with brittle, thin or dry and fibrous bark (e.g. *Pycnanthus angolensis*, *Celtis*, *Guarea cedrata* and *Pterygota macrocarpa*). Variations in incidence of wood decay after wounding may also be explained by the natural durability of the sapwood and heartwood of the respective species as noted in several studies (e.g. *Ifebueme*, 1977; *Onuorah*, 2000; *Supriana*, 1998; *Guariguta* and *Gilbert*, 1996). For instance, mean wound depths were higher in species such as *Pycnanthus angolensis*, *Sterculia rhinopetala* and *Antiaris toxicaria* that have less durable timber (Irvine, 1961).

(b) Stem size and logging wound decay

Below 50 cm dbh, decay depths appeared to increase with increasing stem diameter (Figure 7). Mean depths were 31 mm ±8 SE, 61 mm ±12 SE and 112 mm ±30 SE in the 20-29, 30-39 and 40-49 cm dbh classes respectively. However, it fell to 47 mm ±10 SE in the 50+ cm dbh class.

According to *Albers* and *Heyd*, (2000) the ability of the wounded stem to recover quickly from injury is influenced by several factors including growth rate, which is also related stem dbh (or age), and crown status. For instance, Whitford and William (2002) found that incidence of hollows in *Eucalyptus* trees increased with tree size, and larger hollows were more likely in highly senescent crowns.

Stem diameter increments for Ghanaian trees reported by *Alder* (1990) showed that in all diameter size classes, trees with shaded crowns have lower increment than those in sunlight. For example, stem increment for trees 10-70 cm dbh growing wholly or partially under main canopy is seen to rise rapidly between 10-30 cm dbh and drops after 30 cm dbh. However, trees with overhead light show a decreasing growth rate with increasing diameter. Under these circumstances, if rate of stem increment determines the rate of wound healing, then depending on the crown status, results of wound healing after logging damage can be highly variable. Thus the variation in decay depths found among stem sizes in this study do not necessarily indicate a definite relationship between decay depth and stem size.

![Figure 7: Box plot for decay depths in the unhealed wounds among stem size (dbh) classes of all sampled species](image-url)

(c) Wood loss from logging wounds

As the sample was not selected per unit area, results are discussed only in relation to the total sample. The results showed that wounds sustained during logging by trees in 11 of the sampled species, led to decay within 4-5 years after logging. Larger wounds size also appeared to facilitate development of decay.
Figure 8. Histogram of % basal area of stems in the small (20-49 cm dbh) and large (> 50 cm dbh) trees sizes of the 15 species affected with unhealed wounds and likely to be lost due to decay. Anr = Aningeria sp, Ant = Antiaris toxicaria, Cem = Cellis milbraedii/zenkeri, Cp = Ceiba pentandra, Ea = Entandrophragma angolense, Gc = Guarea cedrata, Ki = Khaya ivorennsis, Nes = Nesogodoria papaverifera, Pip = Piptadeniastrum africanum, Ptm = Pterygota macrocarpa, Pyc = Pycnanthus angolensis, Str = Sterculia rhinopetala, Tri = Triplochiton scleroxylon, Ts = Terminalia superba, Tur = Turraeanthus Africana

About 26 m$^2$ (34%) of the total basal area (77 m$^2$) of wounded trees sampled had unhealed wounds. These wounds were in various degrees of deterioration indicated by decay depths ranging between 1 to 350 mm (Figure 6). The percentage basal area loss also ranged from 29.4 to 35.2% among the 4 diameter classes. The quantity of timber likely to be lost as a result of logging-induced wounds will therefore be influenced significantly by the species composition of injured stems.

The majority of stems that receive fatal wounds during logging are those in the smaller diameter class < 50 cm dbh. For example, it is estimated from the Pra-Anum logging study that between 10 and 20 stems ha$^{-1}$ (8-25%) in the <50 cm dbh and less than 2 stems ha$^{-1}$ (4-14%) of the >50cm dbh, sustain injuries but are not killed. The smaller size class (< 50 cm dbh) are stems below the exploitable diameter limits applied for the respective species and may thus not be legally possible to salvage them. This implies a complete loss to current and future production. Although few larger diameter stems are inflicted with fatal wounds, because of their large diameters, they constitute a loss of (2-6%) of pre-logging stand basal area ha$^{-1}$ (DBH >50 cm) at Pra-Anum if the wounds lead to decay.

Wound decay after logging also contributes to wood loss because infested wounds provide weak locations on the bole that facilitates stems breakage during storms. For instance, Mattheck (1995) found, in 800 hollow trees, that those with less than 30% of their radius intact were broken.

4.4.4 Conclusion

About 30% of logging wounds found among the species examined had developed into decay. Basal injuries like those found in this study are known to be a major factor in the incidence of bark rot and heart rot in hardwoods (Nair and Sumardi, 2000) for which there is no control other than reducing the incidence of wounds.

Wound treatment in selectively logged forest may not be feasible for economic and operational reasons. For instance, in intensive tree care practices no wound treatment has yet been found which protects large wounds against decay organisms for a usefully long period (Strouts and Winter, 1994). In reviewing treatment of pruning wounds, Mercer (1979) concluded that though many treatments may encourage regenerated bark production around the wound, they do little to prevent infection by decay fungi (cf. Philips and Burdek, 1992).

This study raises questions for the need to study wound-healing mechanisms such as the anatomical, and physiological basis for susceptibility or resistance to decay after wounding in tropical timber trees, and measures to control stem damage during logging. This is very important for the fact that five species that
showed high tendency for decaying (Pycnanthus angolensis, Antiatris toxicaria, Pterygota macrocarpa, Celtis milbraeidi/zenkeri and Triplochiton scleroxylon) constitutes nearly 40% of current standing volume of timber trees in Ghana (Ghartey, 1989).

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APPENDIX 1:

1A: Forest Reserves investigated for tree selection and removals. Table gives year of reservation, forest area, forest type, location, and first logging date for the FRs. Forest type is after Hall & Swaine (1981): MSNW = Moist semi-deciduous Northwest type, MSSE = Moist semi-deciduous southeast type, WE = Wet Evergreen, and UE = Upland Evergreen.

<table>
<thead>
<tr>
<th>Forest Reserve (FR)</th>
<th>Year of Reservation</th>
<th>Area Km²</th>
<th>Forest Type</th>
<th>Location</th>
<th>1st Exploitation Entry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ateawa Range</td>
<td>1926</td>
<td>232.3</td>
<td>UE</td>
<td>6 10 N 0 36 W</td>
<td>1967</td>
</tr>
<tr>
<td>Wawahi</td>
<td>1929</td>
<td>138.9</td>
<td>MSSE</td>
<td>5 40 N 1 06 W</td>
<td>1963</td>
</tr>
<tr>
<td>Tano Suhien</td>
<td>1934</td>
<td>84.4</td>
<td>MSNW</td>
<td>6 20 N 2 28 W</td>
<td>1962</td>
</tr>
<tr>
<td>Draw River</td>
<td>1937</td>
<td>235.4</td>
<td>WE</td>
<td>5 12 N 2 20 W</td>
<td>1986</td>
</tr>
<tr>
<td>Mamang</td>
<td>1938</td>
<td>54.4</td>
<td>MSSE</td>
<td>6 16 N 1 03 W</td>
<td>1978</td>
</tr>
<tr>
<td>Offin-Shelterbelt</td>
<td>1951</td>
<td>60.3</td>
<td>MSNW</td>
<td>6 40 N 2 03 W</td>
<td>1957</td>
</tr>
<tr>
<td>Subim</td>
<td>1956</td>
<td>238.3</td>
<td>MSNW</td>
<td>6 47 N 2 47 W</td>
<td>1971</td>
</tr>
</tbody>
</table>

Note: Exploitation did not start at same time in all FR due to several reasons (e.g. Accessibility, alternative timber sources available to Concessionaire, nearness to processing mill or log market) as reflected in the duration between date of reservation and 1st exploitation.

1B: Table of Minimum Felling Diameter (MFD) prescribed for timber (Class 1 & 2) species during different periods of the exploitation history in Ghana. Non-Classified (unc) species were generally exploited at 70 cm dbh or at the discretion of the Forest utilization officer. SP = Species with low stocking or restricted range and are to be exploited under special permit from the forestry commission. R = Species that had their MFD revised again after the 1989 schedule.

<table>
<thead>
<tr>
<th>Species</th>
<th>1907-50a</th>
<th>1950-71b</th>
<th>1972-88c</th>
<th>&gt;1989d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afzelia africana</td>
<td>unc</td>
<td>unc</td>
<td>70unc</td>
<td>70</td>
</tr>
<tr>
<td>Afzelia bella</td>
<td>unc</td>
<td>unc</td>
<td>70unc</td>
<td>70</td>
</tr>
<tr>
<td>Albizia ferruginea</td>
<td>unc</td>
<td>unc</td>
<td>70unc</td>
<td>70</td>
</tr>
<tr>
<td>Albizia zygia</td>
<td>unc</td>
<td>unc</td>
<td>70unc</td>
<td>70</td>
</tr>
<tr>
<td>Alstonia boonei</td>
<td>unc</td>
<td>unc</td>
<td>70unc</td>
<td>110</td>
</tr>
<tr>
<td>Amphimas pterocarpoides</td>
<td>unc</td>
<td>unc</td>
<td>70unc</td>
<td>90</td>
</tr>
<tr>
<td>Aningeria spp</td>
<td>87</td>
<td>unc</td>
<td>70unc</td>
<td>70</td>
</tr>
<tr>
<td>Anopyxis klaineana</td>
<td>unc</td>
<td>110</td>
<td>110</td>
<td>70</td>
</tr>
<tr>
<td>Antherax rusticaria</td>
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<td>unc</td>
<td>70unc</td>
<td>50</td>
</tr>
<tr>
<td>Antrocyron microstres</td>
<td>unc</td>
<td>unc</td>
<td>70unc</td>
<td>70</td>
</tr>
<tr>
<td>Berlinia spp</td>
<td>unc</td>
<td>unc</td>
<td>70unc</td>
<td>70</td>
</tr>
<tr>
<td>Bombax buonopozense</td>
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<td>unc</td>
<td>70unc</td>
<td>70</td>
</tr>
<tr>
<td>Canarium Schweinfurthii</td>
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<td>unc</td>
<td>70unc</td>
<td>70</td>
</tr>
<tr>
<td>Ceiba pentandra</td>
<td>unc</td>
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<td>unc</td>
<td>110</td>
</tr>
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<td>unc</td>
<td>70unc</td>
<td>70</td>
</tr>
<tr>
<td>Chrysothemellium spp</td>
<td>unc</td>
<td>unc</td>
<td>unc</td>
<td>90</td>
</tr>
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<td>Copaifera salikunda</td>
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<td>unc</td>
<td>unc</td>
<td>110 (SP)</td>
</tr>
<tr>
<td>Cordia spp</td>
<td>unc</td>
<td>unc</td>
<td>70unc</td>
<td>70</td>
</tr>
<tr>
<td>Cylicodiscus gabunensis</td>
<td>87</td>
<td>unc</td>
<td>70unc</td>
<td>70</td>
</tr>
<tr>
<td>Cynometra anata</td>
<td>unc</td>
<td>unc</td>
<td>70unc</td>
<td>70</td>
</tr>
<tr>
<td>Daniella spp</td>
<td>unc</td>
<td>unc</td>
<td>70unc</td>
<td>90</td>
</tr>
<tr>
<td>Dialium aubrevillei</td>
<td>unc</td>
<td>unc</td>
<td>70unc</td>
<td>70</td>
</tr>
<tr>
<td>Diospyros sanza-minika</td>
<td>unc</td>
<td>unc</td>
<td>unc</td>
<td>50 (SP)</td>
</tr>
<tr>
<td>Entandropodera rongolense</td>
<td>87</td>
<td>110</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>Entandropodera candoilei</td>
<td>unc</td>
<td>110</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>Entandropodera cylindricum</td>
<td>87</td>
<td>110</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>Entandropodera utile</td>
<td>87</td>
<td>110</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>Erythrophleum spp</td>
<td>unc</td>
<td>unc</td>
<td>70unc</td>
<td>70</td>
</tr>
</tbody>
</table>
APPENDIX 2

Study site and Methodology For Logging Study

The study was conducted in a 128 ha compartment (RWC4) of the Research Working Circle of Pra-Anum forest Reserve (Figure 4.1; Lat. 6° 15' N and Long. 1° 10' W). The forest covers a total land area of 123 km² and has undulating topography. It is classified as moist semi-deciduous forest (Hall and Swaine, 1981), where annual precipitation is recorded between 1500 and 1750 mm with two maxima, first in May-June and the second in September-October. The forest experience 5 months dry period with less than 100 mm of precipitation.

Timber harvesting in this reserve dates back to 1954 and current harvesting rights are held by Topbell Integrated company (formerly Amima Timbers) with its processing mill located in Kumasi about 75 km North West of the forest. Past logging records for the experimental compartment could not be traced, however, there was evidence in the forest of past exploitation as indicated by old skid trails (700 meters) and occasional rotten stumps.

Data collection

Experimental design

Two harvesting intensities (1 Annual Allowable Cut (1 AAC) = 26.32m³ ha⁻¹ and 2AAC = 52.63m³ ha⁻¹) with two combinations of tree size selection (large and small diameter trees) were imposed in a factorial design. Felling intensity treatments were allocated randomly to four sites of 32 hectares each (figure 4.2).

Before selecting trees to be logged, a 100% timber inventory of all commercial timber trees above 50 cm dbh (1.3m above ground) was conducted in each treatment site (400m x 800m) adopting the stock survey and mapping methods prescribed by Ghana forestry department (Forestry Dept, 1995).

With the assumption that felling of large diameter trees creates larger felling gaps while small diameter trees create smaller gaps, a wider range of diameters would have been included to facilitate planning for the experimental tree selection. However, permission was not granted by the forestry department for inclusion of smaller stems below the minimum-felling diameter (MFD). All trees selected for felling, either large or small
diameter stem, were then, necessarily within the minimum felling diameter for the respective species (Ranging from 50 cm, 70 cm, 90 cm to 110 cm DBH).

The criteria for stem size selection, was therefore to include in the small size category more than 50% of stems from within 20 cm of the MFD of respective species. In the large size category, more than 50% of trees were of dbh greater than 20 cm of MFD. Thus, ranges of diameters applied were not as wide as intended for the study. Summary of stem numbers, species numbers, and volume per various combination of logging treatments is given in table (4.1). For the high intensity treatment it was impossible increasing the harvesting volume without taking more species, given the requirement to select stems only above MFD.

With the exception of predetermining the location of primary skid trail, no reduced impact logging methods were employed. Felling with chainsaw and ground skidding with a Crawler tractor (D7 Bulldozer) were the methods used. Conduct of logging crew was not under the controlled of the research team. Logging took place between June and September 2000. Swiss Lumber Company conducted the logging for and on behalf of the concession holder.

### Table 1: Allocation of logging treatments to logging sites

<table>
<thead>
<tr>
<th>Treatment s</th>
<th>No. of species</th>
<th>No. of trees</th>
<th>Total vol. m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>High intensity (53m² ha⁻¹)</td>
<td>29</td>
<td>154</td>
<td>1600</td>
</tr>
<tr>
<td>x Large stems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High intensity (53m² ha⁻¹)</td>
<td>22</td>
<td>187</td>
<td>1600</td>
</tr>
<tr>
<td>x Small stems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low intensity (23 m³ ha⁻¹)</td>
<td>19</td>
<td>102</td>
<td>840</td>
</tr>
<tr>
<td>x Small stems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low intensity (23 m³ ha⁻¹)</td>
<td>19</td>
<td>85</td>
<td>840</td>
</tr>
<tr>
<td>x Large stems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site D</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 2.2.2 Logging damage assessment

To provide a basis for estimating damage associated with logging, 16 sample plots (40m x 100m) were established in each treatment site (representing 20% of treatment site area 400m x 800m) prior to logging. Plots were locate in stratified random way with a minimum distance of 50m between any two plots.

Within each assessment plot, all trees with stem diameters at breast height (1.3m above ground) equal to or greater than 50 centimetres were recorded by their species and diameter. Nested subplots were used for smaller stems; Sub-plot of 10m x 100m was used for dbh /20cm, 10m x 50m for dbh/10 cm, and 10m x 25m for dbh/5cm. All trees in each plot were numbered serially starting with plot number and ending with tree number. Estimates of stocking for each diameter class per plot were calculated as the actual stems counted multiplied by the proportion of plot size inventoried (i.e., 50cm dbh x 1, 20-49cm dbh x 4, 10-19cm x 8, 5-9cm x 16). Stock estimates from the 16 plots of each treatment site were used to compute the mean and standard error stocking for the DBH classes at each of the 4 sites. In each of the 16 plots in a treatment site, forest canopy opening was assessed with a spherical forest densiometer from at least six randomly located points.

Logging damage has been expressed by either the number of trees killed or injured for a given density of trees harvested or measuring basal area of trees damaged or killed for a given basal area of trees harvested in felling gaps, skid trails and haulage roads (e.g. Gullison and Harder, 1992; Whitman et al., 1996).

In this study damage assessment was conducted mainly in the sample plots so as to capture the random distribution of logging disturbance. Response variables used for describing logging damage were: forest floor area disturbed by felling and by skidding; canopy openness; total skid trail length; and number of stems (≥ 5cm dbh) damaged (i.e. injured or killed). To be able to differentiate between felling damage and skidding damage, felling assessment was always done before skidding took place in each assessment plot.

Ground area disturbed was described as area of forest vegetation disturbed by the fallen tree, skidder and construction of log-yards. The longest length of the disturbed floor was measured and perpendicular widths taken at regular intervals along the length. The area was calculated using the trapezoidal rule.
For additional analysis of skid trail density in treatment sites, distances covered by the skidder were also surveyed and mapped. Total treatment area disturbed by the Crawler tractor were calculated as trail length multiplied by average of trail width (taken from at least three locations: generally at the start, mid-section and end of each segment of trail or change of direction). Total Skid trail length and areas (m²) in each treatment site were determined for the primary, secondary and tertiary trails. Primary trails are defined here as the midrib of the skid trail network that was used by the skidder on every extraction trip and ran the full length of the treatment site. Tertiary trails were those used to extract individual trees. Secondary trails connect primary to tertiary trails and were used more than once. The log-yard at each treatment site was surveyed (by the triangulation method) using a trailing tape and prismatic hand-oll compass. The area was determined for each site as the sum of the triangles composing the yard and differentiated into landings and loading bays. Landings are locations for piling logs awaiting transportation to mill. Loading bays are areas cleared for the haulage trucks to pack and get loaded. Portions of loading bays were used as work camps.

Post-harvest canopy openness was taken as the loss in canopy cover resulting from logging activities in the plots. It was determined as the difference between the pre-logging average for each plot and post-logging openness (taken from six random locations in each plot) using a spherical forest densiometer.

Damage to residual trees were categorised as: (1) lightly damaged = when ≤25% of tree stem or crown were affected; (2) severely damaged = when ≥25% parts were affected but still standing and; (3) destroyed = when whole tree was destroyed or killed. For each affected tree, the damage score, stem diameter, species, and initial tree number (where possible) were recorded. All damaged stems ≥5 cm dbh in the 16 sample plots per treatment were recorded.

Implications of minimum felling diameter on residual forest damage were explored on the hypothesis that damage to residual trees and vegetation did not differ with sizes of trees felled.

Data analysis
The 16 data plots per treatment site were considered as the replicates for each treatment In order to determine whether total area disturbed differed among treatments, the areas of plots affected were first categorised by the logging activities (felling and skidding) for one analysis, and then summed for another analysis. Due to several cases of no disturbance encountered in the plots, treatment effects were determined using nonparametric (Kruskal-Wallis test) analysis.

To determine whether total number of stems damaged differed among treatments, the affected trees per plot were also categorised according to cause of damage (felling or skidding), by diameter (dbh) classes and by degree of damage (i.e. Injured or killed). The severely damaged and the destroyed categories were combined as trees killed because of the low occurrence of the severely damaged trees. Variations in number of stems damaged (by felling and skidding operations) in the various dbh classes among treatments were however determined with analysis of variance (ANOVA). Variations in total skid trail among treatments were also determined using analysis of variance (ANOVA) in SPSS 11.0.1 by Kinnear and Gray (2000). Relationship between number of stems damaged and area disturbed was examined in a linear regression analysis. Differences in these analyses were considered statistically significant at P = 0.05.

APPENDIX 3
Methodology for study on wood loss due to logging wounds
Study site
Information on logging wounds was collected from 3 compartments (RWC1, 2, 3) of the Research Working Circle in Pra-Anum Forest. The three compartments occupy approximately 520 ha. They were selectively logged between 1995-1997 at a mean intensity of 2 trees ha⁻¹. The vegetation is moist semi-deciduous forest with mean annual rainfall of 1625 mm. The predominant timber species with stems >30 cm dbh in the three compartments are Celtis mildbraedii/zenkeri, Turreanthus africana, Sterculia rhinopetala and Triplochiton scleroxylon.

Sampling design
On the premise that stem growth increment varies with stem size and species, it was assumed that different species and stem diameters would react differently to wounding during logging, even if environmental conditions (biotic and abiotic) were uniform throughout the forest.

So to investigate the occurrence of decay following wounding, sample stems were taken from four diameter classes (20-29, 30-39, 40-49 and 50+ cm dbh) and 15 species in compartments 1-3. For each species at least three samples were taken for each diameter class. Due to low harvest intensity in the study site, it was difficult to find many wounded trees within close vicinity. Therefore sample trees were selected in an
opportunistic manner along old skid trails and within felling gaps. Due to lack of proper tree climbing gear, observations were made only on wounds located on the lower bole (i.e. 4 meters off ground).

For each sample, species name and stem dbh were recorded. Wounds were recorded by location on stem, size and condition. Location was determined as the above ground distance between the base of tree and the mid-point of the wound area measured in centimetres with a linen tape. Wound size was described as the wound surface area \( \text{(cm}^2\text{)} \), calculated as average length multiplied by average width. The length was taken as the longest distance between two opposite ends of the wound. Widths were measured at 2-3 locations at right angle to the chosen length. Wound conditions were recorded as 1 = Healed (completely covered with regenerated bark), and 2 = Unhealed (no regenerated bark and still showing dead wood scar).

It has been observed that external signs of stem injury do not always lead to wood decay beneath the regenerated bark (Albers and Heyd, 2000). For instance, Trockenbrodt and others (2002) observed that among 28 shorea trees identified to have hollow stems, 9 (32%) were not hollow or had insignificant deterioration when felled. It was therefore assumed in this study that wounds completely covered with regenerated bark were better protected against deterioration than the uncovered wounds. Therefore, only wound without regenerated bark were investigated for wood degradation. From more than one point on the uncovered wound surface, stem increment borer was pushed into the wound to detect decay. The decay was measured as the length (mm) of the wood core showing discoloration or soft wood tissue resulting from decaying wound.

To estimate potential loss of economic timber due to logging wounds, stem (dbh) basal area of all wounded sample tree were determined and grouped into 4 dbh classes (20-29, 30-49, 40-49 & 50+ cm) and by wound categories (healed and unhealed). Stem volumes were not used in this study because tree volume equations derived for Ghanaian timber trees are applicable to stems \( \leq 30 \text{ cm dbh} \) (Wong, 1989).

Wounded sample tree included both felling and skid-damaged stems (e.g. Plate 5.1).

Data analysis
Responses to wounding were assessed as the occurrence of healed or unhealed wound and the decay depth in unhealed wound five years after logging. The factors for comparing responses were species, diameter class of wounded tree, size of wound and wound location.

The null hypothesis that the occurrence of healed and unhealed wound conditions on stems following wounding is independent of species was tested analysis using Chi-square contingency table in SPSS 11.0.1. Correlations between wound location, wound size, decay depth and stem dbh were examined using scatter graphs and Pearson's correlation analysis. Variations in decay depths among species and among stem diameter classes were examined using two-way analysis of variance (ANOVA) test in SPSS 11.0.1.