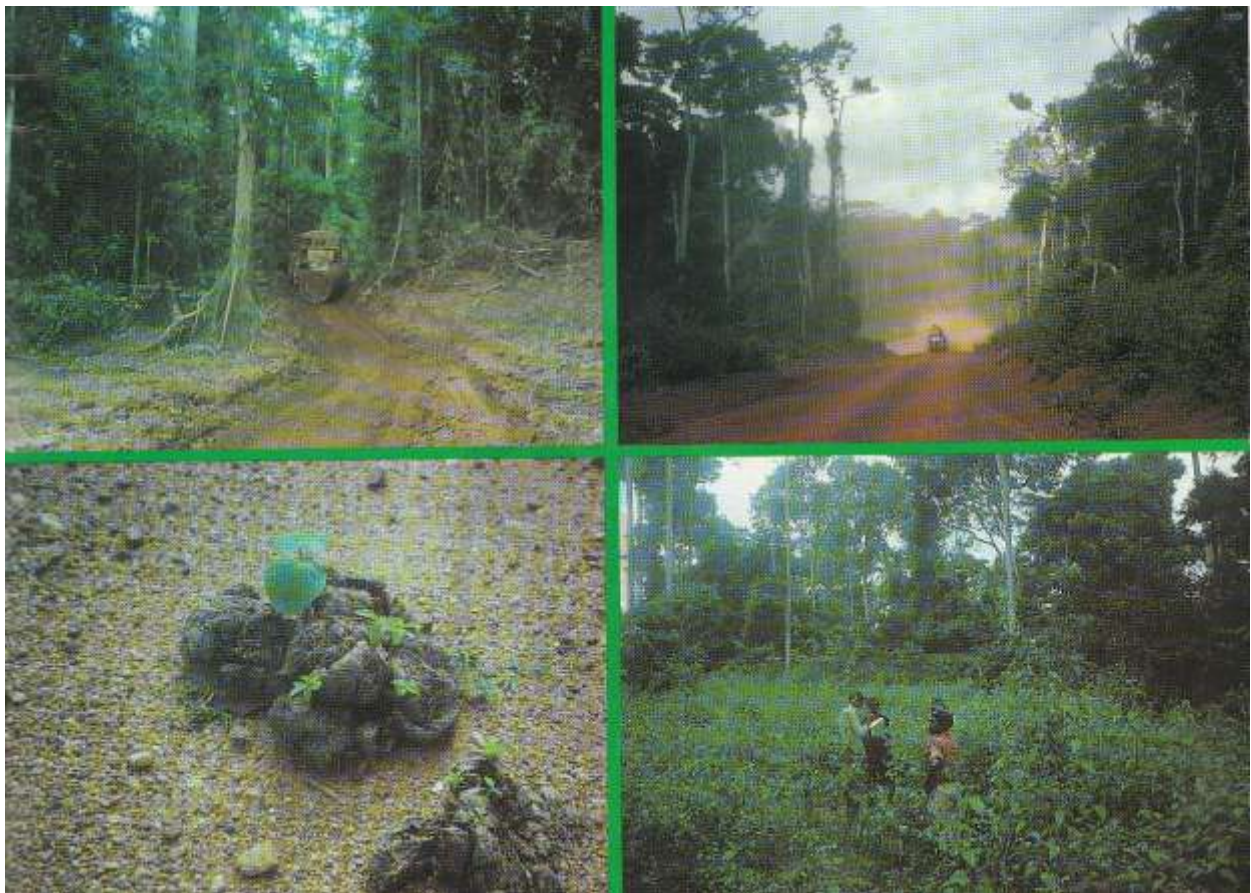


The Impact of Logging Damage on Tropical Rainforests, their Recovery and Regeneration

an Annotated Bibliography



W. D. Hawthorne, C. A. M. Marshall, M. Abu Juam and
V. K. Agyeman



Cover Illustrations

Top left: Skidding a log along a skid trail, viewed from a larger cleared area

Top right: Larger gaps, which regenerate poorly, include the main logging roads.

Bottom left: Seedlings in elephant dung, including *Desplatsia* spp. (smaller) and *Ricinodendron*. Elephants in Bia South are disturbed by logging, yet help with the regeneration of some plant species.

Bottom right: Regeneration in loading bays is usually poor except around the edges. Here it dominated by the alien invasive weed *Chromolaena odorata*. A sample transect across the area is being recorded by the field team.

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BACKGROUND

This annotated bibliography is an output from a DFID/FRP project (R6716 – *Impact of harvesting on forest mortality and regeneration in the high forest zones of Ghana*). The aim of the project as a whole was to improve our knowledge of the negative impacts of logging in tropical rainforests, and to recommend improvements in the logging system. The focus of the bibliography therefore has a Ghanaian/West African slant, although papers from across the tropics are included as well as some relevant papers from temperate regions.

At its core, the bibliography summarises available knowledge on logging damage and recovery, forest regeneration, and the allometry, growth, dispersal, reproduction and death of trees related to logging disturbance. It also documents the logging system in Ghana. Some key zoological references are included, mainly thanks to the efforts of A. G. Johns and L. Darcy, which cover the impact of logging on tropical forest animal biodiversity, the role of animals as dispersers and pollinators, and as bio-indicators of forest condition. Social and economic impacts of logging are not treated, although they are of direct relevance to tropical forest management and conservation.

This is a broad set of subject areas, each of which is extensive on its own, with a disproportionate amount of unpublished 'grey' literature circulating in internal reports and bulletins. We have tried to obtain some of the more relevant documents in the time available, but there must be very many more.

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INTRODUCTION

Data are presented in many ways in the literature, which can make the conclusions of different studies difficult to compare. It is hard to be certain of the relevance of two studies to each other when the species list is different, increasingly so when they are from different continents, and compounded by the use of different methods of evaluation and categorisation by researchers. Some topics, like the amount of damage to be expected when trees of various sizes are felled, travel better than others, such as phenology. Nevertheless, some consensus on the impacts of logging exists. Integrated reviews of many topics covered here, as they might be applied to forest management, can be found in a number of summary papers and books (e.g. Baur, 1968; Chazdon, 2003; Dawkins, 1958; De Graaf, 1986; Ghazoul & Shiel, 2010; Gomez-Pompa *et al.*, 1991; Lamb, 2011; Meijaard *et al.*, 2005; Mergen & Vincent, 1987; Putz & Viana, 1996; Ter Steege, 1996).

Logging Damage

When tropical forest is logged under a typical selection system, logging roads leading into the heart of the forest are built off the public road network. Major forest roads lead to minor forest roads, eventually reaching a loading bay. Logs are usually dragged ('skidded') from their stump to the loading bays, leaving skid trails. Loading bays and roads are completely cleared of vegetation, and the soil often becomes very degraded through compaction, and they show poor regeneration. However, because they are reused each cycle, and one or two will suffice for a large logging compartment, their impact is perhaps more minimal than that of the skid trails

and felled tree gaps (Hawthorne, 2003). Skid trails are therefore the focus of 'regeneratable' damage (FAO, 1977, 1980, 1983; Hawthorne, 1993; Heinrich, 1978) and the regeneration of skid trails in particular is covered e.g. by Bonnell *et al.*, 2011; Dickinson *et al.*, 2000; Guariguata & Dupuy, 1997; Pancel, 1993.

Whereas felling injures neighbouring trees, especially crowns, skidding tends to increase mortality in the very short term (Bertault & Sist, 1995, 1997; Nicholson, 1958, 1979; Pinard & Putz, 1996; Sist *et al.*, 1998). In conventionally logged forest in Indonesia, Sist *et al.* (2003) found that skidding was responsible for twice the number of tree deaths as felling. Because skid trails can be re-used, and felled tree gaps can overlap, Panfil & Gullison (1998) found damage increased in a quadratic function of harvesting intensity.

A great many papers assess logging damage in particular forests: in Indonesia (e.g. Cannon *et al.*, 1998; Slik *et al.*, 2002; Sist & Nguyen-The, 2002; Kartawinata *et al.*, 2001); in Central Guyana (e.g. ter Steege *et al.*, 2002); in the Western Ghats (e.g. Pelissier *et al.*, 1998); in Uganda (e.g. Chapman & Chapman, 1997); in the Brazilian Amazon (e.g. Silva *et al.*, 1995); in French Guyana (e.g. Molino & Sabatier, 2001); in Sabah Malaysia (e.g. Pinard & Putz, 1996; Pinard *et al.*, 2000). Some studies report on damage by tree (e.g. Hernandez-Diaz & Delgado-Pacheco, 1995 in Mexico), or discuss forest areas only (Hawthorne, 2003, in Ghana).

Other studies use mathematical models

to predict the amount of damage associated with the extraction of different amounts of timber by various logging methods, e.g. Boscolo and Vincent, 2000; Buongiorno and Michie, 1980; Crome *et al.*, 1992; Johns, 1992; Macpherson *et al.*, 2010. Verissimo *et al.* (1995) estimated that 30 trees >10cm DBH were severely damaged per tree felled in Brazil, whereas Bird (1988) observed averages of 0.5, 17 and 50 trees >10cm DBH in Belize. One important source of variation is the size of the trees being felled, and another is slope, where skid trails are obliged to follow contours rather than the most direct route (Hawthorne, 2003).

More recently there have been developments in remote sensing of forest degradation and deforestation, allowing canopy monitoring after logging over much larger areas (Asner *et al.*, 2004; Asner *et al.*, 2010). Asner *et al.* (2004) found that loading bays had the largest forest gap fractions, but contributed little to landscape level gap dynamics. Tree falls were spatially the most extensive form of canopy damage, but the canopy gap fractions resulting from them were small. Regional-scale analysis in Amazonia showed that half of the canopy gaps had closed one year after logging.

Logging disturbance can be important for the regeneration of certain species, such as *Swietenia macrophylla* and *Cedrela* spp. in the Americas, *Entandrophragma* spp. in Africa, and *Shorea leprosula* in Asia (Fredericksen and Putz, 2003). In other circumstances, logging disturbance may create an environment that is unfavourable, particularly if combined with heavy harvest pressure (Chazdon, 2003), as is the case with many highly valuable

species in the Amazon region (Schulze *et al.*, 2008).

There are various modes of logging, but selective logging or Reduced Impact Logging ('RIL') techniques (e.g. Dykstra, 2002) are now well established. Some barriers to full implementation exist (e.g. Pokomy *et al.*, 2005; Putz *et al.*, 2001). There is evidence that RIL reduces the damage associated with logging: Sist *et al.* (1998) found that RIL reduced damage overall by 50% compared with conventional logging at a harvest intensity of 8 stems/ha, but at higher logging intensities improvements were less marked. Pinard & Putz (1996) found that conventional and RIL areas contained biomass equivalent to 44% and 67%, respectively, of pre-logging levels, one year after logging. Holdsworth & Uhl (1997) found that RIL reduced the risk of fire subsequent to logging; Macpherson *et al.* (2010) found that RIL reduced forest recovery time in their matrix model compared with conventional logging.

An important aspect of RIL is the pre-felling cutting of lianas. Lianas have been shown to exacerbate the effects of logging, and also have a negative effect on growth and yield, so have been increasingly studied in this context (Appanah & Putz, 1984; Cedergren, 1996; Fox, 1968; Gerwing & Uhl, 2001; Liew, 1973; Neil, 1984; Parren & Bongers, 2001; Pinard & Putz, 1994; Putz, 1984; Putz *et al.*, 1984; Schnitzer *et al.*, 2004).

Appanah & Putz (1984) found that climber cutting reduced the number of trees pulled down with logged trees by half in forest with high climber density (376/ha >2cm DBH); although in a different context Cedergren (1996) found

that climber cutting had no effect, and Parren & Bongers (2001) also found that climber-cutting did not significantly decrease tree mortality or damage. Putz (1984) found that 90% of cut adult lianas survive when they are dragged into felled gaps, and this strong regeneration of climbers can inhibit the recolonisation of gaps by tree species (Neil, 1984). Pre-cutting of lianas in Brazilian forests was shown to significantly reduce liana proliferation in logging gaps after 6 years (Gerwing & Uhl, 2002), and Schnitzer *et al.*, (2004) concluded that liana cutting was an effective method to reduce the abundance of lianas in logging gaps, minimising the detrimental effect on regenerating trees.

Yeom (1984) reported that global timber production from natural tropical forests low (5-35m³ of merchantable wood per hectare). However, at least half of the remaining stems are beyond recovery during logging (Barbier *et al.*, 1992). This coupled with extremely arduous working conditions in the forest make harvesting operations expensive (FAO, 1993). A solution to the high cost of exploitation per unit area is to increase yield by minimising logging waste and encouraging increased exploitation and utilisation of less used species (LUS) (Yeom, 1984; Wehiong, 1990).

Although almost all work has concentrated on commercial logging, Lawes *et al.* (2007) noted that the impact of commercial logging 100 years ago at a site in South Africa can still be seen today because the understorey species that regenerated in the logging gaps have subsequently been the focus of local subsistence harvesting of small DBH poles from the forest. There is also a literature on the impact of salvage

logging, when timber is recovered from forests following natural disturbances such as hurricanes. Lindenmayer & Noss (2006) stated that impacts can be negative, positive or neutral, additional to or different from the effects of traditional logging, and depend on initial circumstances. See also Peterson & Leach, 2008; Phillips *et al.*, 2006.

The species richness of animal populations (ants, birds, and Lepidoptera) following a) logging and b) conversion of forest to agricultural land is reviewed by Dunn (2004), using data from 34 studies. Meijaard *et al.* (2005) review ecological and life-history information for a range of Bornean wildlife species, aimed at identifying what makes these species sensitive to timber harvesting practices and associated impacts. Other reviews addressing the impact of logging on fauna include Johns, 1997 and Putz *et al.*, 2000.

Literature addressing the impact of timber harvesting methods and operations on animal taxa is biased towards birds and primates. For birds (e.g. Abbott & van Heurck, 1985; Allport *et al.*, 1989; Ayres & Johns 1987; Cleary *et al.*, 2008; Cockle *et al.*, 2010; Dale & Slemby, 2005; Du Plessis 1995; Edwards *et al.*, 2009; Eyre *et al.*, 2009; Holbech, 2005; Johns, 1986; Johns, 1991a; Kalina, 1988; Kofron & Chapman, 1995; Mason, 1996; Massimino *et al.*, 2008; Obua, 1992; Peh *et al.*, 2005; Pinto Henriques *et al.*, 2008; Thiollay, 1992; Whitman *et al.*, 1996; Wunderle *et al.*, 2006; Zurita & Zuleta, 2009), authors have variously reported: significant decreases in bird species richness and diversity; only slight differences in species diversity; and similarity in bird richness, but with

important changes in species abundance and composition after logging.

Primate responses to logging (Asibey, 1978; Bonnell *et al.*, 2011; Branch, 1983; Chapman *et al.*, 2000; Fairgrieve, 1995; Gillespie *et al.*, 2003; Johns, 1991b; Johns, 1983; Lehman, 2003; Oates, 1996; Olupot *et al.*, 1994; Petter & Peyrière, 1974; Plumpetre, 2006; White, 1992;) are also variable. Some primate species are highly dependent on undisturbed forest (specialists like *Hylobates* spp.; *Cercopithecus* spp.; *Chiropotes* spp.), while others prefer disturbed habitats and will be more likely to survive in disrupted areas (generalists like *Macaca* spp.; *Colobus* spp.; *Cebus* spp.) (Azevedo-Ramos, 2005). After logging, the intensity of hunting increases primarily because of easier access to remote forests by new roads and of the greater human presence in the area, and this impact is an important component of the impact of logging (Bennett & Robinson 2000; Putz *et al.* 2000).

There has been some interest in the use of animal groups as bioindicators for forest condition (Aguilar-Amuchastegui & Henebry, 2007; Azevedo-Ramos, 2005), but due to the relative expense of surveying animal groups, the lack of consistent results between studies and paucity of evidence linking particular animal groups to others, the results are not particularly encouraging.

Recovery after Logging

Many studies focus on structural measures of logged forest recovery, such as basal area, aboveground biomass, tree height, or stem density (e.g. Abdulhadi, 1981; Bertault & Sist, 1995; Bird, 1998; Bonnell *et al.*, 2011; Cannon *et al.*, 1994; Chandrashekara &

Sreejith, 2006; Chazdon *et al.*, 2007; Elias, 1995; Gerwing, 2002; Johns, 1988; Jonkers, 1987; Ola-Adams, 1987, Silva *et al.*, 1995; Tang, 1976; Taylor *et al.*, 1996; Van der Hout, 1996; Wong, 1998). Other studies have examined changes in canopy structure, the frequency and size of canopy gaps, and light availability during forest recovery (e.g. Denslow & Guzman, 2000; Nicotra *et al.*, 1999; Yavitt *et al.* 1995).

Changes in species composition occur independently of changes in structural variables, and show far more long-lasting legacies of disturbance (Chazdon, 2003). Aboveground biomass re-accumulation can occur on a scale of decades, while species composition recovery can take centuries (Guariguata & Ostertag, 2001). Studies that focus on changes in species composition, density, richness, evenness or diversity after logging include Aide *et al.*, 2000; Bergstedt *et al.*, 2008; Castro-Luna *et al.*, 2011; Dupuy & Chazdon, 2008; Gutierrez-Granados *et al.*, 2011; Hall *et al.*, 2003; Hawthorne, 1993; Kasenene & Murphy, 1991; and Liebsch *et al.*, 2009; Makana & Thomas, 2006.

In addition, Chua *et al.* (1998) found that although alpha species diversity and species richness had increased following logging in Malaysia, the concentration of globally restricted species (the 'bioquality') had decreased, so that logged areas were relatively more dominated by globally widespread species. However, King & Chapman (1983) found that a logged forest area with 90% of its canopy removed had recovered all species after 25 years. Although much of the literature focus on the recovery of timber tree species, recovery has been examined for herbs, lianas, and non-vascular epiphytes, e.g.

by Turner *et al.*, 1996; Romero, 1999; Costa & Magnusson, 2002; Schnitzer & Bongers, 2002; Parrotta, 1995.

The impact of logging on soil nutrients and cycling is another important area of research (Gillman *et al.*, 1985; Nussbaum *et al.*, 1995; Silver *et al.* 1996). Disturbance that impacts soils as well as above ground vegetation, such as the use of bulldozers and skidders during logging operations, can significantly slow down the rate of forest structural recovery and can have long-lasting effects on species composition. The recovery of soil fertility is closely linked with the recovery of aboveground biomass (Chazdon, 2003).

Forest recovery can also be measured in terms of the abundance and richness of species used for non-timber products, e.g. Adnan & Holscher (2011) found that 10 important medicinal species were most abundant in old-growth forests in NW Pakistan. The Brazil nut (*Bertholletia excelsum*), appears to regenerate best in large gaps and other disturbed areas (Myers *et al.* 2000). Dirzo & Miranda (1991) suggested that the recovery of species interactions is another metric that should be used more widely. Several studies have examined recovery of particular species, with a focus on tree population structure, genetic diversity, and overall changes in abundance (e.g. Andre *et al.*, 2006; Degen *et al.*, 2006; Jennings *et al.*, 2001; Wernsdorfer *et al.* 2011).

Regeneration after Logging

The natural regeneration of many species is gap size dependent (Schulze, 1960; Swaine and Whitmore, 1988). Even shade bearers regenerate more frequently in small gaps compared to

the forest understorey (Swaine and Whitmore, 1988; Hawthorne, 1993). The sizes of gaps created determines the type of species which regenerate and the extent of natural regeneration. Medium sized openings resulting from felling gaps and skid trails favour the natural regeneration of most of the economic timber tree species, many of which are non-pioneer light demanders, compared to other gaps. Small (branch or small tree fall) and large (multiple tree fall, haulage roads and loading bays) results in reduced regeneration and a decline in the economic value of the tropical high forests of Ghana (Hawthorne, 1993; Swaine *et al.*, 1998). This underscores the importance of gaps in regeneration (Hartshorn, 1978; Whitmore, 1990). Timber harvesting affects the forest micro-environment (Chazdon and Fetcher, 1984; Jans *et al.*, 1993) and also stimulates the growth and regeneration of tree species.

A study by Swaine *et al.* (1998) which focused on damage immediately following timber exploitation show that disturbances due to logging markedly reduce the pre-existing tree seedlings in felling gaps and skid trails. However, enhanced regeneration was observed in small gaps and skid trails 3 years after timber harvesting in Bia-South Forest Reserve (Hawthorne, 1993) and 15 years after timber harvesting in wet and dry forests (Appiah *et al.*, 1998). This is probably because, the stimulation of new seedling establishment significantly exceeds these losses due primarily to the local enhancement of light, the principal limiting factor for plants in forest.

The most abundant class (diameter size) of tree species following regeneration will be the one adapted for the predominant gap sizes (Denslow, 1984).

More advanced regeneration was observed in the wetter forests compared to the drier ones for similar logging operations. This is probably because of the higher rainfall and greater density of seed trees following logging in the wetter forests (Swaine *et al.*, 1998).

Tropical forest tree species differ markedly in their tolerance of shade and their ability to respond to changes in irradiance. The responses of species to variation in irradiance can be studied by growth analysis (Fetcher *et al.*, 1983, Mitchel & Woodward, 1988), using shadehouses (Popma & Bongers, 1991; Osunkoya *et al.*, 1994), gaps created in the forest (Chazdon, 1986; Brown, 1990) or by light response curves in which changes in the rates of photosynthesis and transpiration are measured instantaneously in the same seedling under varying irradiance (Oberbauer & Strain, 1984; Kwesiga & Grace, 1986). The latter approach records the rapid responses of existing leaves and photosynthetic apparatus to changes in light, usually diffuse and neutral in spectral composition (high red:far-red ratio). Growth analysis may be done in shade houses (usually with neutral shade) or in the forest by creating canopy openings of different size, effectively using natural shade where light quality varies with irradiance. In theory, experimental conditions can be more closely controlled and more precise questions addressed by the approach of measuring photosynthesis, but it is very difficult to use the results to predict outcomes for tree seedlings growing in forests. Forest growth analysis experiments are effective at answering questions about how trees will respond to canopy opening, but are less effective at determining which of

the changed environmental variables are the cause of the seedlings' response.

Based on field experience of tree growth and more particularly the distribution of young seedlings in different forest light environments, it has been possible to define fairly robust classifications of species according to the light requirements (Hawthorne & Musah, 1993; Swaine & Whitmore, 1988). The simplest classification divides tree species into pioneers (requiring gaps for seedling establishment and growth) and non-pioneers (able to establish and grow in forest shade). Growth analysis and photosynthesis measurements have shown how these contrasting species guilds differ in growth physiology. Pioneers have high dark respiration, high compensation and saturation points and high quantum efficiency. These characteristics give them substantial flexibility for growth in different light environments, but not sufficient for survival in deep forest shade - shade tolerance appears to be sacrificed for the benefit of very rapid growth in high irradiance. By contrast, non-pioneers have low dark respiration, low compensation and saturation points and show relatively little increase in growth when irradiance increases. Their forte is growth and persistence in deep forest shade. These differences are well exemplified by Kwesiga & Grace (1986).

Differences amongst tree species responses to irradiance as determined by such experiments offer the possibility of predicting seedling growth in canopy openings in natural forest. However, forest gaps differ not only in irradiance, but also light quality, humidity, air temperatures and water balance - many potential causes to confound the predictions based on light. Thus it is

important to test the applicability of experimental results by trials in the forest. Since environmental conditions differ significantly between forest types, we must also test in more than one type.

Exploitation of tropical forest for timber causes canopy opening, leading to changes in microclimate (Minckler *et al.*, 1973, Vitousek & Sanford, 1986) which influence the remaining trees. Reduced competition, principally for light, allows increases in growth rates for some of the remaining trees, but also to an increase in tree mortality (Primack *et al.*, 1985). For tree seedlings, similar effects occur, but with greater magnitude (Brown, 1990). These microclimatic changes vary with the size of canopy opening, so that the manner and intensity of logging operations can have a profound influence on the recovery of the forest.

Changes in microclimate are driven by differences in the radiation incident in the forest so that incident radiation and other microclimatic variables are closely correlated (Whitmore *et al.*, 1993). Changes in microclimate between canopy gaps of different size are thus fairly predictable: in large canopy openings with high irradiance, the increases in air and surface soil temperatures, in red:far red ratio, and reduction in humidity, are greater than in small openings (Whitmore *et al.*, 1993; Brown, 1993). These physical processes mean that gap size is most appropriately measured as total radiation, though the dependent microclimatic variables, which may be easier to measure, can be used as surrogates. Brokaw's (1982) measurement of gap area is a widely used surrogate, but is not linearly

related to irradiance and is therefore inaccurate for small gap sizes and for comparing forests of different stature (Whitmore *et al.*, 1993). Many studies on gap microclimates are restricted to one kind of forest, though it is expected that different kinds of forest will have different microclimates as a result of differences in macroclimate, stature, canopy density and seasonal variation.

Reproduction, Dispersal and Recruitment

Much of what needs to be known about forests, in a way which will facilitate understanding of empirical results on logging damage, is at the species by species (autecological) scale. The literature and inventory data on the autecology of Ghanaian trees is reviewed in Hawthorne (1995). Community-level regeneration studies will benefit from the resurrection of some silvicultural literature, e.g. Lamb, 1940; Webb, 1948; Macgregor, 1948; Lancaster, 1954; Letouzey, 1957; Quist-Arcton, 1958; Sawyer, 1960; Alexandre, 1977, 1978; Lowe 1984; Corbassion & Souvannavong, 1988.

Proximity of disturbed areas to remnant forest patches with 'seed trees' promotes more rapid recovery, particularly in species composition. Dispersal syndromes are potentially of great significance to logging prescriptions, especially concerning guidelines for retention of seed trees. When considering the distance that a tree can expect to project its offspring, it is profitable to group species into groups with similar dispersal syndromes (Alvarez Buylla & Martinez-Ramos, 1990; Appanah & Mohd.-Rasol, 1995; Augspurger, 1986; Augspurger & Franson, 1987; Augspurger & Hogan, 1983; Beer & Swaine, 1977; Denslow *et*

al., 1990; Howe & Smallwood, 1982; Keay, 1957; Kitajima & Augspurger, 1989; Van der Burgt, 1997).

Tree fruiting phenology is perhaps less significant where there is some temporal buffer for the regeneration, either in a soil seed bank (Cheke *et al.*, 1979; Epp, 1987; Hall & Swaine, 1979; Hopkins & Graham, 1983; Viana & Anderson, 1990), or in the seedling 'bank' (i.e. established seedlings) which will however be more susceptible to logging damage. Very few timber species, a subset of the pioneer guild, occur in the seed bank in Ghanaian forest, including *Milicia*, *Nauclea* (Kyereh *et al.*, 1999), and probably *Hallea* spp. in swamps.

Variation in seed production capacity occurs on many levels (Baur & Hadley, 1990; Schuppe, 1990) which ought to influence differential tree retention. Integration of seed dispersal and dynamics in the bigger picture of tropical forest regeneration (e.g. Whitmore, 1996) is still a long way from providing many practical solutions. We need more of these studies if we are to make much headway in using such research to guide logging practices.

When the interaction between dispersal distance and stand dynamics are considered, various other trends have been examined - for instance the role of the Janzen-Connell 'escape' hypothesis, whereby seedlings distant from parents perhaps have a greater chance of survival, either due to density dependent mortality (Condit *et al.*, 1994) or distance (from parent)-dependent mortality (Connell, 1971; Howe and Smallwood, 1982; Hubbell, 1980; Janzen, 1970). In many cases, the escape hypothesis has been supported

or partially supported e.g. depending on annual variations or scale of analysis (24 studies reviewed by Clark & Clark, 1984; Cintra, 1997). For example, rodent dispersed species including *Carapa procera* are dispersed and hoarded up to tens of metres from mother trees (Forget, 1990), but the final distribution of successful regeneration is strongly shaped by other factors such as soils or canopy gaps.

As the number of variables studied increases, this subject area merges considerably with others, e.g. the already complex issue of guilds and gaps (Alexandre, 1977; Augspurger, 1983 & 1984; Augspurger & Kelly, 1984; Augspurger & Kitajima, 1992; Forget, 1989, Lieberman & Li, 1992; Lopea & Ferrari, 1994; Loubry, 1992). In some cases, seed-centred studies have focussed on these and related issues in the context of the effects of logging or efficiency of silvicultural systems (Appanah & Manaf, 1990; Appanah & Mohd.-Rasol, 1991 & 1995; Gorchov *et al.*, 1993; Hammond *et al.*, 1996; Hostettler, 1996; Plumptre *et al.*, 1994; Putz, 1983).

One approach that has been used to predict recruitment is to calculate the proportion of recruited species as a function of stand basal area, site productivity and the relative abundance in the stand. Alder (1995) notes that it is logical to expect a consistent relationship between the basal area removed and the number of trees recruited (after a lag), because basal area losses correlate directly with crown area lost, and hence growing space created. Recruits are of similar size so the number of recruits will be proportional to the growing space available.

Various other autecological subtleties, such as the implications of dioecy (Lawton, 1955; Kigomo *et al.*, 1994), should be accounted for in the formulation of yield guidelines aimed at protecting seed trees (presumably twice the density of functionally dioecious trees would, in general, be needed as seed trees if males tend to equal females in number).

Forest Cover and Long Term Site Potential in Ghana

The size class distribution of tropical forests shows a geometric decrease in number of trees with increasing tree size. This distribution pattern was also observed by Rollet (1978) for tropical rain forests outside Africa. Generally, size class distribution patterns in the tropics have been influenced by the number and frequency of canopy gaps (Golley, 1983), severe disturbance of the forest stand in the past (Rollet, 1978) and the intrinsic physiological and ecological characteristics of the tree species (Jonkers, 1987). Logging also opens up the forest canopy which upsets the natural balance of the forest ecosystem resulting in an increased impact on the long-term functioning of the ecosystem (White and Pickett, 1985). However, the extent of the impact depends on the intensity, frequency and duration of logging.

Uncontrolled logging results in the removal of up to 3 trees ha⁻¹ in Ghana (Agyeman *et al.*, 1995) and 2 trees ha⁻¹ in Cameroun (Duiker and van Gernerden, 1989) which affects up to 13% and 20% of the total area in Ghana (Hawthorne, 1993; Agyeman *et al.*, 1995) and Cameroun (Duiker and van Gernerden, 1989) respectively. A higher logging disturbance was recorded in Cameroun compared to Ghana even

though less trees were removed because of the larger diameters of the felled trees. For example, most of the trees felled in Cameroun were greater than 100cm dbh whereas those felled in Ghana were above 70 cm dbh (Agyeman *et al.*, 1995; Duiker and van Gernerden, 1989).

Generally, logging damage is significantly correlated with scale of operations or felling intensity (Swaine *et al.*, 1998). Increasing the felling intensity from 2 to 4 trees ha⁻¹ resulted in a 300% increase in total areas affected by logging in Bura and Draw River Forest Reserves in the moist forests of Ghana (Agyeman *et al.*, 1995). A study on the impacts of logging (ITTO PD 179/91) in Ghana shows that removing 2.6% trees ha⁻¹ resulted in a treefall damage of 8% and skidding/haulage road damage of 5%. Removing twice as many trees in Sapoba Forest Reserve in Nigeria with a vegetation type similar to that of Ghana resulted in a logging disturbance of about 50% of the total forest area (Redhead, 1960) which is about four times that of the disturbance observed in Ghana. Jonkers (1987) also observed that logging damage increases exponentially with felling intensity in a tropical rainforest in Surinam.

The type of damage inflicted on the forest depends on the harvest intensity. Gullison and Hardner (1993) used simulation model to investigate the relationship between harvest intensity and forest damage. At low harvest intensities, most forest damage occurs from the construction of main roads as harvest intensity increases, secondary damage from skid trails and tree felling comes to dominate forest damage. Generally, less damage results to the forest for a given harvest volume if the harvest area is reduced and harvest

intensity increased. The extent of tree damage is influenced by the type of logging operation. For example, total number of trees damaged due to haulage road and skid trail construction were higher than that of felling timber trees. This may be due to inefficient extraction machinery and working practices (Agyeman *et al.*, 1995).

Ofosu-Asiedu *et al.* (1993) noted that on average about 4 commercial timber trees between 10-50cm dbh are completely destroyed for every 100m of skid trails constructed. The high tree damage may be related to the large sizes of the skid trails and haulage roads which are made during extraction. The average skid trails were wider than what is prescribed in the logging manual of the Ghana Forest Service. There were also more loading bays per compartment than what is specified in the logging manual. The type of damage due to felling and skidding are different. Felling affects trees of all size classes while skidding mainly affects trees < 20cm dbh (van der Hout, 1996).

Logging disturbance and tree damage were found to be greater in wet compared to dry tropical forests (Ofosu-Asiedu *et al.*, 1993, Agyeman *et al.*, 1995). These differences may be attributed to the fact that larger trees were felled in the wetter forests as is evident from the larger gap sizes and larger mean volume of the felled trees observed from the results of Swaine *et al.* (1998). Another reason is that most areas in the wetter forests have been logged once (first rotation felling) whereas most of the drier forests have been logged at least twice. Incidentally, the wetter forests are richer in floristic composition and have a greater percentage of fragile environments that need to be protected. Since these areas

also have greater logging disturbance and tree damage per unit volume of wood harvested, there is the need for stricter logging controls in the wetter forests compared to the drier forests. In practice, however, the manual of procedures of forest management in Ghana indicates that a higher felling intensity should be carried out in wet and moist forests (up to 3 trees ha⁻¹) compared to the drier forests (up to 2 trees ha⁻¹). This is probably because the drier forests are subjected to frequent annual fires which have degraded the forests and caused excessive canopy opening. A high felling intensity therefore, predisposes these drier forests to much more severe fire attacks in subsequent years.

Biodiversity of Residual Forest

The main threats to biodiversity in the tropics include increased incidence of annual fires, increased exploitation, and clearing of forests for agriculture (Hawthorne, 1994). Logging activities may result in the disappearance of species thus reducing species diversity and the potential of the forest (Abdulhadi *et al.*, 1981). Uncontrolled logging has considerable impact on biodiversity conservation, forest structure and species composition and may lead to loss and fragmentation of forests (Foaham and Jonkers, 1992).

Selective logging in some sense mimics natural gaps such as tree falls, or chablis (Gormley, 1997) and therefore do not result in more diverse forests (Brown and Press, 1992). Over 70% of felling gaps created by small loggers at Bura and Draw River Forest Reserves in Ghana were less than 400m² (Agyeman *et al.* 1995). Such small gaps randomly damage or kill large and small trees of all species (Johns, 1988) and tend to enhance the structure and floristic and

faunistic diversity of the forest (Laird, 1995; c.f. Gormley, 1997). However, large felling gaps, up to 1000 m² which tend to simplify ecosystems and subsequently reduce biodiversity were also observed after exploitation though infrequently (Agyeman *et al.*, 1995).

Selective logging of mature or superior trees generally causes genetic depletion, consequent loss of potential food sources and disease control, reduction in the stability of ecosystems and a loss of resilience against catastrophes. The removal of seed trees also reduces the potential of the forest to regenerate after logging. The disappearance of species or the alteration of species compositions in ecosystems may cause irreversible losses of natural resources. An increase in the species that are currently being utilised may lead to loss of intra-specific variation, especially in those timber species for which the regeneration requirements are incompatible with silvicultural system and/or felling cycling. This is probably because timber exploitation is known to exert a negative selection pressure on the species harvested as the most vigorous and well-formed individuals are taken and the lesser quality individuals are left to produce seed (Oldfield, 1990).

The impact of logging on forest fauna is similar to that on flora and depends on the ecology of particular species or group of species. Logging also alters the habitat of wildlife by changing or destroying nesting, feeding and breeding sites. According to Myers (1988), forest disturbance affects animal populations even more than plant species, as animals often require large ranges. Since different silvicultural systems produce forest stands with different forest structure, their impacts on animals varies depending on animal

habitat requirements and ability to recognise logged forest (Gullison and Hardner, 1993). According to some local communities in Ghana the noise of logging machinery chases away most mammals and birds (Gronow, J. personal communication).

Another impact of timber harvesting is that on insects. The extent of human interference on the forest ecosystem, especially through logging, determines the risk of pest outbreak (Gray, 1972; Wellman, 1972). This is probably because the degree of devastation by pests is influenced by the complexity of the ecosystem (Cobbinah, 1997) because of selectivity. The more complex the ecosystem the less likely will be the incidence of pest outbreak. For example, the potential for pest outbreaks increase from primary forests through secondary forests to monoculture plantations (Cobbinah, 1997).

Fire

Generally, the incidence of fire increases with forest disturbance caused by logging and thinning operations (Beaman *et al.*, 1985; Berthault, 1990). Heavily opened up areas suffer the most from fire damage. Hawthorne (1994) observed that logging has exacerbated fire damage in Ghana. The fire damage in Ghana may be linked to climatic changes, but one cannot simply dismiss current levels of fire damage as part of a natural cycle. The vegetation of heavily logged forest a few years after logging is obviously more prone to serious fire damage (c.f. Hawthorne, 1994). At ground level it feels drier and hotter and there are also more thin stems close to the ground in forest gaps than in undisturbed forest understorey. Fire affects the structure and composition of the vegetation and is now by far the

greatest threat to the long-term productivity, genetic wealth and general health of forests in Ghana.

Bush fires in Ghana have been experienced for centuries in both savannah and forest areas, with the destruction of thousands of acres of cocoa farms, food crop farms, villages and trees. Bush fires impoverish the soil by destroying organic matter in the soil, and increasing leaching, wind and water erosion. Bush fires also have significant influence on the composition of the present forest canopy and serious consequences for forest regeneration (Orgle, 1994). Mortality caused by fire is greatest for small trees, whilst more large trees are killed by drought. This thinning allows rapid recolonization, especially by marantaceous and zingiberaceous forbs and pioneer trees. Recurrent fires impede recovery of burnt forest (Hawthorne, 1994). Fire-affected forests generally has a higher proportion of deciduous trees, thick bark, hard slash, deep roots and absence of buttresses and stem fluting compared to closed canopy forests without fire (Kielland-Lund, 1982).

Severe fires can be limited by preventing excessive logging (Hawthorne, 1994). Beaman *et al.* (1985) has shown that fires in Sabah, Malaysia, following dry years, were almost six times more common in logged forest than in unlogged forest. Ecologically sound logging practice should limit the effects of subsequent fires. This can be achieved by limiting the total number of trees removed per compartment and by limiting the number of adjacent trees felled. These two restrictions should be enforced in fire-prone areas. In addition, as most fires probably enter the forest from bush fires in vegetation surrounding the

reserves, logging and other forms of canopy disruption should be prohibited in buffer zones insulating each forest block (Hawthorne, 1994). The prevention of bush fires by education, use of improved agricultural practices and enforcement of bush fire laws should be implemented by all countries in fire prone areas. (Korem, 1985).

Apart from logging, changes in global climate has also been a major factor influencing the incidence of forest fires. For example, the drought of 1982-3 resulted in widespread occurrences of fire in most parts of Africa (Sanford *et al.*, 1985; Beaman *et al.*, 1985). The incidence of fire is extremely high at the transition zone between forests and savannah in Ghana (Brookman-Amissah *et al.*, 1980). Other factors influencing forest fires in the country include, slash and burn agricultural system, hunting and palm-wine tapping. Drought and other forms of forest degradation results in reduced canopy cover leading to a drier, more inflammable forest. This has made them highly susceptible to fire. According to Swaine *et al.* (1997), drought and fires in the humid forests of Africa are not new and may be attributed to the long lasting effects of severe droughts that have hit the region in the past.

Soils

A number of studies have indicated that soil compaction is a greater problem following logging than soil erosion (Tachie-Obeng, 1995; Appiah *et al.*, 1998), especially viewed against the background that current road construction activities of large companies tends to cause a cumulative loss of production over several felling cycles due to serious soil compaction. Timber harvesting as currently practised in tropical Africa leads to slight

reduction in soil productivity in felling gaps (Tachie-Obeng, 1995) since all the branches, leaves and almost 50% of standing tree volume are left in the forest as residue. However, significant changes in soil productivity were observed on haulage roads and skid trails (Tachie-Obeng, 1995). In a similar study, Gent *et al.* (1983) observed significant changes in soil physical properties from the surface to the 30cm depth in the skid trail plots following logging, however, significant changes in soil properties in treefall gaps were limited to the upper 15cm of soil.

Another major impact of logging is the removal of the top soil during log dump, haulage road and large skid trail construction resulting in loss of soil fertility. Congdon and Herbohn (1993) observed that nutrient concentrations in felling gaps were depressed in wet tropical forests compared to unlogged forests even 25 years after selective felling. Conventionally, harvesting removes about 5-30% of the total nutrients taken up in the above ground stand (Stone, 1968). There is a world-wide concern that increased removal of tree biomass with its nutrient content causes a decline in soil nutrient and forest productivity (Jordan, 1985). Additionally, opening up the canopy through logging results in higher day time temperatures and reduced day-time humidity on the forest floor (Schulz, 1960) which invariably influences nutrient cycling.

Tropical forests are considerably capable of compensating for slight reductions in soil nutrient content arising from relatively low logging intensity by taking up nutrients directly from rainfall and from the air by means of nitrogen fixing organisms (Jordan and Herrera, 1981). However, as logging

intensity increases nutrient loss also increases and it takes a much longer felling cycle for the forests to cope with such loss. With the present increasing and persistent destruction of the tropical forest, the entire forest ecosystem may not be capable of sustaining itself if realistic measures are not taken to reduce nutrient loss through tree harvest (Nye and Greenland, 1990).

Timber Harvesting and Management in the Tropics

The general objective of forest management in the tropics is *“the sustainable production of timber to provide a perpetual flow of wood products to domestic and export markets and to provide revenue for the resource owners; and to fund forest management whilst maintaining environmental quality and social responsibility”*. Thus forest management in the tropics has traditionally concentrated on timber harvesting and it is these systems that are best developed in tropical Africa and Asia. Timber management is based on the principles of sustained yield management using low intensity selection harvesting and natural regeneration as a silvicultural tool.

Timber production from the tropics has largely been based on two main management systems, namely the Uniform and Selection systems. The Uniform system was applied with the aim of producing an even-aged forest stand made up of only a few economic timber species. This idea is laudable as it makes management simpler. Its major drawback, however, is that it does not allow the floristic richness which is characteristic of natural tropical forests, to be maintained. The system also

tended to be rather expensive in its application and was consequently abandoned (Osafo, 1970; Alder 1993).

The Selection system, on the other hand, seems to maintain the natural composition of the forest, thereby ensuring biodiversity conservation and constant supply of both timber and non-timber produce. It also has a higher potential for meeting the changing needs of people with time. A characteristic feature of this system is the removal of single trees of economic species scattered over a given area of the forest. The removal is controlled by a felling cycle, diameter limit and annual production quota (the annual allowable cut). This system is widely applied in the tropics but has undergone modifications in several aspects of its application. The current thinking is that logging alone could be used to improve the condition of the selection forest. What needs to be done is to develop more efficient management control measures by determining sustainable felling cycles, realistic felling quotas (allowable cut) and more appropriate exploitable diameter limits for the various species to ensure that the forest resource is managed sustainably.

The Selection System is currently the most widely adopted forest management practice in the tropics. For example, the selection system continues to be the main management system in Ghana. Generally, the system involves commercial logging with or without regeneration or silvicultural treatment. The logging, consist of the removal of single economic tree species scattered throughout the forest. The forests are divided into forest management units (FMUs) with a number of more or less equal compartments for ease of logging and purposes of controlling exploitation.

The annual felling takes place in one or more compartments depending on the length of the felling cycle and total area of the forest. Felling cycles ranging between 15 and 40 years have been applied over the years in the tropics. Timber exploitation is generally preceded by a stock survey during which a 100% count of all commercial timber species with minimum dbh of 30 cm was made, especially in tropical Commonwealth Countries. The concessionnaire is allowed to exploit a certain number of trees or basal area per unit area prescribed by the management plans for the given forest.

However, the ability of the Selection system to ensure sustainability of the tropical forests has not been adequately tested experimentally. It has been observed that logging based on the Selection System alone (i.e. selective cyclical cutting), without any pre- or post-logging silvicultural treatment reduces the stocking density and species composition (Alder, 1990; Adam *et al.*, 1994). This implies that commercial logging should always be preceded by or followed with some form of silvicultural treatment. For instance climber cutting has been recommended in areas with good natural regeneration.

In spite of the significant contribution of timber harvesting to the national economy of tropical countries, the sector is dependent on the exploitation and marketing of a relatively few prime timber tree species. The small number of species that are commercially exploited tends to make profitable logging and sustained yield management difficult to attain (FAO, 1993). For example, only about 7% of tree species in the tropical forests of Ghana were being exploited prior to 1990s, and in addition, over 70% of

timber exported in 1990 was from only two species (FPIB, 1991). A similar situation is found in Cameroun where 86% of timber harvested is from 15 species out of 56 commercially exploitable species (Evans, 1990). The restriction of exports to a relatively small number of species may be attributed to the fact that most importers from industrialised countries are reluctant to import lesser-known species from Africa probably because of the availability of adequate supplies of the more established species from a variety of African countries (Agyeman *et al.*, 1997). Secondly, consumer preferences and tastes are slow to change (Smith and Eastin, 1990). The failure of producer countries to successfully introduce new tree species and industrial products is largely the result of inadequate preliminary marketing analysis and the failure to develop effective marketing strategies (Cooper, 1979). Efforts are being made to utilise more species for both local and export markets. Governments of most tropical African countries are thus encouraging their timber industries to expand the species base in order to increase the net revenue (TEDB undated).

Stock Surveys

A stock survey is usually undertaken before permission is granted to a timber contractor to exploit a compartment, which is the basic unit of forest management in Ghana. The main purpose of the stock survey is to know the current stocking of exploitable trees as well as that of the replacement crop. It is also to provide information on the location of the exploitable trees so as to ensure proper road and skid trail layout. The most important use of the stock survey data is to calculate the volume of the exploitable trees and mark out the

selected trees. It involves a 100% enumeration of all commercial timber species above a certain minimum diameter, e.g. 30cm dbh in Ghana (Baidoe, 1970) and 42cm dbh in Liberia (Parren and de Graaf, 1995).

In addition to the stock map, a stand table is prepared showing the tree numbers recorded according to species and diameter classes. The stand table provides the stem numbers needed for the yield calculation and the stock map helps in yield selection. The advantage of using a stock survey map to determine yield is that it gives an indication of species richness, density and distribution for different concessions in the same forest type and for different forest types. A properly executed stock survey generally enhances sustainable management of the forest.

Felling Limits

The application of a diameter felling limit has been considered as one of the useful timber production control tools applicable to both reserved and off-reserve forests even though other methods based, for instance on basal area or volume removed per unit area is deemed more efficient. Minimum felling limits are supposed to define the point of maturity of various species suitable for timber and other uses, allowing for the removal of only mature trees. Silviculturally, the effect of applying a felling limit is that it allows the residual stand to be composed mainly of productive trees (i.e. trees that are vigorously growing). Consequently the basal area or volume stocking increases over the period of the felling cycle, and the production of viable seeds is enhanced, thus ensuring adequate natural regeneration (Adam, 1996). For wood processing purposes, the major

effect is the assurance of sustainable supply of good quality logs (i.e. trees occurring in the exploitable diameter will have good quality wood). Therefore in determining appropriate felling limits for various species factors such as stem diameter or volume increment (i.e. growth), tree mortality and wood quality of different size classes should be taken into account.

In Ghana the use of felling limits dates back to 1907, in the early days of timber exploitation in West Africa. There have been revisions of these felling limits in 1910, 1958, 1970 and recently in 1989 (Ghartey, 1992). Other countries in the West African sub-region, notably Liberia, Côte d'Ivoire and Cameroon, have similarly adopted felling limits as a control tool, with some variations in limits applied for similar species in the various countries. Generally, however, the minimum felling limits adopted in Ghana have been higher compared with those applied in these other countries.

The basis for the felling limits applied in Ghana during the colonial era is not known, but according to Ghartey (1992), the limits prescribed in 1970 under the salvage felling regime were based on economic and physiological over-maturity. The prescription of the 1989 felling limit has, however, been based on the relative abundance of a particular species and the degree to which it is threatened by extinction (Ghartey *ibid.*).

Yield Formula

The actual number of trees that can be exploited within a compartment is regulated through the use of a yield formula which allows the removal of individual species growth achievable over the period of the felling cycle (Planning Branch, 1995a). For example, in Ghana, there are two variants of the yield formula, namely; standard yield

formula which is $Z = 0.5Y + 0.2X$, and reduced yield formula which is $Z = 0.25Y + 0.2X$, where Z = number of trees to be removed above the felling limit; Y = number of trees in the diameter class equal to or above the felling limit and X = number of trees in the diameter class immediately below the felling limit. The normal yield formula is applied to red and pink star species in the wetter forests while the reduced yield is applied to scarlet star species and dry forest areas.

Harvesting is only permitted in compartments where the total stocking of exploitable timber tree species with stem diameter greater than 50cm is higher than the average stocking of the vegetation type within which the compartment is situated. However, harvesting is not allowed if the condition index for the compartment is less than 40% in the wetter forests and less than 60% in the drier forests (see Table 1).

Red Star species are common but with exploitation rates greater than 200% of the allowable cut. These species need careful harvesting controls and some tree by tree and area protection.

Pink Star species are common. These species have rates of harvest between 50-200% of their allowable cut. Pink Star species also include non-abundant species of high potential value.

Scarlet Star species are common with exploitation rates less than 50% of their allowable cut. Pink Star species also include non-abundant species of high potential value. The condition index is a numerical expression of the condition of the forest understorey within a compartment. The index is a measure of the health and regenerative capacity of the forest. The yield from a forest is varied depending on the condition index.

Table 1: Criteria used for the selection of yield formula to apply during harvesting of a compartment in the different forest types.

Condition	Selected Reserves in DS and MS	All Other Reserves
Condition index less than 40%	No Harvesting	No Harvesting
Condition index between 40-60%	No Harvesting	No Harvesting
Condition Score 3 Predominant	No Harvesting	Reduced yield formula
Condition Score 1 or 2 Predominant	Reduced yield formula	Standard yield formula

Annual Allowable Cut

The term “Annual Allowable Cut” - AAC is the maximum volume that can be felled each year without reducing the long-term sustainability of the forest resource. Alder (1989) suggests that a felling intensity of $1.23\text{m}^3 \text{ha}^{-1} \text{year}^{-1}$ or $50\text{m}^3 \text{ha}^{-1}$ per felling cycle of 40 years (equivalent to 3 mature trees ha^{-1} per felling cycle) must be enforced in the tropical high forests of Ghana and probably West Africa in order to achieve sustainability. The length of the felling cycle for Ghana (40 years) is similar to that of tropical South East Asia (30-40 years) but higher than that of most tropical Latin American countries (above 10 years) (c.f. Gormley, 1997). There is no long term evidence as to which particular felling cycle is sustainable although obviously the longer the felling cycle the greater the recovery.

Sustainability of Current Timber Harvesting Practices in the Tropics

Sustainable timber harvesting is the use of natural forest which maintains forest environmental services and biological qualities substantially unimpaired, and

implies that similar amounts and types of products (dimensions, quality, species) continue to be harvestable at periodic intervals in perpetuity (Seydack, 1995). Therefore, for harvesting to be sustainable it must be organised in such a way that it remains within the renewability capacity of the forest system both in respect of growth as well as the success and type of regeneration.

Forest management has traditionally concentrated on timber harvesting and it is these systems that are best developed in the tropics. Timber management is based on the principles of sustained yield management using low intensity selection harvesting and natural regeneration as a silvicultural tool (c.f. Planning Branch, 1995b). Currently, tropical African countries have minimum felling limits ranging between 50cm dbh and 70 cm dbh. Additionally, mean felling intensity ranges between $0.33\text{m}^3 \text{ha}^{-1}$ and $0.50 \text{m}^3 \text{ha}^{-1}$ in tropical Africa (Parren and de Graaf, 1995), whereas South East Asia and Latin America have a range of between $0.8 \text{m}^3 \text{ha}^{-1}$ and $1.1\text{m}^3 \text{ha}^{-1}$ (Plumptre, 1996; Gormley, 1997). A tight log monitoring system has been developed in most countries which tracks trees from stock survey maps through felling and extraction, using in most instances chain of custody certification procedures. Harvest controls systems have been developed to ensure that all timber exports are sourced from sustainably managed forests. In addition, efforts have been put in place to minimise logging residue generation and promote improved recovery and value-added production by encouraging efficient secondary and tertiary processing (FDMP, 1996).

The dependence of tropical timber trade on a few species has resulted in the “creaming” of a few prime species, a

reduction in the raw material base and an increase in the cost of sawmilling operations. It is well known that the future security of wood source from tropical forests depends on sustained production of timber. As trade continues to evolve, there will be greater pressure for higher yields. There is therefore the need for a comprehensive programme to encourage the utilisation and marketing of Less Used Species (LUS). This will provide greater opportunity and incentive as well as income to forest managers leading to greater feasibility in silvicultural planning and responsibility towards maintaining sustainable forest management (SFM).

LUS are timber tree species which show promising market potential. Such species tend to be characterised by

- Flexibility in fitting today's rapidly changing markets i.e. the distribution and exploitable volume of the species are sufficient for market interest.
- (Often) strategically positioned as a substitute to prime commercial species and thus are potentially of high value. However, most of these species may have one or more undesirable characteristics (which may or may not be possible to overcome through improved processing techniques).
- A species for which marketing opportunities arise due to greater processing options, and thus a bulk market, relatively low value species, possibly in competition with plantation production.
- Several terms that have similar meanings to LUS have been used extensively in the literature, namely; commercially less acceptable species ((CLAS) as defined by IUFRO), lesser known species (LKS), new species (NS) and previously unmarketable species (PUS). This project seeks to come out with broadly acceptable definitions of LUS and other synonyms.

Increased harvesting of LUS done on an economically and ecologically sound basis is firmly linked to SFM. This is probably because increased harvesting of LUS invariably leads to increased income part of which can be invested in the development and implementation of SFM techniques.

Consequently the International Tropical Timber Organisation (ITTO) and Governments of some tropical countries have designed programmes to ensure both biodiversity conservation and expansion of the species base, as well as the greater utilisation of lesser used species (LUS).

Presently, many of the tropical timbers, especially LUS are being burnt or otherwise wasted after logging in the reserved forests and conversion of forest lands into agricultural use in off-reserve areas. There is the need to initiate programmes aimed at the sustained utilisation of timber especially in countries where logging volumes or yield are low (Yeom, 1984). It is in line with this objective that the ITTO commissioned the International Institute for Environment and Development (IIED) in 1991 to review knowledge in LUS and evaluate the ecological impact of increased harvesting of tropical timber. The study noted that whereas industrial and marketing aspects of timber have received considerable support, ecological impacts of increased timber exploitation and utilisation have received little attention.

According to Planning Branch (1995b), the promotion of LUS has long since been promulgated as a means to keep the timber industry in business in the face of economic extinction of primary species. It is evidently not wise to use this means for ensuring 'sustainability'

of supply and care should be taken to make sure that only species suitable for sustainable exploitation based on natural abundance and growth rates are promoted. Any increase in harvest intensity should be undertaken with greater care since it may lead to substantial ecological damage. For example, in tropical Africa uncontrolled harvesting of timber has resulted in poor regeneration and forest stand condition even 15 years after logging. The large canopy openings, especially logging roads and skid trails created results in a high proportion of pioneers among the regeneration, which are less valuable timber trees compared to light demanders and shade bearers (Appiah *et al.*, 1998). There is therefore the need to ensure that economic concerns are carefully balanced with ecological considerations in timber management in the country.

The Way Forward

The key to providing meaningful forecasts of the future is understanding the past and recognising factors that have shaped patterns of land use, forest utilisation, benefits sharing, trade, investment and other interrelated forests. Analysis of the current status and trends has led to the identification of themes that are likely to be important in determining the future of tropical timber harvesting.

- (i) *Pressures for sustainable management will continue to gather force.*

While some progress has been made in this direction, more is needed to satisfy the principles of sustainable forest management. In particular efforts should be made in reducing harvesting and processing waste. ITTO demand for timber products to be sourced from sustainable managed forest in member

countries is the immediate challenge.

- (ii) *Demand for social equity will increase.*

Although there is a general recognition of the roles of forests in local people livelihoods, in practice however, the social aspects of forestry are often neglected or sacrificed in pursuit of financial expediency. It is expected that demands for greater participation and responsibilities and benefits will intensify in the face of the dwindling resources.

- (iii) *Increasing restrictions on access to forests through physical and regulatory constraints.*

With deforestation rate of 1.3% and overall forest quality decline, it seems evident that the future holds greater physical resource constraints.

- (iv) *Timber trade will remain important.*

In spite of all the above trade in timber products will continue to be important through its contributions to foreign exchange earnings and GDP. Wood demand in the domestic market will also increase due to population growth and other factors. There will be a shift from the so called prime species to lesser-used species and from red woods to light coloured wood species. These development has already started.

Options for the Future

Against the general policy background and factors that are likely to shape the future of timber harvesting in the tropics, the following options have been proposed.

- (i) *Improve efficiency in forest harvesting and wood processing.*

Significant economic gains could be

made if the current rates of product recovery from 50% for harvesting, and from about 30% - 45% for log processing could be improved. Examination of case studies from S.E. Asia suggests that harvesting efficiencies could be increased by at least 10%. The scope for improvement in processing efficiency is perhaps even greater than that of harvesting. Improvements in processing efficiency could help to diminish the pressure on the forests by reducing the volume of logs required to manufacture the same volume of products. Presently total wood utilised is approximately 15-30% of the utilisable volume of wood.

(ii) *Promotion and marketing of lesser-used species.*

Out of the recorded 680 woody, plant species in Ghana's forests, 240 grow to timber size of above 50cm dbh. So far 66 species have been marketed (Kuffour unpublished). Of these 18 species are regularly traded and 8 species representing 90% of the traded species. Over-reliance on small range of species has led to imminent threat on stocking of 15 species (scarlet) a possible economic extinction of about 5 species and significant danger to 17 others (red). In order to reduce imminent danger posed to these species it is important the range of species utilised or traded is broadened through promotion and marketing of the LUS.

(iii) *Increase production from forest plantations particularly on degraded forests lands.*

A relatively new prospect for encouraging investment in plantation is to provide measures for sequestering carbon in exchange for pollution rights under climate change agreements.

While specific details are still to be clarified, the Kyoto Protocol lays a foundation for a potential vast new investment in forest plantations. Ghana, for example, needs to negotiate for investment in this area in support of its plantation development and the Forestry Development Master Plan.

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A 2ha plot (200 x 100m) in dipterocarp forest was located subjectively to cover skid trails, cutover and undisturbed forest, and divided into 200 (10x10m) subplots. All trees >10cm dbh were measured, identified and mapped; and % damage recorded. Damage to crown and branches was assessed in 25% bands (following Nicholson, 1958). Stumps were mapped. Saplings (dbh 2-10cm) were sampled within 5x5m subplots of each plot, and diameters measured at 50cm. Seedlings were sampled within 42 1x1m subplots. 21 were on 'bare' ground and 21 on adjacent undisturbed ground along skid trails. All seedlings were identified and counted and % cover estimated. Tractor paths were mapped. Water permeability of soil was measured by timing water infiltration into a tin can with no ends pressed into the soil in each of the 42 1x1m subplots. Reduction of basal area etc. was estimated (36 to 16.75 m²/ha) by comparing adjacent undisturbed forest (Stem Density fell from 445 to 259 trees/ha). 30 pioneer species invaded; estimated 50 sp. lost. Only 60% of residual trees were undamaged. 18% of trees had crown damage (mostly 75-100%). 23% of trees branch damage, which was generally less severe. 'It is concluded that present logging practices are too damaging to the forest'.

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Seedling crowns of four pioneer species (*Cecropia obtusifolia*, *Heliocarpus appendiculatus*, *Piper auritum*, *Trema micrantha*) were found to be oriented toward diffuse radiation received from the gap, and not toward direct radiation. The mean orientation of the crown, at the whole plant level, was primarily determined by non-random orientation of individual leaves. Study in Veracruz, Mexico.

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Historical data on timber exploitation and forest inventory data were used to assess the effectiveness of forest regulations aimed at ensuring a future crop of marketable trees, from 1900 and 1990. The number of commercial species increased from 3 to 66 species, and felling diameter limits and cutting cycles changed several times. Patterns in exploitation, either in

number of species or total stems removed, were unrelated to the application of harvesting regulations. Milling capacity and political instability are thought to have played a larger role.

Adjers, G. , S. Hadengganan, J. Kuusipalo, K. Nuryanto & L. Vesa. 1995. Enrichment planting of dipterocarps in logged-over secondary forests – effect of width, direction and maintenance method of planting line on *Shorea* species. *Forest Ecology and Management* 73: 259-270.

Adnan, M; Holscher, D. 2011. Medicinal plants in old-growth, degraded and re-growth forests of NW Pakistan. *Forest Ecology and Management* 261: 2105-2114

Old-growth forest, forest degraded by logging, derived woodland, agroforest and regrowth Forest were assessed for their abundance of 10 locally important medicinal species (highest market value). Recovery of these species was assessed in regrowth forests. Mean medicinal species coverage was highest in old-growth forest (7%), low in forest degraded by logging, derived woodland and agroforest (0.3–2%), and intermediate in re-growth forest (4%). The 10 medicinal species are not characterised into successional guilds, but it seems that they are mainly late successional species. Based on these 10, anthropogenic forest degradation leads to a reduction in the abundance of economically viable medicinal plants for the study region.

Agren, A. 1969. Increment loss in thinned stands caused by modern skidding techniques. *Allg. Forstzeitschr.* 24: 758

Study in Sweden shown skidding damages roots and reduces increment in nearby trees.

Aguilar-Amuchastegui, N. & G.M. Henebry. 2007. Assessing sustainability indicators for tropical forests: Spatio-temporal heterogeneity, logging intensity, and dung beetle communities. *Forest Ecology and Management* 253: 56-67

A logging intensity threshold of four trees/ha was identified as a transition to significant differences in forest structural heterogeneity and the richness and diversity of associated dung beetle communities.

Agyeman, V. K. 1994. *Environmental influences on tropical tree seedling growth*. Ph. D thesis. University of Aberdeen, U. K.

Agyeman, V.K., Appiah, S.K. and Siisi-Wilson, E. 1997. A literature review on impacts of increased harvesting of lesser used species (LUS) in the tropical forests of Africa. A Report Submitted to ITTO. 19 pp.

Agyeman, V. K. , C. Turnbull & M. D. Swaine. 1995. Maintenance of biodiversity in the tropical high forests: current research initiatives in Ghana. Abstract: Proc. 10 IUFRO world congress. Pp. 76-77.

Summary of the situation in Ghana. BA Harvest >3. 5 m²/ha will exceed the forest's ability to regenerate. Gap sizes do have an influence on recovery.

Ahmad, N., M.N. Hasan & A.L. Mohamad (in press) Diversity and density of primates in primary and logged lowland tropical rain forest at Danum Valley, Sabah, Borneo. *Biodiversity and Conservation*

Aiba, S. I. and T. Kohyama 1997. Crown architecture and life-history traits of 14 tree species in a warm-temperate rain forest: significance of spatial heterogeneity. *Journal of Ecology* 85: 611-624

Aide, T. M. 1987. Limbfalls: a major cause of sapling mortality for tropical forest plants. *Biotropica* 19: 284-285.

Limbfalls caused 22.2 and 46.7% of deaths of *Connarus turczaninowii* liana saplings in two years of the study in the Barro Colorado PSP, and caused 4.9% and 3.6% of the plants to lose between 90-100 % of their leaf area. Limbfall damage is thought to disproportionately affect shade-tolerant saplings (cf. pioneer species) because they are slower growing and are smaller for longer. It is hypothesised that limbfall could select for particular branching patterns (sapling architecture), and this could explain architectural differences between pioneer and shade-tolerant saplings.

Aide T.M., Zimmerman J.K., Pascarella J.B., Rivera L. and Marcano-Vega H. 2000. Forest regeneration in a chronosequence of tropical abandoned pastures: implications for restoration ecology. *Restoration Ecology* 8: 328–338.

Well-cited paper pointing out that structural composition and alpha diversity of secondary forest (40 year regrowth from land that has been used long-term for agriculture) is similar to original forest, but the species composition is different. Little colonisation of shade-tolerant 'old forest' species in these plots even after 60 years and in spite of nearby source trees. Alien species overrepresented in the secondary forests cf. original.

Akite, P. 2008. Effects of anthropogenic disturbances on the diversity and composition of the butterfly fauna of sites in the Sango Bay and Iriiri areas, Uganda: implications for conservation. *African Journal of Ecology* 46: 3-13

Akutsu, K., C.V. Khen, & M.J. Toda. 2008. Assessment of higher insect taxa as bioindicators for different logging-disturbance regimes in lowland tropical rain forest in Sabah, Malaysia. *Ecological Research* 22: 542-550

Alder, D. 1989. Natural Forest Increment, Growth and Yield. *In*: Ghana Forest Inventory Project Seminar Proceedings. Accra, 29-30 March 1989.

Alder, D. 1990. GHAFOSIM: A Projection System for Natural Forest Growth and Yield in Ghana. Unpublished final Report to Forestry Dept., Ghana. July 1990.

Alder, D. 1992. Simple methods for calculating minimum diameter and sustainable yields in mixed tropical forest. Pp. 189-200 in Miller F. R. & K. L. Adam, (eds.) *Proceedings of the Oxford Conference on Tropical Forests*.

Optimum diameter calculated from the cumulative age and volume of the survivors from a developing cohort, to produce a MAI per 100 seedlings (MAI%). The maximum MAI% represents the optimum felling diameter for timber production. For three timber species in Ghana, this is c. 60cm DBH.

Alder, D. 1993. Growth and Yield Research in Bobiri Forest Reserve. ODA/FIMP Consultancy Report No. 14. May 1993. 71pp.

Alder, D. 1995a. Growth modelling for mixed tropical forests. *Tropical Forestry Papers* 30. Oxford Forestry Institute, UK. 231 pp.

Alder, D. 1995b. Preliminary Analysis of Permanent Sample Plot Data. FIMP/ODA/FD Internal Report. August 1995. 30pp.

First analysis of new series data second enumeration, for 66 plots over 2.5 years, except that many data problems were evident and are highlighted in this report. Problems highlighted include non-use of a tree list at the second enumeration; use of new tree numbers when old numbers were missing and the fact that 75% of measurements are on trees 10-20cm DBH. Increments in ME forests exceeded 1m³/ha/yr for whole stands, but elsewhere increments were often zero or negative. For individual species, average increments (6-7mm./yr) and mortalities (2.7-2.9%) were higher than previous assessments (mortality of 1.25%). The Interim Yield formula would be unsustainable, except for Pink Star species, and an alternative method using Q ratios is explained. It is recommended that min. DBH is increased to 20cm; tree lists are used; the no. plots are reduced from 600 to 200 and quadrat checksums are added, with the remaining plots allocated to research projects.

Alder, D. & T. J. Synnott. 1992. Permanent Sample Plot techniques for mixed tropical forest. *Tropical Forestry Papers* 25. Oxford Forestry Institute, UK. 124 pp.

Alexander, I. J. , N. Ahmad & S. S. Lee. 1992. The role of mycorrhizas in the regeneration of some Malaysia forest trees. *Philosophical Transactions of the Royal Society B. Biol. Sci.* 335: 379-388

Alexandre, D. Y. 1977. Regeneration naturelle d'un arbre caracteristique de la foret equatorielle de

- Cote d'Ivoire: *Trema guineensis* Pellegr. Oecologia Plantarum 12: 241-262.
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- Alexandre, D. Y. 1982. Aspects de la regeneration naturelle en foret dense de Cote d'Ivoire. Candollea 37: 579-588.
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- Allport, G. A., M. Ausden, P.V. Hayman, P. Robertson & P. Wood. 1989. The birds of the Gola Forest and their conservation. ICBP Study Report no. 38.
- Alongi, D.M. & N.A. de Carvalho. 2008. The effect of small-scale logging on stand characteristics and soil biogeochemistry in mangrove forests of Timor Leste. Forest Ecology and Management. 255:1359-1366
- The impact of small-scale cutting of mangroves was examined in three mangrove forests of Timor Leste. After one year forests experienced a 30-50% decline in live stems and a 46-86% loss of above-ground biomass with more canopy gaps between less dense, smaller trees. Concentrations of most particulate nutrients increased in surface soils in the harvested stands, reflecting bark, leaves, twigs, and small branches discarded on the forest floor. Interstitial concentrations of dissolved sulfide, metals, and ammonium also increased due to enhanced soil desiccation (evidenced by increased salinity). Rates of anaerobic soil metabolism (sulfate reduction) declined after the onset of cutting, attributed to the decline in live roots and their metabolic activities. These cutting operations, although small-scale, are unsustainable as these forests are likely to be slow-growing in such highly saline soils.
- Alvarez-Buylla, E. R. 1994. Density dependence and patch dynamics in tropical rain forests: matrix models and applications to tree species. American Naturalist 143: 155-191
- Alvarez-Buylla, E. R. & M. Martinez Ramos. 1990. Seed bank versus seed rain in the regeneration of a tropical pioneer tree. Oecologia 84:314-325.
- Cecropia obtusifolia* seeds have a poor survival rate in soil due to predators and pathogens, but rapid heavy turnover due to good dispersal at least up to 86m from parent.
- Alvarez-Buylla, E. R. & M. Martinez-Ramos. 1992. Demography and allometry of *Cecropia obtusifolia*, a neotropical pioneer tree - evaluation of the climax-pioneer paradigm for tropical rain forests. Journal of Ecology 80: 275-290.
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- An Anel, T. 2001. Floristic composition and diversity of mixed primary and secondary forests in northwest Guyana. Biodiversity and Conservation 10: 1645-1682
- Andersen, A.N., T.D. Penman, N. Debas, & M. Houadria. 2009. Ant community responses to experimental fire and logging in a eucalypt forest of south-eastern Australia. Forest Ecology and Management 258: 188-197
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- Using eight hypervariable microsatellite loci, a significant reduction in the number of alleles, observed heterozygosity, and distinct multilocus genotype number was found in the post-compared to the pre-logging cohort. The results raise concerns about the conservation genetics of logged mahogany populations where a high proportion of adults are removed from the system.

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- Appiah, S.K., Siisi-Wilson, E., Agyeman, V.K., Ortsin, G. And Birikorang, G. 1998. Ecological impact of increased harvesting of lesser-used species (lus). ITTO PD 33/95. Report submitted to the International Tropical Timber Organisation (ITTO), Yokohama, Japan. 53 pp.
- Appanah, S. & A. M. Mohd. -Rasol. 1991. Fruiting and Seedling Survival of dipterocarps in a logged Forest. *Journal of Tropical Forest Science* 6: 215-222.
Selective logging in Malaysian Dipterocarp forest of 50-60 dbh. No attention to regeneration that will form later cuts. Fruiting was poor but predation lower than expected. Seedlings from post logging fruiting survived well and so have positive implications for management of Logged forests.
- Appanah, S. & A. M. Mohd. -Rasol. 1995. Dipterocarp fruit dispersal and seedling distribution. *Journal of Tropical Forest Science* 8: 258-263.
Logged dipterocarp forest in peninsular Malaysia. 90 degree wedge plots of 225m radius divided into 5m sectors. Winged seeds of *Shorea* and *Hopea* species studied weekly and compared with adjacent wedge a year later. Seed density generally rises to 25m from tree then begins to fall as distance increases.
- Appanah, S. & M. R. A. Manaf. 1990. Smaller trees can fruit in logged dipterocarp forests. *Journal of Tropical Forest Science* 3: 80-87.
In hill dipterocarp forests trees 15-50 cm dbh are left to provide seeds and for the next crop. Fruiting of the smaller trees in logged forest was compared to undisturbed forest. In recently logged forest, smaller trees (25+ cm) tended to fruit. Equivalent sized individuals did not, though larger ones (35+) did, in unlogged forest. It may be because of changes in temperature fluctuation promoting flowering. (But, see Thomas & Appanah, 1995).
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In 13 ha of virgin dipterocarp forest of Sungai Tekam Forest Reserve, Pahang [Malaysia], there were an average of 376 climbers/ha > 2 cm dbh (diameter at 1.3 m from the ground). Cutting of climbers before logging reduced the number of trees pulled down during felling by approximately one-half and thus is a useful silvicultural tool. One-half of the climber stems not cut prior to logging survived felling of their host trees and sprouted vigorously. More than one-half of the climbers on infested trees several years after logging sprouted from fallen climbers.
- Appanah, S. & J.M. Turnbull. 1998. A review of dipterocarps, taxonomy, ecology and silviculture. CIFOR, Bogor, Indonesia.
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Armesto, J. J., J. D. Mitchell & C. Villagran. 1986. A comparison of spatial patterns of trees in some tropical and temperate forests. *Biotropica* 18: 1-11.

Clumped spatial patterns predominant in all of a range of forests. Uniform patterns are rare in all forests. Forests with frequent catastrophes should exhibit mainly random patterns; clumping is more common where canopy gaps are the main agent of change.

Arnhem, E., J. Dupain, R.V. Drubbel, C. Devos, & M. Vercauteren. 2008. Selective logging, habitat quality and home range use by sympatric gorillas and chimpanzees: A case study from an active logging concession in Southeast Cameroon. *Folia Primatologica* 79: 1-14

Arnhem, E., J. Dupain, L. Van Elsacker, & M. Vercauteren. 2005. Effect of human activities on spatial distribution of gorillas (*Gorilla gorilla*) and chimpanzees (*Pan troglodytes*) in a logging concession in South East Cameroon: Preliminary results. *Folia Primatologica* 76: 46-47

Arroyo-Mora, J. P., M. Kalacska, R.L. Chazdon, D.L. Civco, G. Obando-Vargas, & A.A.S. Hernandez. 2008. Assessing recovery following selective logging of lowland tropical forests based on hyperspectral imagery. Pp 193-212 in Kalacska, M. & G.A. Sanchez-Azofeifa (eds.)

Hyperspectral Remote Sensing of Tropical and Sub-Tropical Forests CRC Press Florida. 352pp

"The book explores a range of analysis techniques, including hyperspectral reflectance indices, spectral mixture analysis, pattern classification, band selection, partial least-squares, linear discriminant analysis, and radiative transfer models. The chapter authors present a comprehensive review of the current status and innovative achievements in the field, citing approximately six hundred studies." (Amazon.com, 2011)

Asabere, P. K. 1987. Attempts at sustained yield management in the tropical high forests of Ghana. in Mergen, F. & J.R. Vincent (eds.). *Natural Management of Tropical Moist Forests: Silvicultural and Management Prospects of Sustained Utilisation*. Yale University Press

Asdak, C., P.G. Jarvis, P. van Gardingen, & A. Fraser. 1998. Rainfall interception loss in unlogged and logged forest areas of Central Kalimantan, Indonesia. *Journal of Hydrology* 206: 237-244

Over a 6-month-period in 1 hectare of pristine, unlogged, natural, tropical rainforest, the total amount of rainfall interception loss was 251 mm or about 11% of total gross rainfall. In the logged forest, the total rainfall interception loss over 12 months was 219 mm, or 6% of gross rainfall.

Ashton, M.S. & C.M. Peters. 1999. Even-aged silviculture in tropical rainforests of Asia. *Journal of Forestry* 97: 14-19

Ashton, P. S. 1978. Crown characteristics of tropical trees. Pp 591-615 in Tomlinson & Zimmerman (eds.)

Ashton, P.S. (1988) Conservation of genetic resources. In: *The Case for Multiple-Use Management of Tropical Hardwood Forests*. Study produced for the International Tropical Timber Organisation. ITTO, Yokohama (Japan).

Asibey, E.O.A. 1978. Primate conservation in Ghana. Pp 55-59, in Chivers, D. J. & W. Lane-Petter (eds.) *Recent advances in primatology*, Vol. 2. London: Academic Press.

Asner, G.P., M. Keller, R. Pereira, J.C. Zweede, & J.N.M. Silva. 2004. Canopy damage and recovery after selective logging in Amazonia: Field and satellite studies. *Ecological Applications* 14: 280-298

Detailed field study of canopy gap analyses, combined with spectral mixture analyses of Landsat 7 ETM+ satellite Imagery. Forest canopy cover fractions derived from the satellite observations were highly and inversely correlated with the field-based canopy gap fraction. Areas used to stage harvested logs prior to transport had the largest forest gap fractions, but contributed little to landscape level gap dynamics. Tree falls were spatially the most extensive form of canopy damage, but the canopy gap fractions resulting from them were small. RIL resulted in consistently less damage to the forest canopy cf. conventional logging; this was true at scales from roads, skids and tree falls up to the area-integrated scale. A regional-scale study of

the gap fraction using both the field and satellite-based measurements showed that approx. one half of the canopy opening caused by logging had closed within one year of regrowth.

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- Aubreville, A. 1938. La Forest coloniale. *Annales Academie des Sciences Coloniales* 9: 1-245
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- Augeri, D. 2004. Disturbance effects on sun bears and their primary competitors in Indonesia. Presented at International Conference on Conservation Science Cambridge UK
- Augspurger, C. K. 1983a. Offspring recruitment around tropical trees: changes in cohort distance with time. *Oikos* 40: 189-196.
- Platypodium elegans* (legume): for isolated trees, fungus-caused mortality nr. tree caused median distance of surviving 3 month old seedlings greater than that of germinating trees. After one year, the median either increased further, or decreased depending on availability of gaps which enhanced survival. Observed shift implies density or distance dependent mortality.
- Augspurger, C. K. , 1983b. Seed dispersal of the tropical tree, *Platypodium elegans*, and the escape of its seedlings from fungal pathogens. *Journal of Ecology* 71: 759-771
- Patterns of survival related to distance from parent, density of seedlings and the effect of a light gap. Most mortality occurred in first 3 months, caused by fungi, inversely correlated with distance from parents. Less died in light gaps. After 1 year, higher % and absolute number survived further from parent, especially in gaps. Greatest distance measured 100m.
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- Test of hypothesis in Barro Colorado Island, Panama, that seed dispersal enhances survival by escape from density-dependent mortality or colonisation of light gaps. 9 wind-dispersed trees were compared. Wind dispersal advantageous to all for different reasons. All 9 gained from colonisation. At some time over 1 yr all trees gained from 'escape' though differences occurred in distance and timing at which gains were made. Pathogens killed most shaded seedlings in 6/9 species.
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- Augspurger, C. K. & K. Kitajima. 1992. Experimental studies of seedling recruitment from contrasting seed distributions. *Ecology* 73: 1270-1284.
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Augspurger, C. K. & S. E. Franson. 1987. Wind dispersal of artificial fruits varying in mass, area and morphology. *Ecology* 70: 27-34.

Models of 15 types of fruits were dropped from a 40 ft tower under 5 different wind conditions. The horizontal distance travelled is proportional to wind speed divided by square root of wing loading. Wing loading = force of gravity on fruit x projected surface area. The distribution of distance travelled results a left-skewed curve.

Auzel, P. & D.S. Wilkie. 2000. Wildlife use in northern Congo: Hunting in a commercial logging concession Pp 413-426 in Robinson, J.G. & E.L. Bennett (eds.) *Hunting for sustainability in tropical forest*. Columbia University Press. New York USA

Ayres, J. M. & A.D. Johns. 1987. Conservation of white uacaries in Amazonian várzea. *Oryx* 21: 74-80.

Azevedo-Ramos, C., O. de Carvalho, & B.D. do Amaral. 2006. Short-term effects of reduced-impact logging on eastern Amazon fauna. *Forest Ecology and Management* 232: 26-35

Azevedo-Ramos, C., J. R. Oswaldo de Carvalho, Robert, N. 2005. Animal Indicators, a Tool to Assess Biotic Integrity After Logging Tropical Forests? CIFOR.

Azlan J.M. 2003. The Diversity and conservation of mustelids, viverrids and herpestids in a disturbed forest in Peninsular Malaysia. *Small Carnivore Conservation* 29: 8-9

Babaasa, D., G. Eilu, A. Kasangaki, R. Bitariho, & A. McNeilage. 2004. Gap characteristics and regeneration in Bwindi Impenetrable National Park, Uganda. *African Journal of Ecology* 42: 217-224

Mean gap sizes are very large (4460.1m²) even under fairly natural conditions, and logging further enlarges these gap sizes. This has a negative impact on tree regeneration and promotes an alternative successional pathway, where the large gaps become dominated by herbs, shrubs and herbaceous or semi-woody climbers (low-canopy state).

Baharuddin, K. , A. M. Mokhtaruddin & M. Nik Muhamad. 1995. Surface runoff and soil loss from a skid trail and a logging road in a tropical forest. *Journal of Tropical Forest Science* 7: 558-569.

Soil runoff and loss measured using erosion plots from an undisturbed forest, a skid trail and a logging road. Two year study showed 62.9, 391.4 and 545.2 mm/yr respectively (2. 3%, 14. 5% and 20. 3% of the total rainfall). In year 2 losses decreased by 80%, probably due to reestablishment of ground cover. Increases also with slope. e. g. skid trail with a 20, 30, 40% slope had 314, 463, 630 mm surface runoff.

Baidoe, J. F. 1970. The selection system as practised in Ghana. *Commonwealth Forestry Review* 49: 159-165.

Baidoe, J. F. 1976. Yield regulation in the high forest of Ghana. *Ghana Forestry Journal* 2: 22-27.

Baker, P. 1998. Stem and crown relations in four species from an evermoist forest in Sri Lanka. *Journal of Sustainable Forestry* 7: 77-94

Tree crown represents the accumulated historic influences. *Macaranga peltata*, *Schumacheria castaneifolia*, *Shorea megistophylla*, *S. trapezifolia*. Species commonly associated with skid trails. 314 trees with no injury or vines, single-stemmed, not leaning, > 2m tall. All about 15 years old. Results: Crown volume = kR^2Z , where $k = .333$ for cone and $.5$ for paraboloid – latter favoured. Dbh & ht well correlated ($r^2 = 0.728 - .667$) for *Shorea spp.* which also had a steeper slope; *Macaranga* poorly correlated ($r^2 = .211$).

Bakuneeta, C. , K. Johnson, R. Plumptre & V. Reynolds. 1995. Human uses of tree species whose seeds are dispersed by chimpanzees in the Budongo forest. *African Journal of Ecology* 33: 276-278.

Confirms Chapman & Chapman (1994)'s observation made for Kibale forest that Chimpanzees are important dispersal agents for timber and other useful trees.

- Baldwin, V. C. & K. D. Peterson. 1997. Predicting the crown shape of loblolly pine trees. *Canadian Journal of Forest Research* 27: 102-107
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- Bazzaz, F. A. 1991. Regeneration of tropical forests: physiological responses of pioneer and secondary species. Pp 91-118. in Gomez-Pompa, A., T.C. Whitmore and M. Hadley, (eds.). In Rain forest regeneration and management. Man and the biosphere series, Vol. 6. UNESCO Paris.
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1. Directional felling
2. As 1, but min. dbh 60 cm
3. 'Conventional logging'
4. Control, no logging.
On average, logging damaged c. 40% of trees; injured av. 21%; mortality (no resprout after 3 months) av. 19%, but slight decline with treatment 3->1->2. Felling mainly caused injuries; skidding caused most deaths. Injury (% original po.) peaks in the size class 40-50 cm; death % highest in smallest size classes (22%), only 7 of trees >60cm dbh. Controlled logging reduced skidding damage; but not felling damage, due to poor success of directional felling. Area disturbed was similar (12-16%) for <10 trees/ha. For heavily logged plots (15/ha.) damage control reduced area damage from 42% to 28%; sapling injury and mortality from 48% to 30%.

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Conventional compared with reduced impact logging (RIL) using pre- and post-harvesting inventories for volume extracted and damage. Damage classes: bark and wood damage; leaning (0-25, 25-45, >45 degrees); slight to moderate crown injury (<5 main branches broken); Major crown injury (>5); broken trunk, still alive; broken trunk, dead; uprooted.

1000 ha. zone had a 5% pre-inventory. Twelve 200 x 200m plots, each divided into 4, were set up. Trees >10cm dbh were measured, numbered, mapped. Harvesting of dipterocarp trees >60cm dbh. 12 plots grouped into 3 blocks on topography and tree density. Four treatments defined and replicated three times. Treatments were two RIL (>50, >60); conv. and unlogged. RIL included tree marking, liane cutting; main skidtrail network pre-established according to topography. Directional felling; no roads in plot. Original Density 530 +/- 63. 3 stems/ha; BA 31. 4+-3. 2 m²/ha. Dipterocarps had half the BA. Harvest ranged from 5 stems/ha to 15 stems/ha (43 to 174 m³/ha or 9. 8 to 30 m²/ha). Felling mainly injured trees (especially crown damage to trees 30-50 cm dbh), whereas skidding was main cause of mortality (especially uprooting and to trees 10-20 cm dbh). Results: A higher % of damaged trees in the middle size classes. 74. 5% of trees killed were 10-20cm dbh, but this class only holds 63% of trees. RIL reduced damage or death to trees from 48.4% to 30.5% (i.e. extra 95 trees/ha >10 cm dbh remain undamaged). In Borneo damage often exceeds 50%, which is more than Africa or S. America.

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PSP programme, logging experiment and yield allocation methodology in Belize; 70 pp stand tables. Total % dead and damaged trees increased almost linearly with volume/ha removed across 6 sites (from 5m³/ha to 26m³/ha), corresponding to 4. 7% to 9. 8% of the initial basal area. The majority of trees felled were of similar, small (by Ghanaian standards) size (40-70 cm dbh). This probably contributed to low % damage (6-14%), along with the RIL techniques such as careful attention to direction of felling, skid trail planning, and that the areas had been logged before, so skid trails were reused.

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- Expt. 2: Concerns felling only, with climber cutting and directional felling. Gap sizes, damage levels, felling accuracy were estimated. The study comprises 88 trees surrounded by a sampled local stand of 14 x 140m. 39% of trees felled within 5 degrees of desired angle; 24% within 6-10 degrees. Climber cutting didn't improve accuracy, but tree heart rot and slopes made it worse.

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- 144 trees (5' (12.7cm) to 14' (35.6cm) dbh) felled in 33. 6 acres= 4.3 trees felled/acre; av. gap size=. 034/tree; other damage =. 028; total=. 062 acres per tree. Damage caused by 4.3 trees=26% of area. Loss among (pre & post-enumerated) juvenile trees = 25%. 2. 5 miles log tracks av. 13 ft wide. Damage per gap is lower (34%) in this pretreated forest than in an earlier study of untreated forest which had greater mass of climbers and 'Understory'. Also, smaller trees were felled in this study. Author suggests 0. 05 acres total devastation per tree is a reasonable average.
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- Broad discussion of many aspects (inventory, silvicultural system, economics, stand curves etc.) of tropical forest management, and a foundation, or at least justification, for much that is still practiced. In effect a text book of tropical forest management for the 1960s, whose basic principles have yet to be adopted by a significant proportion of tropical forest managers. A few of the topics (e. g. the principle of concentrating on 'leading desirables' in certain forest assessments) have subsequently fallen into disfavour, however.
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- All species stand-table similar in different regions of tropical high forest (THF), where little disturbed. Typical values of Girth Class in ft: Stems per acre: 1:100, 2:41, 3:17, 4:8, 5:4, 5, 6:2, 9, 7:2, 8:1, 4, 9:1, 0, 10:0, 7, 11+:1, 5. Some Australasian forests have higher stocking of middle sizes, and sometimes even-aged. Basal area often around 140 sq. ft. /acre. (100-160). Hence, this is a limiting basal area: when reached no further increment can be expected. Plantations can attain half this. Strong correlation between crown size and girth increment for most species. e. g. a tree of 4ft girth will not grow well without crown of 40ft. Healthy 8ft gbh (244cm dbh) trees have crown diameter up to 60ft (18.3m). Hence, thinning to release older trees often has no

effect: crown development should be encouraged early. Light rarely limiting for photosynthesis, problem is crown does not get bigger in the shade. Therefore, with 60ft crowns, max spacing of big trees is 14/acre. (40ft =31/acre: 50ft=20/acre). Healthy final crop of most trees therefore 20/acre; although narrow crowned trees like *Loroa* and *Celtis* could reach 30/acre. Most trees in THF slow growing: too crowded; crowns generally too small (unless developed in middle of large gap); Most shaded; senility/stagnation of large tree increment can last at least 20 years on healthy trees. Therefore 8ft gbh crops not possible in < 80 years, with these limitations. However, many pioneers can reach this size, if exposed.

The limits on polycyclic systems by felling damage Large crowns needed for fast growth. But large crowns cause more felling damage. In Uganda, 8-12 ft gbh trees devastates 0.1 acre of forest, effectively resetting that area to zero. Without climbers this could be halved; perhaps reduced at most to 0.05 acre/tree. This limits polycyclic systems (where felling cycle rotation). No annual acre yields > 30 ft possible, because: Suppose that five 8ft trees are to be felled per acre every ten years. After four felling cycles (or 6 with greatest care) the entire area will have been felled over. Unless species average > 1 ft girth in 10 yrs when grown among bigger trees; or felling damage reduced to .025 per mature tree felled, then max. yield of African THF is 20 ft3/acre.

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Seventeen tropical trees examined. Most practical relation is given as $\text{Diam} = A - (B \times \text{dbh})$. A is related to tolerance: intolerant species have low a values (unaffected by treatments); tolerant species have variable a values, indicative of treatment. Even-aged crops have negative a values. The relationship of form to 'packing' is explored.

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This section of the manual of procedures, which exists in various version, is the main document describing the technical process of yield allocation and stock map production, for reference by loggers, checkers and yield allocators alike. The 6 sections describe: Presurvey compartment inspection; Stock Survey; Stock survey checks; stock map preparation; yield allocation and diameter measurement on buttressed trees, including details such as the symbols to use for each species of tree.

Forestry Department of Ghana – See also ‘Ghana Forest Service’ for 1998 onwards.

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Forget, P. M. 1989. Natural regeneration of an autochorous species in the forest of French Guiana: *Eperua falcata*. *Biotropica* 21: 115-125.

Seeds ejected during low humidity. c. 60% of seeds < 10m from parent; max dispersal 30m. Seeds slowly eaten by rodents, not distance dependent. Seedling mortality low; shade-tolerant, boosted greatly by gaps. Saplings found optimal distance is ½ way between two trees, outside crown limit.

Forget, P. M., F. Mercier & F. Collinet. 1999. Spatial patterns of two rodent-dispersed rain forest trees *Carapa procera* (Meliaceae) and *Vouacapoua americana* (Caesalpinaceae) at Paracou, French Guiana.

Both species dispersed by rodents within range of 50m of adults, *V. americana* strongly aggregated but *Carapa* more random. Soils found to influence the patterns, which are described at different scales.

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Fox, J. E. D. 1968b. Defect, damage and wastage. *The Malayan Forester* 31: 326-347.

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- Hawthorne, W. D. 1995a. Ecological profiles of Ghanaian forest trees. Tropical Forestry Papers 29. Oxford Forestry Institute, UK.
 Summary of autecology of all species of tree in Ghana which exceed 5 cm dbh, with explanatory notes about guilds, stars and crown exposure trends.
- Hawthorne, W. D. 1995b. FROGGIE-Forest Reserves of Ghana: Graphical Information Exhibitor (manual for the program). IUCN, Gland, Switzerland and Cambridge, UK.
 Description of the data held FROGGIE map-database, and a manual for its operation. The program allows inspection of inventory data for all tree species in Ghana, with distributional

data for all (>2000) forest species. Data can be overlaid on maps of the forest types and Forest Reserves, or textual summaries can be viewed.

- Hawthorne, W. D. 1996. Holes and the sums of parts in Ghanaian forest: regeneration, scale and sustainable use. *Proceedings of the Royal Society of Edinburgh* 104b (This volume edited by Swaine *et al.*): 75-176.

Highlights how factors across many scales, from biogeographic to local ecological, interact to influence local forest composition. Even over short distances, the composition of the forest on a scale of hundreds of hectares will influence the outcome of a local disturbance such as logging. As the broader scale picture is far from deterministic, purely eco-physiological influences will not explain forest recovery. Also, 'refugia' are not discrete biogeographical phenomena, but exist on all scales and need to be documented and understood before any sort of sustainable forest production can be achieved. The paper also provides a complete check-list with the guilds and conservation status of all forest species in Ghana.

- Hawthorne, W. D. & M. Abu-Juam. 1995. Forest protection in Ghana. IUCN, Gland, Switzerland and Cambridge, UK

Review of forest reserve condition and history in Ghana, with recommendations for improvement. Results of a botanical survey, including a vegetation scoring system of 'Genetic heat Index' and 'Economic Index', which provides a conservation priority 'league table' for patches of forest in Ghana. Recommendations are made for a new framework of protection policy which respects such patterns on various scales.

- Hawthorne, W. D., D. L. Filer & D. J. Turnbull, 1999. Tree data management, mapping, and the development of the TREMA software. *International Forestry Review*. 1:87-96
Summary of TREMA software, with examples from the current and other studies.

- Hawthorne W.D. & M.P.E. Parren, 2000. How important are the forest elephants to the survival of woody plant species in upper Guinean forests? *Journal of Tropical Ecology* 16: 133-150

- Heinrich, R. (ed.). 1978. Mountain forest roads and harvesting. Technical report of the second FAO/Austria training course, Austria 1978. FAO. FAO, Rome. 1-154.

A multi-author volume on all aspects of the title. See FAO 1983 for updated version.

- Heinrich, R. 1995. Environmentally sound harvesting to sustain tropical forests. IUFRO XX World congress report (Tampere, Finland). IUFRO secretariat, Austria. 436-446.

Several FAO and grey-literature reports are in effect summarised. General discussion leading up to presentation of the FAO programme on environmentally sound forest harvesting and engineering. Low impact harvesting has 4 components. Harvest planning. Topographical and census data (cf Marn & Jonkers, 1982). Felling operations: Mark trees well before felling, for felling or retention as seed trees. Directional felling feasible for 60-70% trees cut. Wood extraction systems: Keep skidding etc. to a minimum - easier with harvest planning. Cables, balloons and cyclocraft mentioned.

- Henderson, J. 1990. Damage controlled logging in managed tropical rain forest in Suriname. Pudoc, The Netherlands.

Part of CELOS, method devised to reduce logging damage. Felling damage as gaps and no. damaged trees. Directional felling to facilitate skidding reduced damage a lot. Plan skid trails on maps.

- Hens, L. 2006. Indigenous knowledge and biodiversity conservation and management in Ghana. *Journal of Human Ecology* 20: 21-30

- Henwood, A. 1986. Moth trapping in the rain forest of Borneo. Report to Yayasan Sabah, Kota Kinabalu.

- Herauld, B; Ouallet, J; Blanc, L; Wagner, F; Baraloto, C. 2010. Growth responses of neotropical trees to logging gaps. *Journal of Applied Ecology* 47: 821-831

- Hernandez-Diaz, J. C. & M. Delgado-Pacheco. 1995. Damage evaluation to remaining standing trees

- in a timber yarding operation (case study). Abstract: Proc. XX IUFRO world congress. 221.
Mexico: 1.845 m³/ha of residual commercial size trees were damaged by timber yarding with a 'motogrua' yarding crane in a forest with 41 m³/ha (or 1.9 trees/ha.).
- Hertel, D., C. Leuschner, M. Harteveld, & M. Wiens, 2007. Fine root mass, distribution and regeneration in disturbed primary forests and secondary forests of the moist tropics. Pp 89-108 in Tcharntke, T., C. Leuschner, M. Zeller, E. Guhardja, & A. Bidin, (eds.) Stability of Tropical Rainforest Margins: Linking Ecological, Economical and Social Constraints of Land Use and Conservation International Symposium on Stability of Tropical Rainforest Margins SEP, 2005. Georg-August-Univ Goettingen, Goettingen, Germany
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- Heydon, M. J. 1994. The ecology and management of rain-forest ungulates in Sabah, Malaysia: implications forest disturbance. Report to O.D.A/NERC project F3CR26/G1/05, Institute of South-east Asian Biology, University of Aberdeen.
- Heydon, M.J. & P. Bulloh. 1996. The impact of selective logging on sympatric civet species in Borneo. Oryx 30: 31-36.
- Heydon, M.J. & P. Bulloh. 1997. Mousedeer densities in a tropical rainforest: the impact of selective logging. Journal of Applied Ecology 34: 484-496
- Hicks, T.C., R.S. Fouts, & D.H. Fouts. 2009. A Survey of Chimpanzees (*Pan troglodytes*) and Gorillas (*Gorilla gorilla*) in the Selectively Logged Ngotto Forest, Central African Republic. Journal of Applied Animal Welfare and Science 12:165-188
- Hietz-Seifert, U., P. Hietz, & S. Guevara. 1996 Epiphyte vegetation and diversity on remnant trees after forest clearance in southern Veracruz, Mexico. Biological Conservation 72: 103-111
- Hill, J.K. 1999. Butterfly spatial distribution and habitat requirements in a tropical forest: impacts of selective logging. Journal of Applied Ecology 36: 564-572
- Hill, J.K, K.C. Hamer, M.M. Dawood, J. Tangah, & V.K. Chey. 2000. Rainfall but not selective logging affect changes in abundance of tropical forest butterfly in Sabah, Borneo. Journal of Tropical Biology 19: 35-42
- Hill, J.K., K.C. Hamer, L.A. Lace, & W.M.T. Banham. 1995. Effects of selective logging on tropical forest butterflies on Buru, Indonesia. Journal of Applied Ecology 32: 754-760
- Hilton, R. G. B. 1987. Nutrient cycling in tropical rainforests: Implications for management and sustained yield. Forest Ecology and Management 22: 297-300
- Hitimana, J., J.L. Kiyapi, & J.T. Njunge. 2004. Forest structure characteristics in disturbed and undisturbed sites of Mt. Elgon moist lower montane forest, western Kenya. Forest Ecology and Management 194: 269-291
- Regeneration and recruitment patterns of the forest and of individual tree species varied among heavily and lightly logged-over sites; and in spite of a good overall forest regeneration, this did not necessarily mirror the regeneration status of constituent tree species. The forest is classified as an under-stocked tropical mixed rain forest.
- Hladik, A. & D. Mitja. 1996. Seedlings, saplings and tree temperaments: potential for agroforestry in the African rain forest. Pp173-192, Swaine M.D (ed.) The ecology of tropical forest seedlings. Man and the Biosphere Series V:17 UNESCO and the Parthenon Publishing Group Paris.
- Discusses the various types of seedling and how they relate to dispersal and sapling growth. Growth and mortality were followed in Gabon, Makoukou forest in two PSPs (400x10m; 1800x5m), for trees >5 or >30 cm dbh. Overall mortality was 10%, compensated by

- recruitment. Pioneers (*Macaranga*, *Ficus*, *Croton*, and *Alstonia*) have a distinct 'Type 1' seedling. Type 1 seedlings were also amongst non-pioneers though. In fallows, many more Type 1 seedlings (24 pioneers - good correspondence with Ghana classification) were found.
- Hogberg, P., & J. Wester. 1998. Root biomass and symbiosis in *Acacia mangium* replacing tropical forest after logging. *Forest ecology and Management* 102: 333-338
- Holbech, L.H. 2009. The conservation importance of luxuriant tree plantations for lower storey forest birds in south-west Ghana. *Bird Conservation International* 19: 287-308
- Holbech, L.H. 2005. The implications of selective logging and forest fragmentation for the conservation of avian diversity in evergreen forests of south-west Ghana. *Bird Conservation International* 15: 27-52
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- Holloway, J. D. 1984. Moths as indicator organisms for categorizing rain-forest and monitoring changes and regeneration processes. Pp 235-242 in Chadwick, A. C & S. L. Sutton, (eds.) *Tropical rain-forest: the Leeds symposium*, Leeds: Leeds Philosophical and Literary Society.
- Holloway, J.D., A.H. Kirk-Spriggs & V.K Chey. 1992. The response of some rain forest insect groups to logging and conversion to plantations. *Phil. Trans. R. Soc. London B* 335: 425-436
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- Hopkins, M. S., J. Kikkawa, A.W. Graham, J.G. Tracey, & L.J. Webb. 1977. An ecological basis for the management of rainforest. Pp. 57-66 in Munroe, R. & N. C. Stevens (eds.) *The border ranges: a land use conflict in regional perspective*, Brisbane: Royal Society of Queensland.
- Horn, H. S. , 1971. *The adaptive geometry of trees*. Princeton University Press. Princeton.
Multi-layer and mono-layer crowned trees discussed for temperate forests, hypothesising that mutli-layer trees give access to more sunlight therefore are more productive.
- Horne, R. & J. Gwalter. 1984. Recovery of rainforest overstorey following logging. I. Subtropical rainforest. *Australian Forest Research* 13: 29-44.
An area 3.9 ha of 14 yr old regrowth (following 70-80% basal area removal) measured 5 times; 100-220 years estimate for recovery, but only 30-60 years needed if 30% basal area removed. A growth model is used, assuming the overstorey composed of trees >30m high (when dbh 46cm); When mature, overstorey BA increment is 0; after logging residual overstorey species respond to release; 'recovery' has occurred when BA reaches equilibrium value; NetBA growth of recovering overstorey declines with time due to increasing competition and mortality; all overstorey and potential overstorey trees have an equal chance of mortality during recovery period. Trees with >10cm dbhn growth increments increased after logging.
- Horne, R., G. Watts, & G. Robinson. 1991. Current forms and extent of retention areas with a selectively logged blackbutt forest in NSW: a case study. *Australian Forestry* 54: 148-153.
- Hostettler, S. 1996. Dispersal and regeneration probability in wind-, animal- and explosively-dispersed timber trees. B.Sc Hons. Dis. Environmental Science, University of Aberdeen.
Comparison of different dispersal modes; 7 species, seedling distributions and regeneration probabilities, with the ultimate aim of developing models applicable to forest regeneration after logging. All seedling distributions are leptokurtic, negative exponential from the mode outwards. Median distance of seedling from older cohorts is significantly higher than median dispersal distance, suggesting higher mortality near parent. In the equation. $\ln(y)=a+mx$, where y =density & x =distance and $d1$ =radial distance where 1 seedling expected.
WIND: *Nesogordonia* $\ln y=9.17-0.25x$ $r^2=.936$; *Pterygota* $\ln y=7.85-0.2x$ $r^2=.9540$; *Khaya* $\ln y=6.39-0.24x$ $r^2=.8526$

ANIMAL: *Aningeria* $\ln y = 9.93 - 0.32x$ $r^2 = .98$ 31; *Cola gig.* $\ln y = 8 - 0.24x$ $r^2 = .9$ 33; *Antiaris* $\ln y = 8.28 - 0.23x$ $r^2 = .97$ 36

EXPLOSIVE: *Bussea* $\ln y = 5.98 - 0.23x$ $r^2 = .91$ 26

No sig. diff. between slopes, but max. distance varies. Herbivory damage declines for *Pterygota*, increases for *Nesogordonia* and showed little pattern for other species. Animal dispersed seedlings generally more abundant, esp. under mother. The concept of a constant for a species, describing how much forest could be restocked by a single mature tree is discussed. For all species, dispersal greater than 100m from the tree is vanishingly rare.

Howe, H. & J. Smallwood. 1982. Ecology of seed dispersal. *Annual Review of Ecology and Systematics* 13: 201-228.

Discuss general aspects of seed dispersal, plus gives typical profiles of dispersal types for different forests.

Howlett, B.E. & D.W. Davidson .1996. Dipterocarp seed and seedling performance in secondary logged forest dominated by *Macaranga* spp. Pg 256-266 in Appanah, S., & K.C. Khoo (eds.) *Proceedings fifth round table conference on Dipterocarps, Chang Mai, Thailand 7-10 November 1994*

Huang, M., G.P. Asner, M. Keller, & J.A. Berry, 2008. An ecosystem model for tropical forest disturbance and selective logging. *Journal of Geophysical research-Biogeosciences* 113:

Huang, MY; Asner, GP. 2010. Long-term carbon loss and recovery following selective logging in Amazon forests. *Global Biogeochemical Cycles* 24, art.no.-GB3028

Hubbell, S.P. 1980. Seed predation and the coexistence of tree species in tropical forests. *Oikos* 35: 214-229.

Hubbell, S.P. 1999. The maintenance of diversity in a neotropical tree community: Conceptual issues, current evidence and the challenges ahead. Pp 17-44. in *Forest Biodiversity, Research and Monitoring and Modeling*. Vol 20. *Man and the Biosphere Series*, UNESCO and Parthenon Paris.

Based largely on BCI data. Density dependence in 25ha. quadrat scale across 40ha.. Small trees are often old (Estimated from polynomial regression on growth rates $>1\text{cm}$, danger of overestimate, because growth rates included those dying, hence only 10% fastest growth rates) For 1cm DBH trees, the Median is 16.6 yrs. *Ouratea lucens* >80 yrs. *Trichilia* and *Alseis* canopy trees c 20-25 yrs. old at 1cm. *Cecropia* and *Zanthoxylum* <1 yr at 1cm. Non pioneer species spend long time in Understory, hence relative abundance determined here. 1/3 to 1. 2 of parents of a sapling cohort may have died, hence losing focal tree density dependence. Niches do not control the presence/absence or current relative abundance of species: Immigration & extinction more are controlling. Density dependence on mortality and recruitment classical. However, $\text{BCI} = \text{density vague recruitment} - \text{population density}$ sets an upper limit only. Stochastic events affect year to year fecundity; seed and seedling mortality. e. g. *Trichillia*

Hubbell, S. P. & R. B. Foster 1986. Biology, chance and history and the structure of tropical forest communities. Pp 314-324 In Diamond, J. M. & T. J. Case. *Community Ecology*: Harper & Row, New York.

Hubbell, S.P., F.L. He, R. Condit, L. Borda-de-Agua, J. Kellner, & H. ter Steege, 2008. How many tree species and how many of them are there in the Amazon will go extinct? *Proceedings of the National Academy of Sciences of the United States of America* 105: 11498-11504

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. *Ecological Monographs* 54: 187-211

Hubbell, S. P. , R. B. Foster, S. T. O'Brien, K. E Harms, R. Condit, B. Wechsler, S. J. Wright, & S. Loo de Lao. 1999. Light-gap disturbances, recruitment limitation, and tree diversity in a neotropical forest. *Science* 283: 554-557.

Discusses intermediate disturbance hypothesis, suggesting gap diversity promotes species diversity, based on 13 years study on >1200 gaps. Gaps increased seedling establishment and sapling densities, but the effect was non-specific. Species richness per stem the same in non-gap control sites. Species composition of gaps unpredictable. Strong recruitment limitation. 200 seed traps caught 260 species over 10yrs, but no seeds from >50 species with adults in the plot. Similar dispersal limitation evident for seedlings. Mortality in gaps a random thinning process, as no change seen in gaps over 12 years. Pioneers persisted in gaps over 12 years. Gaps promote whatever species in the area, neutrally.

Hughes, R. F., J. B. Kauffman & D. L. Cummings. 2002. Dynamics of aboveground and soil carbon and nitrogen stocks and cycling of available nitrogen along a land-use gradient in Rondônia, Brazil. *Ecosystems* 5: 244–259.

Hunter, M.L., 1993. Natural fire regimes as spatial models for managing boreal forests. *Biological Conservation* 65: 115–120

Hussin, Bin. M.Z. & C.M. Francis. 2001. The effects of logging on birds in tropical forests in Indo Australia. Pg 167-192 in Fimbel, R.A., A. Grajal and J.G Robinson (eds.) *The cutting edge: conserving wildlife in logged tropical forest*. Columbia University Press New York USA

Hutchinson, J. & J. M. Dalziel. 1972. *Flora of West Tropical Africa*. 2nd edition Revised by Keay, R. W. J. & F. N. Hepper. Crown Agents, London.

Hutchings T.R., A.J. Moffat, & C.J. French. 2002. Soil compaction under timber harvesting machinery: a preliminary report on the role of brash mats in its prevention. *Soil Use and Management* 18: 34-38

Study from Northumberland, UK. The thickest brash mat, composed of residues from 10 rows of trees, was unable to prevent compaction completely, but offers protection over passes on bare soil. The point at which compaction becomes detrimental remains uncertain.

Huth, A., Ditzer, T., & H. Bossel. 1997. Rainforest growth model FORMIX3: A tool for forest management planning towards sustainability. Model development and case study for Dermakot Reserve in Sabah, Malaysia. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Eschborn, 78pp.

Huth, A., M. Drechsler, & P. Kohler. 2005. Using multicriteria decision analysis and a forest growth model to assess impacts of tree harvesting in Dipterocarp lowland rain forests. *Forest Ecology and Management* 207: 215-232

Using the rain forest growth model FORMIND, and a stochastic extension of the PROMETHEE method to select optimum endpoints, five scenarios proved to be optimum for a wide range of priorities concerning different forest functions. They all use reduced-impact logging and long logging cycles (≥ 60 years), either with a minimum cutting limit of 50 or 60 cm stem diameter, or with medium logging intensities.

IIED/Forestry Department of Ghana. 1993. Study of incentives for the sustainable management of the tropical high forest of Ghana. Unpublished, draft report. IIED and Forestry Department, Accra, Ghana.

Ilisson, T. & H.Y.H. Chen. 2009. Response of Six Boreal Tree Species to Stand Replacing Fire and Clearcutting. *Ecosystems* 12: 820-829

Isabirye-Basuta, G. & J. M. Kasenene. 1987. Small rodent populations in selectively felled and mature tracts of Kiibale forest, Uganda. *Biotropica* 19: 260-266.

Two plots examined, one selectively felled, the other undamaged. 14 species of small rodents were examined. Two species were most abundant in both plots. Those species more commonly associated with savanna and edge habitats were more common in the logged area. Rodent densities were about equal in the plots but there was greater species diversity in the logged plot and was positively highly correlated with ground cover vegetation (higher in the felled plot). Rodent species diversity was inversely correlated with tree species diversity.

- Iskandar, D.T. & D.Y. Setyanto. 1999. Environmental impact assessment in four logged forest condition in South Kalimantan. Presented at Asia Pacific Congress on the Biology of the Environment. Singapore 21-24 November 1999
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- Islam, K.R., M.R. Ahmed, M.K. Bhuiyan, & A. Badruddin. 2001. Deforestation effects on vegetative regeneration and soil quality in tropical semi-evergreen degraded and protected forests of Bangladesh. *Land Degradation and Development* 12: 45-56
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Dryobalanops aromatica & *D. lanceolata* in areas where they have 17-20% of basal area. Distribution of <2yr seedlings restricted to <40m from adult. <1cm seedlings most dense around trees >30cm dbh. 1-5cm saplings and adults had negative spatial patterns (avoidance). but most 1-30cm poles were 15-20m from adults. Seedlings of both were randomly distributed with respect to light conditions (2 indices), but saplings were found under more open conditions.
- Jack, W. H. 1960. A 'check' method applied to tropical high forest. *Empire Forestry Review* 39: 195-201.
 Discusses stocking, ingrowth, felling and mortality over 9. 5 years in Bobiri F. R. , Ghana, using stock maps and field checks. Bobiri was opened for exploitation in 1945. $\frac{3}{5}$ of the forest was given a 'selection' treatment of climber cutting before exploitation.
- Jack, W. H. 1961. The spatial distribution of tree stems in a tropical high forest. *Empire Forestry Review* 40: 234-241.
 Pra Anum, Ghana. 17,280 plots within 4320 acres, combined in various groups, shapes and sizes. Distribution not normal Gaussian nor Poisson but contagious negative binomial. Small sizes of *Triplochiton* and *Khaya ivorensis* related to larger sizes in the same areas. Long narrow samples across drainage gave lowest sample error.
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Bats visit *Andia* to eat the fruits, during this process many seeds fall, but mortality by weevil predation is high under the roosting trees. Seeds dropped in transit may have the best chance of maturing.
- Jennings, S.B., N.D. Brown, D.H. Brown, D.H. Boshier, T.C. Whitmore & J.D.A. Lopes 2001. Ecology provides a pragmatic solution to the maintenance of genetic diversity in sustainable managed tropical rain forest. *Forest Ecology and Management* 154: 1-10
Most tropical rain forest tree species have many more individuals below the minimum size for commercial exploitation than above. The genetic diversity of these species will be little affected by logging, as the stems removed form only a small fraction of the total population. Similarly, for most species, disruption of normal mating patterns will either not occur or be transient, because reproduction commences at sizes well below felling limits, or because, after logging, juveniles will be recruited to the sexually mature size classes.
Strongly light-demanding species with a commercial value are most likely to suffer loss of genetic diversity from logging. Characteristically, these have populations in which only a small proportion of the total population lies in small size classes. In order to conserve genetic diversity, pre-felling silvicultural treatments will be required to increase the survival and growth of juveniles. Ecological and genetic research needs to focus on these light-demanding species.
- Johns, A. D. 1981. The effects of selective logging on the social structure of resident primates. *Malaysian Applied Biology* 10: 221-226.
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- Johns, A. D. 1985. Behavioural responses of two Malaysian primates (*Hylobates lar*) and (*Presbytis melalophos*) to selective logging: vocal behaviour, territoriality and non-emigration. *International Journal of Primatology* 6: 421-431.
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- Johns, A. D. 1989b. Timber, the environment and wildlife in Malaysian rain forests. Final Report to

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- Johns, A. G. 1988. Effects of 'selective' timber logging on rainforest structure and composition and some consequences for frugivores and folivores. *Biotropica* 20: 31-37.
51% of trees destroyed in W. Malaysia dipterocarp forest as a consequence of extracting 3.3% of trees. Damaged equally shared between all sizes and taxa. Food availability seriously reduced for frugivores and folivores. Selective logging removes only trees 145-192 cm dbh; 18 stems/ha. removed (24m³/ha BA). Basal area reduced from 35 m² to 18 m². Many colonisers attain 30 cm dbh in 5-6 yrs.
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Includes a theoretical minimum damage level by mathematical simulation i.e. 2 trees/ha=10% damage.
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Effects of planning on tree felling, machine manoeuvring, skidding, loading bay construction and logging road construction. Planned logging used rubber wheels or bulldozer; vine cutting 2 years prior to logging and planned operation used directional felling. For each tree felled, unplanned logging, resulted in 16 more trees >10cm dbh damaged, and 100 m² extra area affected. Tree felling caused most damage to other trees per ha. , with planning this was halved from 124 to 64 trees per ha. Probably profit margin increased by planning due to greater efficiency.
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In heavily logged forest more live than dead trees snapped off and were uprooted, whereas in the control, the converse was true. The density of canopy trees falling was not significantly different between cut and mature forest. Species composition of tree falls differed between the three compartments. All three samples showed two peaks of tree fall with size: between 21-50cm dbh and a larger peak between 60-80cm dbh. Heavily logged forest had the highest fall rate in the larger dbh band, followed by lightly logged forest. Hence, heavy selective felling changed the pattern of tree fall, with more live than dead trees falling. Mortality was 1.3 (heavy), 3.3 (light) and 1.74 (uncut) which corresponds to earlier studies. Small tree mortality may largely be a function of larger tree falls.

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335:357-366

Colonising seedlings monitored for 3 yrs in lowland rainforest, Sabah, in newly made gaps and under primary forest. Germination not affected by gap size, but increased with soil exposure or disturbance. Diversity of regenerating vegetation was negatively related to gap size. Seedling mortality was less in large gaps and without competition from advance regeneration; opposite true for seedling growth. Gap size unlikely to influence colonising vegetation composition by controlling germination, but differential mortality may be important.

Khan, N. 1995. Protection of North Selangor peat swamp forest, Malaysia. *Parks* 5: 24-31.

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Kigomo, B. N. , S. R. Woodell & P. S. Savill. 1994. Phenological patterns and some aspects of the reproductive biology of *Brachylaea huillensis* O. Hoffm. *African Journal of Ecology* 32: 296-307.

More males than females. 80% loss of fruit predispersal due to insects. 6% viability in forest; loss of viability accelerated by sunlight and soil organisms - complete loss in forest in 15 weeks. Sustained regeneration probably requires attention to balance of sexes.

Kim, J. , Y. Son, Z. Kim, J. S. Kim, Y. H. Son & Z. S. Kim. 1995. Allometry and canopy dynamics of *Pinus rigida*, *Larix leptolepis*, and *Quercus serrata* stands in Yangpyeong area. *Journal of Korean Forestry Society* 84: 186-197

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King, D. A. 1990. Allometry of saplings and Understory trees of a Panamanian forest. *Functional Ecology* 4: 27-32.

The allometry of understory tree species (6 spp.) were contrasted with saplings of larger canopy trees in Panama. Smaller understory trees have thicker trunks and wider, heavier, leafier crowns than similar height (2-5m) saplings of canopy spp. Understory species are optimised for living there, unlike larger trees which are optimised for height growth.

King, D. A. 1991. Correlations between biomass allocation, relative growth rate and light environment in tropical forest saplings. *Functional Ecology* 5: 485-492

Nine species in Costa Rican wet forest. Gap-associated species allocate $2/3$ of above ground growth to the stem and branches under all measured conditions.

King, D. A. 1996. Allometry and life history of tropical trees. *Journal of Tropical Ecology* 12: 25-44.

14 common Costa Rican trees from wet lowland forest: relationship between crown size and trunk diameter. Adults of understory trees are larger-crowned than similar stature (6-15m) saplings of canopy trees; Species common in gaps as saplings are larger-crowned than shade-tolerant species when 1-6m high; long-lived canopy species show greater increases in crown breadth as height increase than shorter-lived trees. Related to, the need to withstand high winds in the upper canopy. DBH/height relations are shown to lie within mechanical constraints.

King, G. C. & W. S. Chapman. 1983. Floristic composition and structure of a rainforest area 25 years after logging. *Australian Journal of Ecology* 8: 415-423.

Forest might take 140-190 yrs to recover. After 25 yrs, a 7.8 ha area of logged forest which had had 90% of the canopy trees removed had recovered all plant species, but regrowth canopy was 12m rather than 35m tall.

- Kinnaird M. F., E.W, Sanderson, T.G, O'Brien, H.T, Wibisono, & G. Woolmer. 2003. Deforestation trends in a tropical landscape and implications for endangered larger mammals. *Conservation Biology* 12: 245-956
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Hyperbolic (almost linear, than asymptote) relation between tree height and DBH. Height decreases with rainfall. Total wood biomass density decreases vertically in forest, but leaf biomass peaks at 1.3m and c. 25-35m.
- Kirika, J.M., N.Farwig, & K. Bohning-Gaese. 2008. Effects of local disturbance of tropical forests on frugivores and seed removal of a small-seeded afrotropical tree. *Conservation Biology*. 22: 318-328
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2 yr study on BCI, Panama. High seedling survival and abundant production associated with monocarpic fruiting.
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Recovery of forest had been delayed by dominance of *Gleichenia* fern and *Melastoma*, although trees were appearing after 30 years.
- Koehler, P.; Huth, A.. 2010. Towards ground-truthing of spaceborne estimates of above-ground life biomass and leaf area index in tropical rain forests. *Biogeosciences* 7 (8)
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Nine common shade-tolerant saplings from lowland rain forest in Sumatra examined. Detected interspecific differences explained as a result of trade-off between height growth and area extension. Saplings of emergent favoured height growth.
- Kohyama, T. 1991. A functional model describing sapling growth under a tropical forest canopy. *Functional Ecology* 5: 83-90.
Model based on published data on allometry of shade-tolerant saplings. Distinction between branch-developing and trunk developing saplings. The former have greater larger trunk diameter, wider crown area and lower leaf area density at the same height than trunk developing ones.
- Kohyama, T. 1992. Size-structured multi-species model of rain forest trees. *Functional Ecology* 6: 206-212.
- Kohyama, T. 1993. Size-structured tree populations in gap-dynamic forest - the forest architecture hypothesis for the stable co-existence of species. *Journal of Ecology* 81: 131-143.
- Kohyama, T. & M. Hotta. 1990. Significance of allometry in tropical saplings. *Functional Ecology* 4: 515-521.
Nine species from West Sumatra, all 'shade-tolerant', but various maximum heights. Species were different in intercepts but not in the slope of log (dimensions). Emergent's saplings

emphasised height growth rather than expansion of crown. Advantages of maintaining assimilative area at present height lower in a habitat with a steeper light gradient or higher growth rate like tropical forests.

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- Korning, J. & H. Balslev, 1994. Growth rates and mortality patterns of tropical lowland tree species and the relation to forest structure in Amazonian Ecuador. *Journal of Tropical Ecology* 10: 151-166
- Kouadio, Y.L. & J.L. Doucet. 2009. Study of the behaviour of *Baillonella toxisperma* Pierre (moabi) in enriched logging gaps. *Biotechnologie Agronomie Societe et Environment* 13: 317-324
- Krajicek, J. E. , K. A. Brinkman, & S. F. Gringrich. 1961. Crown competition - a measure of density. *Forest Science* 7: 35-42.
- Kubota, Y. & T. Hara 1996. Allometry and competition between saplings of *Picea jezoensis* and *Abies sachalinensis* in a sub-boreal coniferous forest, northern Japan. *Annals of Botany* 77: 529-537
- Kuerpick, P. , U. Kuerpick & A. Huth. The influence of logging on a Malaysian dipterocarp rain forest. A study using a forest gap model. *Journal of theoretical Biology* 185: 47-54.
Simulation of different logging techniques in gap-aware model on forest composition and logged biomass. With or without incidental damage to trees, the latter suggesting 100 years logging cycle to maximise yield, 200 years to restore species composition. 20 year cycles low yield and greater change in composition. Logging damage very important to take into account when modelling.
- Kunisaki, T. & M. Imada 1996. DBH-height relationship for Japanese red pine (*Pinus densiflora*) in extensive natural forests in southern Japan. *Journal of Forest Planning* 2: 115-123
- Kushawa S. P. S. , P. S. Ramakrishnan & R. S. Tripathi. 1981. Population dynamics of *Eupatorium odoratum* in successional environments following slash and burn agriculture. *Journal of Applied Ecology* 66: 247-295.
- Kuuluvainen, T. 1991. Relationships between crown projected area and components of above-ground biomass in Norway spruce stands: empirical results and their interpretation. *Forest Ecology and management* 40: 243-260.
- Kuusipalo, J., Y. Jafarsidik, G. Adjers, & K. Tuomela. 1996. Population dynamics of seedlings in a mixed dipterocarp rain-forest before and after logging and crown liberation. *Forest Ecology and Management* 81: 85-94
- Kyereh, B. 1994. *Seed phenology and germination of Ghanaian forest trees*. PhD thesis. University of Aberdeen, U. K.
- Kyereh, B. , M. D. Swaine & J. Thompson. 1999. Effect of light on the germination of forest trees in Ghana. *Journal of Ecology* 87: 772-783.
19 species of tree tested in various light qualities including full light and dark. Germination only reduced in dark for *Musanga*, *Nauclea* and *Milicia* (with smallest seeds, and spp. from the seedbank). Only subsets of pioneers are photoblastic – other species like *Terminalia* and *Ricinodendron* can germinate in shade. Some disagreement between forest and shade-house (*Pericopsis* increased % germination in high light only in shade-house), probably due to drought in forest, where not watered. Oddly, *Ricinodendron* 42% germinates in dark, but zero in 2% light.
- Lacoste, J. F. & D. Y. Alexandre. 1991. Kopi (*Goupia glabra*), a promising timber tree for forestry in French Guiana: a literature review. *Annales des Sciences Forestieres* 48: 429-441.

Review of ecology etc. of this fast growing pioneer in the neotropics, which rapidly colonises open areas and has straight stems and durable timber. Early removal of undesirable pioneer competition (*Cecropia*, *Vismia*, *Solanum*) nevertheless useful in regrowth forests.

Lada, H., J.R. Thomson, R. Mac Nally, G. Horrocks, & A.C. Taylor. 2007. Evaluating simultaneous impacts of three anthropogenic effects on a floodplain-dwelling marsupial *Antechinus flavipes*. *Biological Conservation* 134: 527-536

Laidlaw, R. K. 1994. The Virgin Jungle Reserves of peninsular Malaysia: the ecology and dynamics of small protected areas in managed forest. PhD thesis. University of Cambridge, UK.

Laird, S. 1995. *The natural management of tropical forests for timber and non-timber products*. OFI-Occasional-Papers, No. 49. Oxford Forestry Institute, Oxford, UK.

Lamb, A. F. A. 1940. On the siculture of Obeche. *Nigerian Forester*. 2: 15-20.

Lamb, D. 1990. Exploiting the tropical rain forest: an account of pulpwood logging in Papua New Guinea. Man and the Biosphere series. UNESCO & Parthenon.

The book as a whole explores clear-felling in Papua New Guinea. Chapter 5 explores environmental consequences in the Gogol valley. Normal patterns of regrowth of pioneers, where regenerating seedling densities are inversely proportional to soil disturbance. Animal, soil, water aspects are summarised in turn. 'Neither selective logging or clear-felling produced a dramatic hydrological impact'. Likewise sediment in rivers is naturally high, and logging effects therefore difficult to detect. The role of residual seedling is judged small; the soil seed bank is important for a few early pioneer species; vegetative regrowth may play a significant role in the re-establishment of logged forest, especially for 'large secondary' or primary forest species. Measured seed rain included no primary forest species, but many secondary forest ones. However, this was probably due to undersampling as primary forest species may arrive from elsewhere.

Lamb, D. 2011. *Regreening the Bare Hills: Tropical Forest Restoration in the Asia-Pacific Region*. Series: World Forests, Vol. 8, Springer, pp. 547.

Explores how reforestation might be carried out both to conserve biological diversity and to improve the livelihoods of the rural poor. Combines a theoretical-research perspective with practical aspects of restoration.

Lambert, F. R. 1992. The consequences of selective logging for Bornean lowland forest birds. Pp 443-457. in Marshall A. G. & M. D. Swaine (eds.) *Tropical rain forest: disturbance and recovery*, London: The Royal Society.

Lambert, F.R. & N.J. Collar. 2002. The future for Sundaic lowland forest birds: long-term effects of commercial logging and fragmentation. *Forktail* 18: 127-146

Lammertink, M. 2004. A multiple-site comparison of woodpecker communities in Bornean lowland and hill forests: effects of logging and conservation implications *Conservation Biology* 18: 746-757

Lammerts van Beuren, E. M. & J.F. Duivenvoorden. 1996. Towards priorities of biodiversity research in support of policy and management of tropical rainforests. Wageningen: The Tropenbos Foundation

Lancaster, P. C. 1954. *Khaya ivorensis* regeneration - interim observations. *Nigerian Forestry Information Bulletin* (August 1954).

Lancaster, P. C. 1961. Experiments with natural regeneration in the Omo forest reserve. *Nigerian Forestry Information Bulletin* 13: 5-16.

Laporte, N.T., J.A. Stabach, R. Grosch, T.S. Lin, & S.J. Goetz. 2007. Expansion of industrial logging in Central Africa. *Science* 316: 1451-1451

Regular monitoring with satellite remote sensing provides a consistent approach to monitor both legal and illegal logging activities. Industrial logging has become the most extensive land use in Central Africa, with more than 600,000 square kilometers (30%) of forest currently under concession. A new frontier of logging expansion was identified within the Democratic Republic of Congo, which contains 63% of the remaining forest of the region. Tree felling and skid trails increased disturbance in selectively logged areas.

- Laurance, W.F. 1999. Reflections on the tropical deforestation crisis. *Biodiversity and Conservation* 91: 109-117
- Laurance, W. F. 1991. Ecological correlates of extinction proneness in Australian tropical rain forest mammals. *Conservation Biology* 5: 79-89.
- Laurance, W.F., A. Alonso, M. Lee, & P. Campbell. 2006. Challenges for forest conservation in Gabon, central Africa. *Futures* 38: 454-470
- Laurance, W.F., B.M. Croes, N. Guissouegou, R. Buij, M. Dethier, & A. Alonso. 2008. Impacts of roads, hunting, and habitat alteration on nocturnal mammals in African rainforests. *Conservation Biology* 22: 721-732
- Laurance, W.F., J.M. Fay, R.J. Parnell, G.P. Sounquet, A. Formia, & M.E. Lee. 2008. Does rainforest logging threaten marine turtles? *Oryx* 42: 246-251
- Laurence, W. F. & S. G. W Laurence. 1996. Responses of five Arboreal Marsupials to recent selective logging in tropical Australia. *Biotropica* 28: 310-322.
Censuses were conducted of a diverse assemblage of folivorous marsupials over 1yr prior and 3yrs after logging. An average of 8-10 trees/ha were extracted. Two formerly logged sites were used as control. Lemuroid ringtail possums declined significantly while three other possums and a tree kangaroo were apparently not greatly affected. The amount of structural damage in logging would have the most effect on ecological and behavioural traits.
- Laurance, W.F. & D.C. Useche. 2009. Environmental Synergisms and Extinctions of Tropical Species. *Conservation Biology* 23: 1427-1437
- Laurance, WF; Camargo, JLC; Luizao, RCC; Laurance, SG; Pimm, SL; Bruna, EM; Stouffer, PC; Williamson, GB; Benitez-Malvido, J; Vasconcelos, HL; Van Houtan, KS; Zartman, CE; Boyle, SA; Didham, RK; Andrade, A; Lovejoy, TE. 2011. The fate of Amazonian forest fragments: A 32-year investigation. *Biological Conservation* 144: 56-67
- Lawes, M.J., M.E. Griffiths, & S. Boudreau. 2007. Colonial logging and recent subsistence harvesting affect the composition and physiognomy of a podocarp dominated Afrotropical forest. *Forest Ecology and Management* 247: 48-60
The impact of logging 100 years ago in South Africa can still be seen today because the understorey angiosperm-dominated species that regenerated in the logging gaps have subsequently been the focus of local subsistence harvesting of small DBH poles from the forest. The preferred, straight poles tend to be canopy species, and this pattern of use is preventing regeneration of the original Podocarp forest. Vegetation that is reduced stature, with thicket-like physiognomy, less diverse and less dominated by conifers is the expected successional outcome without intervention.
- Lawes, M.J. & C.A. Chapman. 2006. Does the herb *Acanthus pubescens* and/or elephants suppress tree regeneration in disturbed Afrotropical forest? *Forest Ecology and Management* 221: 278-284
- Lawes, M.J. & J.A.F. Obiri. 2003. Using the spatial grain of regeneration to select harvestable tree species in subtropical forest. *Forest Ecology and Management* 184: 105-114
- Lawson, G. W. (ed.). 1986. *Plant Ecology in West Africa*. John Wiley & Sons Ltd.
- Lawton, R. M. 1955. The relationship between crown form and sex in *Chlorophora excelsa*. *Empire*

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Recommends scoring forest condition every c.30m, summarising pioneer dominance of the understory, to help improve stock survey.
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Logging loss of 44-107 m³/ha with 63% of this felled and only 43% removed. Manaus, 4 ha plots. Density of trees <10 cm DBH greater in logged plots 3 and 7-8 years after logging. Total potential value of regeneration 23% greater in logged plots, though not significant. Recommends enrichment planting.
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Description of three sets of silvicultural trials established by Sodefor in 1976 in the Ivory Coast. Blocks of 400ha were divided into 25x16 ha plots; each plot was treated throughout, with measurements on 10 cm dbh trees (70 commercial species only named; but others counted) in the central 4 ha. The same type of trial was repeated in three types of forest (Irobo-evergreen; La Tene-semideciduous; Mopri-transition). In each block, 30 were untouched; 35 were thinned by killing non-commercials (40% or 30% BA); 10 in La Tene only were exploited for all principal species >=80cm dbh (av. 53 m³/ha). 2-10cm dbh trees recorded in 40 (10x10m) subplots in each plot. 48000 trees, renumerated every 2 years. The third set of data is summarised. Thinning leads to 50-100% greater dbh increment of commercials, especially for

medium-sized stems. Dendrographs show accelerated diameter growth is progressively more pronounced.

Recruitment to 10cm+ over the four observation years is greatly enhanced. Logging is not as beneficial to the remaining commercials as thinning but much better than the controls. Similar BA is removed, but more heterogeneous. No clear effect on mortality is noted, but 2-10cm plants hardly changed by thinning. 16% of trees counted were of species likely to exceed 40 cm dbh.

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A similar summary to the previous. MAI for *Khaya anthotheca* =0.2 (10-25cm trees) to 0.61 (25-65 cm), increasing slightly where thinned. Mortality around 4. 1% over 4 yrs. *Triplochiton* MAI=0.6-0.79 (control); 1. 53-1. 48 (thinned); 0.87-1.13 (harvested blocks) with mortality for 4 year period 2. 8-1. 5/2. 5/1. 4. 5. 7/2. 8. Treatment by exploitation increases volume production, but not as much as thinning, because harvesting produces irregular gaps, with poorly distributed large holes. Most benefit due to more active growth of small and medium trees. Doubling of production due to treatment (extra 270m³/ha, of which about half is 'principal species').

- Makana, J.R., & S.C. Thomas. 2005. Effects of light gaps and litter removal on the seedling performance of six African timber species. *Biotropica* 37: 227-237

- Makana, J.R., & S.C. Thomas. 2006. Impacts of selective logging and agricultural clearing on forest structure, floristic composition and diversity, and timber tree regeneration in the Ituri Forest, Democratic Republic of Congo. *Biological Conservation* 15: 1375-1397

Secondary forests growing after the initial clearing of primary forests for shifting cultivation show surprisingly high levels of tree species diversity (Shannon Weiner) for small stem sizes. Overall diversity measures of trees <1 cm dbh were similar between secondary and primary forest stands. However, notwithstanding the similarity in overall tree diversity, the floristic compositions of the two forest types were very different. Secondary forest was particularly depauperate in common species characteristic of old-growth forests in the region, particularly *G. dewevrei* and *J. seretii*, and understory specialists such as *S. dewevrei*, *Drypetes* spp. *Rinorea* spp., and *Pancovia harmsiana*. In this respect, our results corroborate those of other studies on tropical forest succession.

- Malcom, J.R. & J.C. Ray. 2000. Influence of timber extraction routes on Central African small mammal communities, forest structure and tree diversity. *Conservation Biology* 14: 1623-1638

- Mallory, E. P. & N.V.L. Brokaw. 1996. Impacts of Birds silvicultural trials on birds and tree regeneration in the Chiquibul Forest Reserve. Consultant report no. 20, Forest Planning and Management Project, Ministry of Natural resources, Belmopan, Belize.

- Malvas, J. D. Jr. 1987. Development of forest sector planning, Malaysia. A report on the logging demonstration cum training coupe. UNDP/FAO Field Document MAL/85/004, no. 7.

- Manokaran, N. , & K. M. Kochumen. 1987. Recruitment, growth and mortality of tree species in a lowland dipterocarp forest in Peninsular Malaysia. *Journal of Tropical Ecology* 3: 315-330.

- Marcello, H. B. & E. T. Tagudar. 1956. Residual stands in selective high-lead logging. *Philippines Journal of Forestry* 123: 101-116.

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Sarawak. FAO FP:MAL/76/008, working paper 5. Kuching, Sarawak.

Results discussed from two studies carried out in mixed dipterocarp forest, Sarawak. In first, efficiency of current logging compared with one directed at minimising damage and reducing costs (directional felling, planning of skid trails). Directional felling in herring bone pattern, avoiding being perpendicular to skid trails. Main skid trails and landings were mapped (1:3000) with 'map showing concentrations of commercial trees'. Main trails as close as possible to denser stands of timber, ideally parallel to each other and perpendicular to main road, yet on a favourable grade. Where trees were evenly distributed, trails spacing=100-150m; however terrain sometimes overruled. Secondary skid trails were <50m long, located ad hoc., but carried as many logs to main trail as possible and 45° to 90° from main trail where possible. Damage was halved, efficiency increased by 36%, and costs were not increased. Damage measured over 2.4 ha. in each block 6 months after logging. c. 56/137 trees were damaged or broken in RIL, compared with c. 75/150 in the control. In second study, data analysed for three intensities (10, 32 and 55 m³/ha, equivalent to about 2-3 trees, 6-7 trees and >13 trees / ha). Area occupied by skid trail and landings was 'virtually the same' although 'there are some indications that the area occupied by temporary open space increases with intensity'. Open space increased 5%, 9.4%, and 30.4%. 'All open areas' (= bare soil + open space) increased 12.9%, 22. %, and 40.8%. In the traditional logging, 27.5% of the area was opened. The results are compatible with earlier results of Nicholson (1958).

Marn, H. M. & W. Jonkers. 1982. Logging damage in tropical high forest. Pp 27-38 in Srivastava, P.B.L., A.M. Ahmad, K. Awang, A. Muktar, R.A. Kader, F.C. Yom & L.S. See (eds.) *Tropical forests, source of energy through optimisation and diversification* Serdang; Universiti Pertanian Malaysia.

Operations preceded by comprehensive planning had fewer accidents; fewer timber trees left unfelled; and fewer logs lost after felling. Also operations cost 20-45% less than comparable operations with minimal planning.

Marcot, B. G., R. E Gullison, & J.R. Barborak. 2001. The effects of logging on tropical forest ungulates in Fimbel, R.A., A. Grajal & J.G Robinson (eds.) *The cutting edge: conserving wildlife in logged tropical forest*. Columbia University Press New York USA

Marsden, S.J. 1998. Changes in bird abundance following selective logging on Seram, Indonesia. *Conservation Biology* 12: 605-611

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Marsh, C. W., A.D. Johns & J.M. Ayres. 1987. Effects of habitat disturbance on rain forest primates. Pp. 83-107. in Marsh, W.C & R.A. Mittermeier (eds.) *Primate conservation in the tropical rain forest*, New York: Alan R. Liss Incorporated.

Marshall, A. G. & M. D. Swaine (eds.). 1992. *Tropical rain forest: disturbance and recovery*. The Royal Society. London. 457 pp.

Symposium volume, compiling papers on the Royal Societies S. E. Asian programme on forest recovery after disturbance. Several studies on different aspects; including animals, soils, plants. See Kennedy and Swaine (1992).

Martin, C. 1991. *The rainforests of West Africa; ecology, threats, conservation*. Basel: Birkhauser Verlag.

Martin-Smith, K.M. 1998. Effects of disturbance caused by selective timber extraction on fish communities in Sabah, Malaysia. *Environmental Biology of Fishes* 53: 155-167

Martinez-Ramos, M. , A. Soto Castro, T. H. Fleming & A. Estrada. 1993. Seed rain and advanced regeneration in a tropical rain forest. *Vegetatio* 107: 299-318.

Seed rain, seedling and sapling communities compared. 50% of species entering 5 (25x25m) plots during one year came from fruiting trees within sites. Lianes and emergent trees were bias amongst immigrants.

- Martinez-Ramos, M. & K. C. Samper. 1998. Tree life history patterns and forest dynamics: a conceptual model for the study of plant demography in patchy environments. *Journal of Sustainable Forestry* 6: 85-125
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Trees ≥ 10 cm DBH mapped before logging, Rondonia, Brazil. 98 trees/ha damaged (22. 9%), mostly during tree felling.
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Outline summary of the historical development and current practices

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Report on a desk study, including literature and FD inventory data, and a survey in 18 sawmills on the defects in 118 logs from 22 species. PCA was used to define groups with similar stem diameter distributions, growth, mortality and wood quality. The groups so defined have doubtful meaning, especially as the groups were assumed to have the same increments, based on only the few species (12 in totals, based on Alder's earlier PSP study) in each group for which good increment data were known. The stand tables erroneously under-estimate the numbers of trees <20cm dbh because the inventory data was not adjusted for the smaller sample sizes for smaller trees. Hence the attempt to define felling limit groups based on the optimum MAI of the group as a whole is highly suspect. . It is proposed that *Triplochiton* and *Pterygota* have their felling limits reduced due to high incidence of defects for logs supposedly from trees >90cm DBH. The impacts of changing limits were estimated but this is also apparently calculated in error, applying the Interim Yield formula to the average stocking of forest zones as a whole, rather than at the compartment scale
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Pasoh, Malaysia. Examination of density-dependent recruitment and mortality; variation of sapling density with distance from adult; General relationship between distributions of samplings and trees; sapling mortality and recruitment between two censuses. 444 spp. 56/444 lower density near adults (29% of emergent spp. are like this), 28 in other layers (11%); 53/444 decline with distance. No support for Janzen hypothesis that juveniles not found near parents, nor that adults more regularly dispersed than juveniles. Emergent and canopy species suffer higher mortality than others
- Ola-Adams, B. A. 1987. Effects of logging on the residual stands of a lowland forest at Omo Forest Reserve, Nigeria. The Malaysian Forester 50: 403-413.

Results based on a single 1ha plot located subjectively in a five month old logged comp. Logging was 'manual' with trees cross cut and loaded directly onto lorries which gained access along hand-cut access routes. Undisturbed forest there generally has a Basal Area of c. 29 m²/ha; disturbed forest has 14.3 m²/ha and secondary regrowth 11.7 m²/ha. The commonest trees in the plot were *Sterculia rhinopetala*, *Strombosia* and *Diospyros* spp. ('Moist evergreen'). Trees >10cm gbh (girth) were measured and tracks mapped. c. 9m³/ha were extracted in the forest as a whole. The 1 ha. plot had 3 stumps; with 670 trees left >10cm gbh. 17.74% had suffered some form of damage (crown= 9.4%; branch = 1.19%; stem=0.09%; remainder= unknown). 51 trees had been knocked over, mostly in the '+30cm girth class' mostly along tracks and around harvested trees. The maps showed damage left 8% of the ground bare (compared with 30% for mechanised logging).

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Discussion of tree architecture and temperament, including aberrations from Horn (1971) such as large-leaved nearly mono-layer, light-demanding trees like *Musanga* (see also Givnish, 1984); and pauci-layer 'pagoda-trees' of *Terminalia* and *Alstonia*. Suppressed juveniles of canopy trees have tall narrow crowns. Gymnosperms and palms are also discussed.

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the woody flora and vegetation of the Catapu logging concession, Cheringoma District, Mozambique *Biothalia* 37: 57-73

Checklist of 238 woody species (trees, shrubs, lianes). Includes the Sena names for 191 species, 77 of which are recorded for the first time.

Pancel, L. 1993. *Tropical Forestry handbook* (Vols. 1 & 2). Springer-Verlag.

Broad ranging, extensive overview. Makes available various literature otherwise not so easily found. E.g. Chapters 20-21 by Sessions and Heinrich on forest roads and harvesting (pp 1269-1424) reviews many aspects e. g. of ideal spacing of various levels of road- or skidding, including five main skidding patterns (parallel, radial, starburst, random and herring-bone). Ghana's preferred method could add another -'dendritic', a hybrid of herringbone and random. Equations are given for optimising road, spur road and skidder distances.

Panfil, S. N. & R. E. Gullison. 1998. Short term impacts of experimental timber harvest intensity on forest structure and composition in the Chimanes Forest, Bolivia. *Forest Ecology and Management* 102: 235-243.

Harvest manipulated from 1 to 6 trees/ha. Damage increased in a quadratic function of harvesting intensity, with less damage per tree felled at higher intensities due to reuse of skid trails and overlapping of felled tree gaps. The median distance of residual forest to the nearest gap decreased from 25m for 1 tree/ha. to 8.3m at 6 trees/ha. Although mortality increased in proportion to total basal area extracted (quadratic function), residual basal area damage was low because damage was concentrated on small trees. For commercial species, seedlings and saplings of only *Hura crepitans* had a higher significantly increased relative growth rate related to harvest intensity.

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Overview of forestry in Upper Guinean rain forests. There were some colonial differences. Ghana and Liberia favoured natural regeneration while the French favoured artificial regeneration. In some cases, important silvicultural records were not available. Forest managers often are unaware of the basis on which past decisions have been made. Tropical Shelterwood and similar silviculture proved too complicated and uneconomical due to poor gains in increment. See Parren and de Graaf (95) for updated version.

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

33 square 1-ha research plots were established over an area of 500 ha. In 5 control plots, no logging and no silvicultural treatments were applied. The remaining 28 plots were all logged and in 16 of them pre-exploitation climber cutting was applied. Felling was carried out 9 months later. Harvest levels were set at one tree per ha over 60 cm DRH, resembling normal exploitation practice in the region (but a very low harvest level in general). Lianas were very abundant here compared with other plots globally. Some 70% of monitored lianas had died 22 months after cutting. Felling gapsizes averaged 550m² per felled tree, and tree mortality averaged 12 trees per felled tree, with 20 other trees damaged. These figures were not significantly reduced by pre-felling climber cutting. Suggest that only very big lianas are cut on trees to be logged, and only those lianas that are significantly weaker once dead.

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Logging operations leave denuded vegetation and topsoil vulnerable to erosion. Pioneer species create special conditions. In lightly disturbed areas and on skid trails and landings pioneer species do not increase greatly. To increase the amount of pioneer trees on skids and landings, ground must be first being treated for the compaction that has occurred during logging operations. Seed source is less of a limitation than suitable microsite availability.
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Budongo forest, Uganda. 5x 2km transects in each of 8 compartments with 7 metre circular plots at 100m intervals, all trees >10cm dbh. Total of 5640 trees visited twice a month from Jan 1993-Jan 1994. Assessed fruits etc on a 0-4 scale (1=1-25% crown with plant part, 4=75 %+). Timber and primate food trees. *Khaya anthotheca*, *Entandrophragma spp*, *Holoptelea*, *Maesopsis*, *Chrysophyllum albidum*, *C. perpulchrum*, *Antiaris*, *Albizia spp* (6), *Strychnos mitis*, *Funtumia elastica*, *Ficus sur*, *Cynometra alexandrii*, *Celtis durandii*, *C. mildbraedii*, *C. zenkeri*, *Aningeria altissima*. Fruit scores estimated as DBH x mean phenology score. From inventory data, estimates of total fruit production in logged and unlogged. % of trees fruiting: 25% maximum at 25-35cm (*Khaya*, *Maesopsis*, *Holoptelea*, *Chrysophyllum*, *Antiaris*, *Albizia*) or larger (*Entandrophragma*= 70cm); fruit production rises to a peak at 100cm (*Entandrophragma*), or 70-90 (*Khaya*) or 50-70 (others). % of trees fruiting reaches 100% at lower sizes (*Funtumia*, *Aningeria*, *Celtis* =40 cm). For small trees logged and unlogged similar production, but for *Khaya* & *Entandrophragma* fruit production less in exploited forest (because fewer large trees). *Khaya* shows highest correlation with seedling density for trees > 50 cm dbh.

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Study of how vines affect tree regeneration, and how treatment affects vines. The effects on % trees carrying vines are compared of several post-felling silvicultural treatments (tree thinning and vine-cutting). Form and growth rates of trees are studied 3-5 yrs after treatment. Treatments were liberation thinning (girdle trees competing with potential timber) and several variants of the generally more severe Malayan Uniform System (trees surviving logging are poison girdled). In all treatments all woody vines had been cut.

Pioneer trees in all plots carried vines significantly less frequently than 'preferred' and 'acceptable' timber species. Pioneer trees were more common in treated plots, so this obscured the relationship between treatment and vine abundance. In some MUS plots, vines were more common than in untreated plots in spite of removal of vines from the former five years earlier. The worst vine tangles were in abandoned log yards and along old roads, where pioneers also abound, so the dissociation is more remarkable. Hypotheses to account for the effect include: fast 'escape' growth of the trees; Greater 'swaying' or more flexible pioneers (discounted); greater shedding of large pioneer leaves (discounted); ants, as most the pioneers were Macaranga. The pioneers may be acting as a protective 'cover crop' for timber trees.

Vines had a slight negative effect on tree growth rates; the effect was expected to rise with time. Some trees were completely smothered, but most had a few small vines. However infestation was only recorded as presence/ absence, so potential effects on growth were probably underestimated. Nearly 50% of vine stems were of sprouts from vines which fell during logging. Post felling vine cutting was not very effective, and pre-felling vine-cutting is recommended.

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>10cm dbh. 12% >10 cm dbh lost crowns; also 11% uprooted; 3% suffered bark damage. Hence 2% harvested, but 26% killed or damaged. 16% BA was extracted, but an extra 28% BA damaged. Canopy cover c. halved from 80%. 8% of total logged areas were roads, of which primary roads were half (18% of road length).

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- Van Daalen, J. C. 1993. The value of crown position and form as growth indicators in mixed evergreen forest. *South African Forestry Journal* 165: 29-35.

Diameter increment over 13 yrs correlated well with crown position and form scores for Cape forest tree species (e. g. *Olea*, *Podocarpus*, *Psydrax*). Growth of sub canopy species (e. g. *Cassine eucleiformis*, *Diospyros whyteana*, *Ocotea bullata*) not related to crown position (except *Ochna arborea* which grew best in the shade), but was related to form for some species. Exposed crowns had better forms, if the species was one showing increment-crown correlation.

- Van Gardingen, P. R. 1998. Impacts of logging on the regeneration of lowland dipterocarp forest in Indonesia. *Commonwealth Forestry Review* 77: 71-82.

Emphasis on effects on soil and seedling demography. 9 ha. PSP, with complete inventory \geq 10cm DBH in central one. 10 tree/ha. removed. Sites in primary forest, manually logged, conventionally logged and RIL. Soil and canopy estimated on 5m grids. 38% of canopy removed

and 52% of ground was covered by conventional logging debris or skid trails. Dipterocarp seedlings found along the margin of skid trails and in the undisturbed soil parts of felling gaps. One tree opened av. 390m² of canopy (270-540). NPLD seedlings taller in logged than undisturbed. Decline in mycorrhizae after logging. RIL, although less than conventional, still reduces mycorrhizae. No more than 2 adjacent trees (<650m²) should be felled, to prevent pioneer dominance.

Van Gardingen, P.R., M.J. McLeish, P.D. Phillips, D. Fadilah, G. Tyrie & I. Yasman. 2003. Financial and ecological analysis of managements options for logged over Dipterocarp forest in Indonesian Borneo. *Forest Ecology and Management*. 183: 1-29

Van Gernerden, B.S., G.N. Shu, & H. Olff. 2003. Recovery of conservation values in Central African rain forest after logging and shifting cultivation. *Biodiversity and Conservation*. 12: 1553-1570

Van Nieuwstadt, M.G.L, D. Sheil & K. Kartawinata. 2001. The ecological consequences of logging in burned forests of East Kalimantan, Indonesia. *Conservation Biology* 15: 1183-1186

Van Rompaey, R. S. A. R. 1993. Forest gradients in West Africa. PhD Thesis. Wageningen Agricultural University, The Netherlands.

Concentrating on forests in Liberia and Ivory Coast, and using mainly inventory data for larger trees, geographical and local changes in forest composition are described and discussed.

Van Vliet, N. & R. Nasi, 2008. Mammal distribution in a Central African logging concession area. *Biodiversity and Conservation* 17: 1241-1249

Van der Burgt, X. M. 1997. Explosive seed dispersal of the rainforest tree *Tetraberlinia moreliana* (Leguminsae-Caesalpinioideae) in Gabon. *Journal of Tropical Ecology* 13: 145-151.

Explosive dispersal from four *T. moreliana* trees to 60, 52, 51 and 41m. The nearest pods were 39, 32, 30 and 24m above ground. The tree produced 15000-20000 seeds; 1.5-2% in total was found more than 50m from the main tree. The ballistics of dispersal is discussed.

Van der Hout, P. 1996. Effects of logging with different intensities of low impact harvesting. Interim report. Tropenbos-Guyana.

Aims are to: Develop a LIH (low impact harvesting) system in Guyana, based around the CELOS harvesting system; study its effects on the residual stand at different intensities, compared to traditional logging; to develop post harvest silviculture; study economics of the above; and to develop growth and yield models. This report describes work 1992-1994 on the first two aims, describing vegetation, logging pattern and damage. It was too early, with only two measurements, to discuss tree growth and mortality.

The forest in the ('Pibiri') study area is rich in Greenheart ($\frac{1}{3}$ of basal area >40cm dbh) and locally dominated by other timber species as well, probably to a degree that makes the conclusions on some aspects of limited global applicability in tropical rain forest.

There are five components to LIH incorporated here. Enumeration and mapping of harvestable trees; climber cutting before harvest; selection of trees including an element of silviculture/ecology; directional felling to make a herring bone pattern; winching of logs from stump to trail. Four treatments were used. 1. 'Light' LIH (4 trees/ha.); 2. Moderate LIH (8/ha, or c. 25m³/ha) as recommended under the CELOS system; 3. High intensity LIH (16/ha), being about the max. possible, with stems down to 40cm dbh; 4. As 2. , but succeeded by silvicultural treatment; 5. No intervention. Each treatment had a total of three replicates (i.e. 3 randomised blocks). Some samples were also laid in traditionally (uncontrolled) logging areas nearby.

Assessment of damage/efficiency, comparing controlled and uncontrolled logging, was along 3 strips (20x500 m). arranged in recording units (20x20m) within which all trees >20cm dbh (all species) were measured. Trees <5cm dbh were measured in a 5m wide strip. For other assessments, 140x140 blocks of 20 x 20m quadrats were assessed for all trees, all species, >20cm dbh. In the central hectare of quadrats, smaller trees were measured in nested subquadrats within each quadrat (5-20 cm dbh in 10x10m; within which 2-5cm dbh in 5x5m; within which 1.5m high to 2cm dbh trees in 2x2m).

Enumeration of trees ≥ 20 cm dbh was made before logging; all trees were enumerated after logging. BA felled was said not to be proportional to no. trees (N) felled because smaller trees had to be used at higher intensities. However, the relationship $BA = 0.71 + 0.2N$ had a high R^2 (0.91). Other relations established were:

1. Area felling gaps (%) = $-1.99 + 8.72 \times BA$
2. Area skid trails (%) = $3.89 + 1.69 \times BA$
3. Remaining area (%) = $97.12 - 9.52 \times BA$

Equation 2 has a low coefficient of determination ($R^2 = 0.3$).

The relation: The area of felling gaps (%) = $1.04 + 1.82 \times N$ has an R^2 of 0.79, which is said to be not quite as good a predictor as BA (whose r^2 is not mentioned) as it takes no account of tree size. 1+2+3 is not quite 100% because of skid trails in felling gaps were 'double booked'.

With a $BA < 0.8$ (m²/Ha), skid trail area exceeds felling gaps, and 90% of the forest is unaffected. Above this, the opposite applies. At 4m²/ha 60% is unaffected. Topography is a better indicator of skid trails than BA felled, although a distinction is made between planned skid trails (3-7%) which did not correlate with BA, and unplanned ones (2% in light harvest) which were slightly more closely correlated with BA. Results are compared with those of Jonkers (87), Schmitt (89) and Hendrison (96), who all used different assessment techniques. Generally smaller % gaps were found for equivalent exploitation at lower intensities; and higher % gaps at higher levels. This is partly because natural gaps were included, and trees were generally smaller. However, LIH methods did reduce skidding damage. Gap areas (measured by 'projection of gap coordinates') occurred mainly above the stumps (due to smallish trees, regular canopy and directional felling).

The felling techniques used are extensively discussed. 89% of trees could be felled in the desired quadrant, an improvement on Hendrison (1990) because of the enhanced techniques. Winching short distances was often convenient. 20m winch distances were not implemented 49% of time due to impracticalities.

The frequency distribution of gap sizes is discussed. 7.5% of the gaps (8 trees/ha LIH) or 14% (16 trees/ha) were 'unacceptably' large (> 500 m²). Mean gap size for single tree = 176 m²; for 2 tree gaps = 399 m² ($n=12$); for 3 trees = 617 m² ($n=3$), suggesting 2 trees/gap is maximal if 500 m² is unacceptable. Gap area increased with intensity, surprising because no savings evident due to shared gaps.

Equations are also given for tree damage. One conclusion is that % completely undamaged trees after felling and skidding strongly correlates with, but is slightly higher than % area totally unaffected. Most damage to trees by skidding is classed as minor. % destroyed stems is in proportion to intensity, but % injury does not increase so. Accidental logging damage affected 15% of trees > 20 cm dbh after a light harvest or 33% after a fourfold increase of BA extracted. In total 18%, 29% and 42% of commercial trees > 20 cm dbh were affected somehow after logging 4, 8 or 16 trees per hectare.

Van der Meer, P.J., F. Bongers, L. Chatrou & B. Riera. 1994. Defining canopy gaps in a tropical rain forest: effects of gap size and turnover time. *Acta Oecologia* 15: 701-714

French Guiana: 18 gaps. Size affected by definition, but strongly correlated. Turnover time on forest floor 4-8 times lower than turnover time in the forest canopy.

Van der Meer, P.J. 1995. Canopy dynamics of a tropical rain forest in French Guiana. Thesis Landbouwwuniversiteit Wageningen. 149 pp.

Van der Weert, R. 1974. Influence of mechanical forest clearing on soil conditions and the resulting effect on root growth. *Tropical Agriculture (Trinidad)* 51: 325-331.

Bulk density increases, especially nr. surface. Larger pores disappear. Citrus tree roots cannot penetrate so well.

Vanclay, J. K., 1989. A growth model for North Queensland rainforests. *Forest Ecology and Management* 27: 245-271

Cohort model for 100 commercial species in 20 groups based on growth, habitat, volume relationships and commercial aspects. Increment and mortality patterns modelled for parent

material, DBH and stand basal area, for each group. Recruitment composition predicted by site quality, stand basal area, and basal area of each group.

Vanclay, J. K. , 1990. Effects of selection logging on rainforest productivity. *Australian Forestry* 53: 200-214

Data from 212 PSPs provided no evidence of decline in rainforest productivity after three cycles of selective logging, as determined by difference between observed diameter increments and those predicted by theoretical functions. Trees with negative increments were excluded. No data from plots with two harvests – most had been logged once and had measurements which did not span logging activity. Gross biomass production not considered as 'reduction of production could be due to reduced occupancy of the site'. No evidence for long term decline found 'any decline does not exceed 6% per harvest'.

Vanclay, J. K, 1991a. , Aggregating tree species to develop diameter increment equations for tropical rainforests. *Forest Ecology and management*: 42: 134-168

Vanclay, J. K. 1991b. Mortality functions for North Queensland rain forests. *Journal of Tropical Forest Science* 4: 15-36

Vanclay, J. K. 1991c. Data requirements for developing growth models for tropical moist forests. *Commonwealth Forestry Review*. 248-271.

Vanclay, J. K. 1993a. Review of the forest inventory and management project. Annex 4 in Kemp *et al.* 1993. unpublished.

Vanclay wrote 'an analysis of the yield formula' whilst reviewing the project. In 5 years 5. 1% of trees will die. 40 yr survival is $1 - (0.949^8) = 34\%$. 16. 2% of surviving trees will advance one class in 5 years; 40 year probability of tree moving one or more class is $(1 - 0.243^8) = 0.757$. $0.757 \times 0.658 = c. 50\%$. Yield formula is $= 0.5Y + 0.2X$; trees left $= 0.5Y - 0.2X$. ($Y \geq dbh$; $X < dbh$). Assume no damage > felling limit, but 20% below it, leaving $0.8X$. In 40 yrs, 66% of trees >dbh limit will survive; 50% below will survive. At next harvest there will be $0.33Y + 0.27X$ above the felling limit. The harvests will be equal if $Y = 0.33Y + 0.27X$ ($X = 2.5Y$). If de Liocourt's $Q = 2.5$, harvests will be equal. Q can be calculated as $(1 - 0.5S) / (0.8G - 0.2S)$, where S is 40 yr probability of survival and growing a class; 0.8 is prob. of surviving a harvest undamaged, and 0.5 and 0.2 from the yield formula. Serious omission of trees which move two size classes in 40 years. This Annex also includes a useful, brief summary of the status of the PSPs in Ghana.

Vanclay, J.K. 1993b. Environmentally sound timber harvesting: logging guidelines, conservation reserves and rehabilitation. Pp. 185-192 in Leigh H & M. Lohmann (eds.) *Restoration of tropical forest ecosystems*. Dordrecht: Kluwer Academic Publishers.

Vanclay, J. K. 1994. *Modelling forest growth and Yield*. CAB International, Wallingford UK. 312pp. Textbook on how to model forests, especially from a commercial perspective.

Vanclay, J.K. 1995. Sustainable silvicultural systems: lessons from Queensland, Australia. Pp. 169-181 in O. Sandbukt (ed.) *Management of tropical forests: towards an integrated perspective*, Oslo: Centre for Development and the Environment, University of Oslo.

Vanclay, J. K. 1996a. Lessons from the Queensland rainforests: Steps towards sustainability. *Journal of Sustainable Forestry* 3: 1-27.

Vanclay, J. K. 1996b. Assessing the sustainability of timber harvests from natural forests: limitations of indices based on sustainable harvests. *Journal of Sustainable Forestry* 3: 47-58

Four models demonstrate that maintaining a sustainable original harvest and sustainable disturbance harvest (defined as ratios successive harvests) are poor criteria for long term sustainable use, which should also consider the condition and vitality of the residual stand.

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neighbours. Gross asymmetries of crown are the rule, and most gap edge trees are asymmetrical. Non gap trees tend to be asymmetrical away from nearest neighbours. Gap regeneration is therefore retarded by re-falls of lopsided trees. In 5yrs of data of 50ha plot, sites within larger gaps were significantly more likely to be re-disturbed by secondary tree-falls than elsewhere. Hence tree-fall gaps may be more persistent than thought. 127 trees with >20 cm dbh in a 0.8 ha subplot were mapped, showing crown shape along each of eight compass points. Crown asymmetry: 'a line was drawn through the bole perpendicular to a line between the centre of crown area and the base of the bole. The areas on either side of this line were calculated with an area meter, and absolute asymmetry calculated as the greater of the two areas divided by the total area.

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