Chapter 4

The effects of logging on forest vegetation.

Introduction.

Selective logging typically results in the destruction of about 50% of trees present before logging (e.g., Ewel & Conde, 1976; Johns 1983, 1989; Whitmore, 1984), but this varies greatly with the stocking density of commercially viable timber species, which is dependent upon the botanical composition of the forest, prevailing economic conditions and the methods of exploitation.

The rain forests of Central Africa cover about 1.7 million km^2 (FAO, 1981). These forests are diverse, but few detailed botanical studies have been undertaken in the region (Reitsma, 1988). Commercial timber extraction is underway in much of this area, but no detailed studies have been undertaken to investigate how logging is affecting forest structure and composition, although exploitation is generally thought to be at low intensity (Doumenge, 1950; Dowsett-Lemaire, 1941; Gartlan, 1589; Wilks, 1990).

This chapter describes in detail damage caused by logging to vegetation in Site 3.

Methods.

The area in which Site 3 was located was logged between November 1989 and April 1990. Only *2.5* km of the transect (see Chapter 2) was logged, from 1900-4400m (the remaining area contained steep terrain where logging was not financially viable, but may be exploited at some time in the future), so this chapter deals with the logged section only (i.e., samples of 1.25 and 12.5 ha of trees >10 and *>70* cm dbh respectively). After logging activities had finished all labelled individuals in the >10 cm and *>70* cm dbh botanical samples (see Chapter *2)* were checked for signs of damage, and canopy cover measurements were repeated. Where trees had been destroyed the cause was recorded (e.g., cut for extraction, road construction). In addition, the proportion of the transect covered by major roads (lorry roads), secondary haul roads (along which cut lugs were hauled to loading areas located along major roads), skidder trails (leading from the cut tree to secondary haul roads) and fallen canopies was recorded.

The Kolmogorov-Smirnov one-sample non-parametric statistical test (Siegel & Castellan, 1988) was used to test for differences between observed and expected frequency of trees lost to logging.

Results.

Sample of trees >70 cm dbh

In the 12.5 ha sample of trees >70 cm dbh there were 202 trees of 51 species and at least 19 taxonomic families. Table 4.1 gives the "top 15" species in terms of basal area, and Table 4.2 lists the "top 10" families. There was little change from data presented in Chapter 2 for the whole length of the transect (see Tables 2.5 & 2.6), except the prominence of *Cylicodiscus gabonensis* due to the presence of two large individuals in this part of the transect, and the replacement of Papilionaceae as tenth most important family by Meliaceae. Table 4.3 shows botanical data for the transect and gives changes that occurred during logging.

During logging 33 trees died and one died later, as a result of damage sustained, making a total of 34 (16.8%) and a total loss in basal area of 150.7 m^2 (20.1%). A total of 23 trees were cut, 25 of which were extracted, giving an extraction rate of two trees per hectare (Plate 4.1). *Aucoumea Klaineana* accounted for 64% of trees felled. Three species, *Baillonella toxisperma, Celtis tessmannii* and *Entandophragma utile* were no longer present after logging but diversity, as measured by Shannon's and Simpson's indices rose from 3.14 to 3.23 and 0.083 to 0.062 respectively. Table 4.4 summarises the changes due to logging.

There was no difference between the number of individuals killed in each girth class and the expected values, but there was a significant difference between the observed and expected numbers of each species killed ($N=51$, $D=0.27$, $P<0.01$) due to selection for *Aucoumea klaineana*

Plate 4.1.

The stump of an *Aucoumea klaineana* tree cut on the transect - note the numbered aluminium tag, which facilitated reliable identification of trees after logging.

A ***Baillonella*** **toxisperma** (Moabi) tree that has been dragged out to a road. Fruit of this species are an important food for many animal species, including humans

Table 4.1: "Top 15" species >70 cm dbh (in terms of basal area).

Species	**Family**	**Basal Area**[1]	**No. Stems**
Aucoumea klaineana	BURSERACEAE	43.8	49
Dacryodes buettneri	BURSERACEAE	13.6	22
Klainedoxa gabonensis	IRVINGIACEAE	9.9	12
Scyphocephalium ochocoa	MYRISTICACEAE	7.5	12
Desbordesia glaucescens	IRVINGIACEAE	5.9	8
Pycnanthus angolensis	MYRISTICACEAE	5.5	6
Maranthes glabra	CHRYSOBALANACEAE	3.8	6
Pentaclethra macrophylla	MIMOSACEAE	3.7	6
Strombosiopsis sp. ?nov	OLACACEAE	3.6	5
Cylicodiscus gabonensis	MIMOSACEAE	3.6	2
Erismadelphus exsul	VOCHYSIACEAE	3.4	6
Klainedoxa trilesii	IRVINGIACEAE	3.1	5
Fillaeopsis discophora	MIMOSACEAE	2.9	5
Staudtia gabonensis	MYRISTICACEAE	2.7	5
Coula edulis	OLACACEAE	2.6	5

[1]- m^2 in 12.5 ha sample.

Table 4.2: "Top 10" families >70 cm dbh (in terms of basal area).

Family	**Basal Area**[1]
BURSERACEAE	60.2
IRVINGIACEAE	19.4
MYRISTICACEAE	16.2
CAESALPINIACEAE	13.3
MIMOSACEAE	11.3
OLACACEAE	7.2
CHRYSOBALANACEAE	3.9
VOCHYSIACEAE	3.4
SAPOTACEAE	2.5
MELIACEAE	2.4

[1]- m^2 in 12.5 ha sample.

Table 4.3: Botanical data for plants >70 cm dbh.

Family/ Scientific name	Before Logging		After logging	
	Basal Area (cm^2)	No	Basal Area (cm^2)	No
ANACARDIACEAE				
Pseudospondias microcarpa	5027	1	5027	1
ANNONACEAE				
Hexalobus crispiflorus	9503	1	9503	1
BOMBACACEAE				
Rhodognaphalon sp. LJTW 188	3959	1	3959	1
BURSERACEAE				
Aucoumea klaineana	438612	49	251320	31
Canarium schweinfurthii	20453	2	20453	2
Dacryodes buettneri	136497	22	102175	18
Dacryodes igaganga	6362	1	6362	1
CAESALPINIACEAE				
Amphimas ferrugineus	7854	1	7854	1
Daniellia klainei	4418	1	4418	1
Dialium pachyphyllum	19242	2	19242	2
Dialium sp. ?nov	10936	1	10936	1
Gilbertiodendron sp. LJTW 336	4418	1	4418	1
Guibourtia tessmannii	17357	2	7854	1
Hylodendron gabunense	7088	1	7088	1
Hymenostegia ?klainei	8659	1	8659	1
Paraberlinia bifoliolata	20336	3	20336	3
Sindoropsis le-testui	3959	1	3959	1
Swartzia fistuloides	24440	3	3959	1
LJTW 596	4418	1	4418	1
CHRYSOBALANACEAE				
Maranthes glabra	38847	6	38847	6
EUPHORBIACEAE				
Crotonogyne argentea	16332	2	16332	2
Plagiostyles africana	3848	1	3848	1

Table 4.3: Botanical data for plants >70 cm dbh / continued.

Family/ Scientific name	Before Logging		After logging	
	Basal Area (cm^2)	No	Basal Area (cm^2)	No
IRVINGIACEAE				
Desbordesia glaucescens	59448	8	59448	8
Irvingia robur	7698	1	7698	1
Klainedoxa gabonensis	96602	12	96602	12
MELIACEAE				
* *Entandophragma utile*	16513	1	0	0
Guarea sp. LJTW 108	3848	1	3848	1
Lovoa trichilioides Harms	4072	1	4072	1
MIMOSACEAE				
Cylicodiscus gabonensis	36041	2	36041	2
Fillaeopsis discophora	29099	5	22737	4
Parkia bicolor	10547	2	10547	2
Pentaclethra macrophylla	37445	6	37445	6
MYRISTICACEAE				
Coelocaryon preussi	6362	1	6362	1
Pycnanthus angolensis	54531	6	54531	6
Scyphocephalium ochocoa	74995	12	69969	11
Staudtia gabonensis	26543	5	17814	3
MYRTACEAE				
Syzygium sp. LJTW 31	4536	1	4536	1
OCHNACEAE				
Lophira alata	9161	1	9161	1
OLACACEAE				
Coula edulis	26206	5	26206	5
Ongokea gore	9161	1	9161	1
Strombosiopsis sp. ?nov	36391	5	36391	5
PAPILIONACEAE				
Pterocarpus soyauxii	13077	2	8659	1

Table 4.3: Botanical data for plants >70 cm dbh / continued.

Family/ Scientific name	Before Logging		After logging	
	Basal Area (cm^2)	No	Basal Area (cm^2)	No
RHIZOPHORACEAE				
Poga oleosa	21794	2	21794	2
SAPOTACEAE				
* *Baillonella toxisperma*	8332	1	0	0
Gambeya africana	13077	2	13077	2
Gambeya subnuda	4072	1	4072	1
SCYTOPETALACEAE				
Scytopetalum klaineanum	6362	1	6362	1
ULMACEAE				
* *Celtis tessmannii*	4657	1	0	0
VOCHYSIACEAE				
Erismadelphus exsul	33781	6	33781	6
FAMILY UNKNOWN				
LJTW 456	9503	1	9503	1
TOTALS	**1507167**	**202**	**120153**	**169**

* - species lost after logging

Table 4.4: Summary of logging damage to trees >70 cm dbh.

Species[1]	Family[2]	Number Lost					Basal Area Lost (cm²)					No. Damaged			Basal Area (cm²)		
		CE	CL	R	T	All	CE	CL	R	T	All	B	Ca	All	B	Ca	All
A. klaineana	BUR.	17	1			18	174018	13273			187291						
B. toxisperma	SAPO.	1				1	8332				8332						
C. tessmannii	ULM.			1		1	4657				4657						
D. buettneri	BURS.	4				4	24819				24819		1*	1		9503	9503
E. utile	MELI.	1				1	16513				16513						
F. discaphora	MIMO.			1		1			6362		6362						
G. tessmanni	CAES.	1				1	9503				9503						
M. glabra	CHRY.											1		1	8659		8659
P. soyauxii	PAP.				1	1				4418	4418						
S. acachoa	MYRI.				1	1				5027	5027						
S. gabonensis	MYRI.		1	1		2		4657	4072		8729						
S. fistuloides	CAES.	1	1			2	8012	12469			20481						
TOTALS		25	3	3	2	33	245854	30399	10434	9445	296132	1	1	2	8659	9503	18162

CE - cut and extracted; CL - cut and left; R - road construction; T - treefall; B - bark damage; Ca- canopy loss (<90%).

[1]- For unabbreviated species name see Table 4.3; [2] - For unabbreviated family name see Table 4.3; * - subsequently died.

Sample of plants >10cm dbh.

The 1.25 ha sample of trees and lianes >10 cm dbh contained 507 individuals of 116 species from at least 32 taxonomic families. Vegetation composition was similar to that described for the entire length of the transect (Chapter 2), but the relative abundance of some species and families were different. Table 4.5 lists the 'Top 15' species in terms of basal area and frequency. Table 4.6 lists the 'Top 10' families in terms of basal area (see Tables 2.1 & 2.2, Chapter 2, for comparison). Table 4.7 shows botanical data for the transect and gives details of the changes that occurred during logging.

Table 4.5: "Top 15" species for plants >10cm dbh (in terms of basal area and number of individuals).

Species	**Family**	**Basal Area**[1]	**Rank**	**No. Stems**	**Rank**
Aucoumea klaineana	BURSERACEAE	4.8	1	12	9
Pentaclethra macrophylla	MIMOSACEAE	3.1	2	11	12
Scyphocephalium ochocoa	MYRISTICACEAE	2.5	3	7	19
Coula edulis	OLACACEAE	2.4	4	12	9
Santiria trimera	BURSERACEAE	2.3	5	44	2
Staudtia gabonensis	MYRISTICACEAE	1.8	6	10	13
Desbordesia glaucescens	IRVINGIACEAE	1.8	7	13	8
Strombosiopsis tetrandra	OLACACEAE	1.7	8	23	3
Strombosiopsis sp. ?nov	OLACACEAE	1.3	9	3	38
Erismadelphus exsul	VOCHYSIACEAE	1.3	10	7	19
Dialium sp. ?nov	CAESALPINIACEAE	1.1	11	2	41
Parkia bicolor	MIMOSACEAE	1.0	12	3	38
Conceveiba africana	EUPHORBIACEAE	1.0	13	45	1
Klainedoxa gabonensis	IRVINGIACEAE	1.0	14	5	26
Swartzia fistuloides	CAESALPINIACEAE	0.8	15	1	54
Centroplacus glaucinas	PANDACEAE	0.4	29	20	4
Xylopia quintasii	ANNONACEAE	0.4	31	18	5
Coryanthe mayumbensis	RUBIACEAE	0.4	37	15	6
Diospyros suaveolens	EBENACEAE	0.8	16	14	7
Thomandersia hensii	ACANTHACEAE	0.2	55	12	9
Enantia chlorantha	ANNONACEAE	0.4	36	9	14
Diospyros dendo	EBENACEAE	0.1	57	9	14

[1]- m^2 for the 1.25ha sample.

Table 4.6: "Top 10" families for plants >10cm dbh (in terms of basal area).

Family	Basal Area[1]
BURSERACEAE	8.4
OLACACEAE	6.0
MYRISTICACEAE	5.1
MIMOSACEAE	5.0
IRVINGIACEAE	4.0
CAESALPINIACEAE	3.6
EUPHORBIACEAE	2.2
ANNONACEAE	1.5
VOCHYSIACEAE	1.3
EBENACEAE	1.2

1- m^2 for the 12.5 ha sample.

During logging 54 individuals (10.7%)of 36 species wet-e destroyed, including two trees that were cut and extracted, and a further 16 individuals (3.2%)suffered bark damage or canopy loss but were still alive one year after logging. Over half of the mortalities (N=29) were due to falling trees, whilst skidder and extractor roads accounted for 16 and 7 trees respectively. Basal area was reduced by 5.2 m^2 (11.2%). Two species, ***Swartzia*** fistuloides and *Fillaeopsis* ***discophora*** were no longer present after logging, although species diversity, measured by Shannon's (Pielou, 1966) **and** Simpson's {Simpson, 1949, see Williams, 1964) indices, increased from 4.09 to 4.14 and *0.028* to 0.025 respectively. Table 4.8 summarises the effects of logging activity.

Figure 4.1 shows the distribution of girth classes befare and after logging. There was no significant difference between observed and expected values of trees killed in each girth class, calculated from the relative proportion of individuals in each class, nor between the number of individuals of each species killed and the expected values calculated from the relative abundance of each species. However, there seemed to be a bias in proportional loss towards small and large individuals, since small trees were pushed aside during construction of skidder and extraction trails (medium- and large-sized trees were avoided) whilst some large trees were felled.

Table 4.7: Botanical data for plants >10 cm dbh.

Family/ Scientific name	Before Logging		After logging	
	Basal Area (cm²)	No	Basal Area (cm²)	No
ACANTHACEAE				
Thomandersia hensii	1622	12	1475	11
ANACARDIACEAE				
Sorindeia sp. LJTW 555	471	1	471	1
Trichoscypha abut	633	1	633	1
Trichoscypha acuminata	3745	7	3505	6
Trichoscypha patens	275	3	275	3
ANNONACEAE				
Enantia chlorantha	3608	9	2531	7
Polyalthia suaveolens var. *gabonica*	3285	5	3190	4
Polyalthia suaveolens var. *suaveolens*	522	2	522	2
Uvaria sp. LJTW 553	196	1	196	1
Xylopia hypolampra	3433	2	3433	2
Xylopia quintasii	4035	18	3160	14
Xylopia staudtii	272	2	272	2
APHROSTYLACACEAE				
Aphrostylax sp. LJTW 363	196	1	196	1
BURSERACEAE				
Aucoumea klaineana	47824	12	30504	11
Dacryodes buettneri	4897	2	4897	2
Dacryodes igaganga	1626	3	1626	3
Dacryodes klaineana	4793	8	4322	7
Dacryodes normandii	1152	1	1152	1
Santiria trimera	23225	44	20076	37
CAESALPINIACEAE				
Berlinia auriculata	119	1	119	1

Table 4.7: Botanical data for plants >10 cm dbh / continued.

Family/ Scientific name	Before Logging		After logging	
	Basal Area (cm²)	No	Basal Area (cm²)	No
CAESALPINIACEAE / continued				
Dialium eurysephalum	1947	2	1947	2
Dialium soyauxii	619	3	619	3
Dialium sp. ?nov	11031	2	11031	2
Dialium sp. LJTW 115	919	1	919	1
Gilbertiodendron sp. LJTW 336	4418	1	4418	1
Hymenostegia sp. LJTW 104	2942	1	2942	1
Paraberlinia bifoliolata	5476	1	5476	1
Sindoropsis le-testui	97	1	97	1
* * *Swartzia fistuloides*	8123	1	0	0
CHRYSOBALANACEAE				
Maranthes gabunensis	5030	5	5030	5
Maranthes glabra	5933	2	5933	2
CONNARACEAE				
*LJTW 539	113	1	113	1
EBENACEAE				
Diospyros cinnabarina	293	1	293	1
Diospyros dendo	1306	9	1129	8
Diospyros piscatoria	150	1	150	1
Diospyros polystemon	1508	4	1508	4
Diospyros suaveolens	7744	14	5939	11
Diospyros viridicans	99	1	99	1
Diospyros zenkeri	691	3	691	3
Diospyros sp. LJTW 120	519	1	519	1
EUPHORBIACEAE				
Antidesma laciniatum	260	1	260	1
Conceveiba africana	9991	45	7802	34
Crotonogyne argentea	2384	1	2384	1

Table 4.7: Botanical data for plants >10 cm dbh / continued.

Family/ Scientific name	Before Logging		After logging	
	Basal Area (cm^2)	No	Basal Area (cm^2)	No
EUPHORBIACEAE / continued				
Klaineanthus gaboniae	1066	4	1066	4
Mapraunea membrenacea	373	1	373	1
Plagiostyles africana	6614	6	6614	6
LJTW 548	994	2	994	2
LJTW 551	366	1	366	1
FLACOURTIACEAE				
Casearia barteri	266	1	266	1
Scottellia sp. LJTW 453	152	1	152	1
GUTTIFERAE				
Garcinia afzelii	814	3	644	2
Garcinia smeathmannii	449	3	449	3
Garcinia sp. LJTW 153	305	1	305	1
Symphonia globulifera	2446	3	2446	3
IRVINGIACEAE				
Desbordesia glaucescens	17700	13	17613	12
Irvingia gabonensis	3802	6	2992	4
Irvingia grandifolia	481	2	481	2
Irvingia robur	7698	1	7698	1
Klainedoxa gabonensis	9900	5	9900	5
LAURACEAE				
Beilschmiedia corbisieri	1709	3	1709	3
Beilschmiedia sp. LJTW 439	3242	4	3242	4
LOGANIACEAE				
Anthocleista sp. LJTW 404	1963	1	1963	1
* *Strychnos* sp. LJTW 531	137	1	137	1
MELASTOMATACEAE				
Memecylon diluviorum	646	3	646	3

Table 4.7: Botanical data for plants >10 cm dbh / continued.

Family/ Scientific name	Before Logging		After logging	
	Basal Area (cm²)	No	Basal Area (cm²)	No
MELIACEAE				
Carapa procera	337	1	337	1
Guarea sp. LJTW 108	897	2	897	2
MIMOSACEAE				
* *Fillaeopsis discophora*	6333	1	0	0
Parkia bicolor	10029	3	8853	2
Pentaclethra eetveldeana	2414	2	1871	1
Pentaclethra macrophylla	30843	11	30843	11
MORACEAE				
Treculia obovoidea	620	8	377	7
MYRISTICACEAE				
Coelocaryon preussi	5385	1	5385	1
Pycnanthus angolensis	1735	1	1735	1
Scyphocephalium ochocoa	25394	7	25394	7
Staudtia kamerunensis	356	1	356	1
Staudtia gabonensis	18338	10	16654	9
MYRTACEAE				
Syzygium sp. LJTW 487	2236	3	2236	3
OCHNACEAE				
Ouratea calophylla	104	1	104	1
OLACACEAE				
Coula edulis	23596	12	23596	12
Heisteria parvifolia	4514	4	4514	4
Strombosia sp. LJTW 128	468	3	321	2
Strombosia sp. LJTW 279	642	1	642	1
Strombosiopsis tetrandra	17336	23	16746	22
Strombosiopsis sp. ?nov	13074	3	13074	3
LJTW 0582	139	1	139	1

Table 4.7: Botanical data for plants >10 cm dbh / continued.

Family/ Scientific name	Before Logging		After logging	
	Basal Area (cm^2)	No	Basal Area (cm^2)	No
PANDACEAE				
Centroplacus glaucinas	4447	20	4212	19
PAPILIONACEAE				
*LJTW 593	999	4	866	3
PASSIFLORACEAE				
Barteria fistulosa	686	5	495	4
RUBIACEAE				
Coryanthe mayumbensis	3566	15	3163	12
Massularia acuminata	79	1	79	1
Nauclea vanderguchtii	2091	1	2091	1
Pausinystalia johimbe	371	2	371	2
Porterandia cladantha	380	1	380	1
LJTW 550	1996	4	1996	4
RUTACEAE				
Fagara tessmannii	973	1	973	1
SAPINDACEAE				
Eriocoelum macrocarpum	430	1	430	1
Pancovia floribunda	92	1	92	1
LJTW 544	87	1	87	1
SAPOTACEAE				
Gambeya subnuda	4015	1	4015	1
LJTW 425	850	1	850	1
SCYTOPETALACEAE				
Rhaptopetalum sindarense	356	1	356	1
Scytopetalum klaineanum	488	1	488	1
Scytopetalum sp. LJTW 227	3349	7	3172	6

Table 4.7: Botanical data for plants >10 cm dbh / continued.

Family/ Scientific name	Before Logging		After logging	
	Basal Area (cm²)	No	Basal Area (cm²)	No
STERCULIACEAE				
Cola lizae	3620	6	3620	6
Scaphopetalum blackii	204	1	204	1
LJTW 334	767	2	767	2
TILIACEAE				
Duboscia macrocarpa	5654	4	5654	4
Grewia coriacea	3333	8	2760	7
VOCHYSIACEAE				
Erismadelphus exsul	12516	7	9782	6
FAMILY UNKNOWN				
LJTW 360	1134	1	1134	1
LJTW 546	230	1	230	1
LJTW 549	111	1	111	1
LJTW 552	5087	4	5087	4
LJTW 554	224	1	224	1
LJTW 589	224	1	224	1
*LJTW 592	87	1	87	1
TOTALS	**461881**	**507**	**409984**	**45**

* = species no longer present after logging

Table 4.8: Summary of logging damage to trees >10 cm dbh.

Species[1]	Family[2]	Number Lost					Basal Area Lost (cm^{-2})					No. Damaged			Basal Area		
		C	R	D	T	All	C	R	D	T	All	B	Ca	All	B	Ca	All
A. laciniatum	EUPH.											1		1	260		260
A. klaineana	BURS.	1				1	17320				17320						
B. fistulosa	PASS.			1		1			191		191						
C. glaucinas	EUPH.				1	1				235	235						
C. lizae	STER.											1		1	1932		1932
C. africana	EUPH.			5	6	11			743	1446	2189	2		2	298		298
C. mayumbensis	RUB.				3	3				403	403						
C. edulis	OLAC.												1	1		1116	1116
D. klaineana	BURS.				1	1				471	471						
D. glaucescens	IRV.				1	1				87	87						
D. dendo	EBEN.				1	1				177	177	1		1	135		135
D. suaveolens	EBEN.			1	2	3			99	1706	1805						
D. zenkeri	EBEN.												1	1		330	330
E. chlorantha	ANN.		1	1		2		625	452		1077						
E. exsul	VOCH.				1	1				2734	2734						
F. discophora	MIM.		1			1		6333			6333						
G. afzelii	GUTT.				1	1				170	170						
G. coriacea	TIL.				1	1				573	573						
I. gabonensis	IRV.				2	2				810	810						
M. diluviarum	MEL.												1	1		99	99
P. bicolor	MIM.				1	1				1176	1176						
P. eetveldeana	MIM.		1			1		543			543						
P. suaveolens	ANN.		1			1		95			95						
S. trimera	BURS.		1	2	4	7		111	836	2202	3149						

Table 4.8: Summary of logging damage to trees >10 cm dbh / continued.

Species[1]	Family[2]	Number Lost					Basal Area Lost (cm^2)					No. Damaged			Basal Area (cm^2)		
		C	R	D	T	All	C	R	D	T	All	B	Ca	All	B	Ca	All
Scytopetalum sp.	SCYT.			1		1			177		177	1		1	412		412
S. gabonensis	MYR.		1			1		1684			1684						
S. ?zenkeri	OLAC.			1		1			147		147						
S. tetrandra	OLAC.				1	1				590	590						
S. fistuloides	CAES.	1				1	8123				8123						
S. globulifera	GUTT.											1		1	817		817
T. hensii	ACAN.		1			1		147			147						
T. obovoidea	MOR.			1		1			243		243						
T. acuminata	ANAC.			1		1			240		240		1	1		1802	1802
X. quintasii	ANN.			2	2	4			564	311	875						
	SAPI.											1		1	87		87
	*PAP.				1	1				133	133						
TOTALS		2	7	16	29	54	25443	9538	3692	13224	51897	8	4	12	3941	3347	7288

C - cut & extracted; R - road construction; D - debardage/skidder trail; T - treefall; B - bark damage; Ca - canopy loss (<90%).
[1]- For unabbreviated species name see Table 4.7; [1]- For unabbreviated family name see Table 4.7; * - Liane.

Figure 4.1: Girth classes for plants >10 cm dbh.

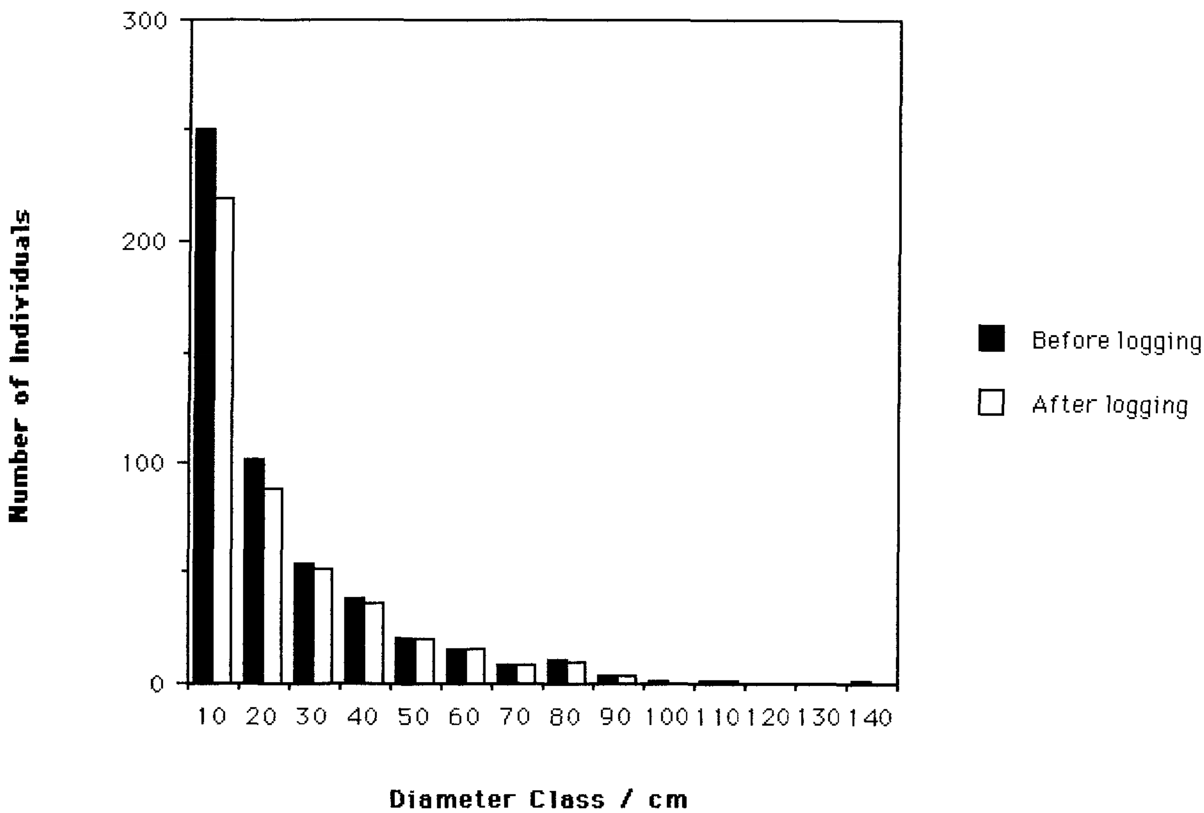

Table 4.9 gives the canopy cover before and after logging. The overall decrease in canopy cover was 10.2% although 49.2 % of the transect was considered to have undergone some changes in canopy structure. Actual loss varied with height, and was highest for the upper canopy (>20m) as was the loss in terms of % of original cover. Absolute loss in the middle canopy (10-20m) was higher than for the lower canopy, but loss in terms of proportion of original cover was lower, perhaps because trees which contributed to the lower canopy were destroyed by skidder and secondary extraction roads, but many trees contributing to the middle canopy were large enough to be avoided rather than pushed over. On the ground 34m (1.4%) of the transect became a major road, 125m *(5.0%)* became secondary extraction roads (thus a total of 159m or 6.4% of the ground was bare soil), 124m *(5%)* became skidder trails and 422m (16.9%) was covered by fallen crowns.

Table 4.9: Canopy cover before and after logging.

Canopy Cover (%)	<10m	10-20m	>20m	Overall
Before Logging	58.2	75.8	71.6	93.4
After Logging	48.2	63.4	58.2	83.2

Some comparative information about logging damage was obtained in the other sites that had been exploited. Site 2 had been logged in early 1986, and roads, skidder and some secondary extraction roads, and areas where canopy had been damaged, were still visible. The first 3500m were logged systematically, and the remaining 1500m, which was in steep terrain, was lightly exploited. For the first 3500m two roads that crossed the transect made up 1.3% of the site, skidder and secondary extraction roads together accounted for *7.5%* (but some of the latter were probably no longer visible), and 51.2% of the canopy had suffered some disturbance. It was not possible to estimate reliably how much of the site had been affected by fallen crowns. In Site 4, logged 10-15 years before this study, roads, skidders and some secondary extraction roads were visible, and all but the final 750m had been affected by logging. Four lorry roads crossed the transect, accounting for 1.8% of the logged area, and the detectable skidder and secondary extraction trails made up 7.2%. Roads were smaller than in areas logged more recently, and were located closer together, presumably because machinery to haul logs out long distances to a road was not available. The transect in Site 1 had been exploited throughout 20-25 years previously, and was crossed by six lorry roads which accounted for *2.0%* of the site. Skidder trails could not be identified with certainty.

Tree species characteristic of secondary vegetation had become established in areas opened up by logging, but were not common in any of the sites, being mostly restricted to roadsides. In Site 2, the only species that had grown fast enough to be recorded >10 cm dbh was Macaranga *monandra* which formed stands

Plate 4.2.

An aerial view of a logging road - note the belt of secondary vegetation on either side.

A large clearing where foresters collect latterite to surface roads - in such areas conditions are reminiscent of those in the savanna, where similar erosion can occur.

in areas of intense disturbance (e.g., in strips 10-20m wide along roads, which were kept clear of vegetation cover to allow direct sunshine to dry out the road surface, where bare soil was colonised after the road was abandoned - see Plate 4.2). In areas that had been abandoned for five years or more (but which did not form a part of this study) other tree species >10 cm dbh were found with Macaranga (e.g., Maprounea membrenancea, Anthocleista spp., Pauridiantha spp., Xylopia spp.). In Site 4 Nauclea diderrichii, Macaranga spp., Porterandia cladantha, Maprounea membrenacea , Discoglypremna coloneura, Psorospermum spp. and Xylopia spp. (principally X. aethiopica) all occurred in sections of the transect that had been damaged by logging, especially along roads. Disturbed areas in Site 1 were dominated by Porterandia clandantha, Maprounea membrenacea, Psorespermum spp. and Xylopia spp., and in places Nauclea diderrichii, Lophira alata and Barteria fistulosa were also common.

Discussion.

Of 20km of transects in this study which were in logged forest, about 15-16km had been exploited, suggesting that on average 20-25% of the forest remained-untouched, due to steep terrain where it was not (presently) economically viable to extract timber. Average damage levels should be adjusted downwards accordingly. In areas of Site 3 affected, logging was of low intensity, with an average of 2 trees ha-1 cut (c. $10m^3$) and extracted. Incidental damage and the cutting of trees that were not extracted resulted in an average loss of 2.7 trees >70 cm dbh ha^{-1}. Three species >70 cm dbh were eliminated during logging: all were present as a single individual; two were valuable timber species which were cut, and one was pushed over during road construction. Extraction rates average 13.5 m^3 ha^{-1} in Africa and in the Neotropics are about 3.4 m^3 ha^{-1} (Yeom, 1984) Typical extraction rates in peninsular Malaysia are 52 m^3 ha^{-1}, but reach 90 m^3 ha^{-1} in Sarawak and 120 m^3 ha-1 in Sabah (Johns, 1989).

One tree, Aucoumea klaineana, accounted for 64% of trees cut, and together with another species of Burseraceae, Dacryodes buettneri accounted for 79%. Only four other species were cut. This is representative of Gabonese logging, which has traditionally concentrated on Aucoumea klaineana and has only recently begun to diversify. Today 55 species are cut, but only 14 accounted for

5,000 m^3 or more of a total of 833,103 m^3 exported from the main port, Owendo, in 1987. *Aucoumea klaineana* made up 72% of this volume (Wilks, 1990). Large tree diversity as measured by Shannon's and Simpson's indices (which take into account species numbers and evenness), increased after logging due to the selective removal of Aucoumea klaineana, the commonest tree in the sample, which made the distribution of species numbers more even.

Data from the >10 cm dbh sample showed that logging in Lopé caused low levels of damage compared to timber extraction in other tropical countries. Elsewhere in Gabon Wilks (1990) estimated that canopy loss (indicative of overall damage) averaged 10% but noted that in regions close to the coast, where logging is more intensive and has been repeated several times, the forests are much changed. Damage levels in some other parts of Central Africa tend to be similarly low (M. Fay- CAR. and D. Wilkie - Congo, personal communications), whilst in Bia South, Ghana, Hawthorne (in press) recorded an extraction rate of 1.6 trees ha-1, which resulted in 20-30% canopy loss, leaving about 3% of the ground covered by roads and loading bays.

Typical figures for incidental loss in other parts of the World are around 50% (e.g., Ewel & Conde, 1976; Johns 1983; Johns, 1989; Whitmore, 1984). As long ago as 1960, Redhead (1960) recorded incidental damage in Nigeria at 44%. Since then, forest exploitation in Nigeria has intensified greatly in response to increased local demand for timber (e.g., Kio, 1983). In Kibale forest, Uganda, Skorupa (1988) recorded reductions of 25% and 50% in basal area of lightly logged and heavily logged forest respectively, together with comparable reductions in basal area, stocking density and species diversity.

In South-East Asia up to 72 trees may be felled ha-1 (Whitmore, 1984), although extraction levels of 20-25 trees ha-1 are more representative (Johns, 1989), and removal of 70% or more of the original forest is not unusual. Johns (1988) undertook a before-and-after study in West Malaysia and recorded 3.3% of trees being extracted. This resulted in 4.8% loss due to road building, 3.6% during log loading and 39.2% during felling and skidding. A further 6% of trees suffered damage and 43.1% remained untouched after logging. It seems that only in seasonally flooded forests in South America, where cut logs are floated out of the forest when waters rise, are damage levels comparable to or lower than for Gabon, and perhaps some of the other central African countries (cf., Johns, 1986).

Ewel and Conde (1976) found that major, skidder and extractor roads can cover up to a third of a site where heavy machinery is used during logging. Hamzah (1978) gave a figure of 6% for main roads and loading areas in East Kalimantan, whilst up to 10.8% of logged forest was covered by skidroads and secondary access roads in peninsular Malaysia (Whitmore 1984). Kartawinata (1978) found that 30-40 % of logged dipterocarp forest can be left bare after logging. These figures again show that equivalent damage levels in Lopé were low compared to other areas.

Skorupa (1988) recorded 20 and 40% decreases in canopy cover in lightly and heavily logged forest respectively in Kibale, Uganda, compared to a control, recorded about 15 years after logging. In Site 4 of this study, logged 10-15 years ago, (Chapter 21 canopy cover below 10m was 61.6%, slightly higher than in Cite 3 before logging. Levels at 10-20m and >20m were slightly decreased (72.0% and 63.6% respectively), although overall cover was similar (93.9%). This suggests that logging gaps in Lopé had been filled by growth of existing or newly established trees and shows that logging in Kibale must have caused a great deal more damage to the canopy.

Johns (1990) produced a theoretical minimum damage curve for mechanised logging operations of different extraction levels by mathematical simulation. The minimum damage level predicted for an extraction level of two trees ha-1 was 10% of the original trees lost. Damage levels due to logging in Lope were close to this figure, which was surprising, as no attempt was made to minimise damage (e.g., by directional felling or careful siting of roads and skidder trails). Marn (1982, cited in Johns, 1989) showed that directional felling and careful siting of skid roads could reduce levels of incidental damage by 50% in Sarawak (and reduce costs by 25%) and Buenaflor & Tiki (1989) reported similar findings in Papua New Guinea. If such an improvement were possible in Lope, average damage levels could be reduced to about 5% each logging cycle. Natural tree mortality is between 1-2 % in Gabonese forests (Hladik, 1982; Reitsma, 1988; Williamson & White, unpublished data).

Loggers in Gabon are constrained by high operation costs and the absence of a significant local market for timber (Chapter 1). Economic considerations, rather than good management, minimise the damage done to the forest. In fact, they pay no attention to the environmental effects of their extraction operations, nor do they make any attempt to limit levels of incidental damage caused during logging. It is therefore surprising that damage levels in Lopé corresponded to the optimal figure proposed by Johns (1990). If similar improvements to those documented by Marn (1982) and Buenaflor and Tiki (1989) were possible in Gabon, average damage levels could be reduced to about 5% or less each logging cycle. Natural tree mortality is between 1-2% in Gabonese forests (Hladik, 1982; Reitsma, 1988; Williamson & White, unpublished data). With such a low level of damage during each logging cycle, Gabon could argue that its logging industry is likely to be "sustainable" and would have a strong claim to be declared a "sustainable logging country", providing it could be shown that commercial hunting, which is often associated with logging in Gabon, is not eliminating vital mammalian and avian seed dispersers, as is the case elsewhere in Central Africa (e.g., Dowsett-Lemaire, 1991; D. Wilkie, personal communication).

At it's eighth Council Session held in Bali in 1990, the International Tropical Timber Organisation (ITTO) targeted the year 2000 as a deadline for making the tropical timber trade sustainable. Gabon would seem to be in a good position to conform with this policy, but. steps need to be taken immediately to initiate a National management strategy if Gabon is to prove that it's logging industry is indeed sustainable. Further research on the effects of logging on vegetation, and especially post-logging stocking densities of commercial species, are required, as well as an analysis of the effects of intensive hunting, that occurs alongside some logging operations, on important mammalian and avian seed dispersers. Legislation relating to selective logging is not yet complete (Wilks,1990), so a review should be initiated with a view to clarifying policy for concession allocation, rotation periods and harvesting intensity. Milks (1990) made detailed management recommendations.

Some oil companies operating in rain forests in Gabon have adopted sensible environmental guidelines to minimise the damaging effects of oil exploration (J. Bickerton, personal communication) and a few routinely employ independent experts to monitor their activities. Such an initiative on the part of logging companies is long overdue, and if it is forthcoming the future of Gabon's forests and timber industry should be assured.