Chapter 2

CENTRAL AFRICAN TROPICAL RAIN FOREST STRUCTURE AND COMPOSITION: UNTANGLING THE EFFECTS OF RAINFALL, ALTITUDE, SOIL, SEA AND HUMAN DISTURBANCE

Gildas Peguy Tchouto Mbatchou [1]

With W.F. de Boer [2], de Wilde J.J.F.E. [3], and van der Maesen L.J.G. [3]

[1] Limbe Botanic Garden, BP 437, Limbe, Cameroon; e-mail: peguy2000@yahoo.com
[2] Tropical Nature Conservation and Vertebrate Ecology Group, Wageningen University, Bornsesteeg 69, 6708 PD, Wageningen, the Netherlands; e-mail: fred.deboer@wur.nl
[3] Biosystematics Group, Wageningen University, Generaal Foulkesweg 37, 6703 BL, Wageningen, the Netherlands; e-mail: jos.vandermaesen@wur.nl

2.1. INTRODUCTION

The Campo-Ma'an area is recognised as an important site within the Guineo-Congolian Centre of Endemism (White, 1983; Gartlan 1989; Davis *et al.*, 1994). Most of the area is covered by lowland evergreen tropical rain forests that extend from Southeast Nigeria to Gabon and the Mayombe area in Congo. Campo-Ma'an is situated at the middle of this belt and the main vegetation type is part of the domain of the dense humid evergreen forest that belongs to the Atlantic Biafran district and the Atlantic littoral district (Letouzey, 1968 & 1985). The Campo area is dominated by lowland evergreen forests rich in Caesalpinioideae, with *Calpocalyx heitzii* and *Sacoglottis gabonensis,* a vegetation type that is only known from this area. The drier Ma'an area in the rain shadow, to the east of Campo, is dominated by a mixed evergreen and semi-deciduous forest. The Campo-Ma'an area also supports a great diversity of habitats from coastal vegetation on sandy shorelines at sea level to the submontane forest at about 1100 m.

Man affects the forest ecosystem with his economic activities, through logging, agro-industrial and shifting agriculture, and hunting. Clearance of the natural forest to provide land for agro-industrial companies is the biggest and most destructive threat to the lowland forests. More than 7.5% of the area has been cleared to establish large plantations of oil palm and rubber. Another use of the forest that leads to impoverishment is logging. Logging concessions represent about 31.4% of the area and a considerable portion of forest has already been logged at least twice during the past 30 years. Although the Campo-Ma'an area has been disturbed by logging and agriculture, the area is still mostly forested. In order to save these remaining forests, a sound botanical assessment should be carried out to provide the baseline data essential for the description and mapping of the existing forest types. The first attempt to classify the vegetation types of Cameroon was made by Letouzey (1968 & 1985) who adopted the phytogeographic approach to map the vegetation of Cameroon at a scale of 1:500,000. These maps were based on aerial photos taken during the 1960's with ground checking and descriptive observations done during field trips in various parts of Cameroon. However, he did not cover the country evenly and the Campo-Ma'an area was apparently poorly investigated, although some major forest types were identified and described.

The importance of environmental variables, past and present human disturbance as well as Pleistocene history in determining plant species richness along ecological gradients in the tropical rain forest has been studied by several authors. It is largely argued that the number of tree species in the tropical rain forest tends to increase with rainfall, seasonality (Gentry, 1988; van Rompaey, 1993; Clinebell *et al.*, 1995; Condit *et al.*, 1996; Swaine, 1996; Givnish, 1999) and soil fertility (Hart *et al.*, 1989; Duivenvoorden & Lips, 1995; Swaine, 1996), and decreases with altitude (Hedberg, 1951; Lebrun, 1960; Gentry, 1988; Tchouto, 1995; Lieberman *et al.*, 1996; Givnish, 1999). Some of these authors argued that rainfall and altitude are likely to lead to stronger distributional patterns than those of soil nutrients. In the present study, we will classify, describe and map the various vegetation types in the Campo-Ma'an area and analyse its forest structure and composition. In order to study the effect of rainfall, altitude, soils, proximity to the sea and human disturbance that influence or delimit these vegetation types, we will test the following predictions:

- Increasing distance from the sea is linked with decreasing annual rainfall gradually changing the forest from a coastal type at sea level to a mixed evergreen and semi-deciduous forest in the interior;
- A change in forest structure and species composition with increasing altitude: the species composition will change progressively with increasing altitude coupled to a decrease in species richness;
- Well-drained nutrient-rich soils support high number of species while poorly drained soils with low nutrient concentrations are associated with species-poor forests;
- Human disturbance in the forest increases the frequency of secondary forest species and lowers species diversity.

2.2. METHODS

Botanical and ecological assessments

A preliminary reconnaissance field trip was carried out in 2000 to identify representative homogeneous vegetation types for sampling. These representative vegetation types were selected on the basis of physical and human factors such as climate (especially rainfall), altitude, slope, soils, the distance from the sea and degree of forest use. Sampling effort was spread throughout the study area by using small plots of 0.1 ha at irregular intervals along a line transect from a random starting point. In mountainous areas, plots were located at an altitudinal interval of 200 m along the slope, on both side of the slope. A total of 147 plots covering 14.7 ha were established, and in each 0.1 ha plot, all trees, shrubs, herbs and lianas with DBH $\geq$ 1 cm were measured, recorded and identified. For unknown species, a voucher specimen was collected. Furthermore, 136 subplots of 5 m x 5 m each were established in some plots (Annex 1) with more emphasis on the herbaceous and ground layer vascular plants for vegetation description. Herbarium specimens were also collected within plot, vegetation types, and specific habitats. In order to assess the influence of soil characteristics on the vegetation, random soil samples were collected in the center of 72 plots located in representative vegetation types as described in Chapter 1(Annex 2).

Data analysis

All information recorded was entered into TREMA (Tree Management) software for data management. TREMA contains both species level and plots data, and can integrate the two directly in analysis. Detrended Correspondence Analysis (DCA or DECORANA) and its relative Canonical Correspondence Analysis (CANOCO or CCA) was used to detect patterns in the vegetation data (Hill, 1979a & 1979b; Jongman *et al.*, 1987; ter Braak, 1986a & 1987b; Kent & Coker, 1992). The distribution of species and samples in the ordination space given by DCA was used to identify species and site clusters, and to corroborate groupings derived from the two-way indicator species analysis (TWINSPAN). CCA ordination methods help to examine relationships between species distribution and the distribution of associated environmental factors. For both methods, species were first arranged in a raw data matrix. Within the data matrix, species were scored for either presence/absence. Environmental factors such as altitude, rainfall (mean annual rainfall in mm year^{-1} recorded between 1937-1977), proximity to the sea (distance from the sea in km) and soil characteristics such as soil types, composition, pH (H_20), electricity conductivity in mS.cm^{-1}, and texture at 0-10 cm depth were used to explain patterns in the vegetation data set. Furthermore, all species with doubtful identification were removed from the analyses and only species that occurred in more than one plot were included in the ordination analysis.

The GIS software ARCVIEW version 3.2 was used to produce the vegetation maps. The phytosociological parameters (basal area, relative density, relative dominance, relative frequency and important value index) as well as the diameter class distribution were used to describe the forest structure and composition. In addition, the physical forest structure such as the height and cover of the various strata (emergent, canopy, midstorey, understorey and ground layer) recorded in each plot were used for vegetation description. Standard physiognomic indices were calculated following Whittaker (1975), Kent & Coker (1992) and Magurran (1988). The SPSS package version 10.0 for Windows was used for statistical analyses and the Pearson's correlation test was used to correlate the species richness with the various environmental variables.

2. 3. RESULTS

Multivariate analyses

TWINSPAN analysis
A cluster analysis of 147 plots with TWINSPAN led to 12 convincing divisions. As shown in Figure 2.1, the data set was initially divided into two groups. All plots located in the mangrove forest, characterised by a distinct floristic composition, edaphic conditions and physiognomy were placed on one side. The remaining plots were divided into 11 groups on the basis of the abundance of Caesalpinioideae, *Calpocalyx heitzii* or *Sacoglottis gabonensis*. Plots from small patches of *Aucoumea klaineana* (Okoumé) communities were put either with the lowland evergreen forest rich in Caesalpinioideae (Okoumé 1) or with the mixed evergreen and semi-deciduous forest (Okoumé 2) group depending on their geographical location. Eleven main forest types were distinguished and can be summarised as follows (Table 2.1, Figures 2.1 & 2.2).

1. Lowland evergreen forest rich in Caesalpinioideae (Caesalp)
It occurs mainly on hills and gentle slopes where the vegetation is still intact and consists of evergreen trees forming a fairly continuous canopy with emergent trees poking through it. This forest type is characterised by its dominance of Caesalpinioideae (more than 70 tree species) with many species that occur gregariously. Many emergent and canopy trees have large buttresses (up to 5-6 m tall) and large diameters (up to 2-3 m above the buttress). Trees are more or less arranged in three strata. Large emergent and upper canopy tree species (about 35-50 m tall) such as *Anthonotha fragrans, Aphanocalyx margininervatus, Brachystegia cynometroides, Desbordesia glaucescens, Erythrophleum ivorensis, Lovoa trichilioides* and *Pterocarpus soyauxii* occur as scattered individuals in the upper storey. The intermediate storey, about 20-35 m high, is dominated by trees species such as *Calpocalyx dinklagei, Dialium pachyphyllum, Dichostemma glaucescens,*

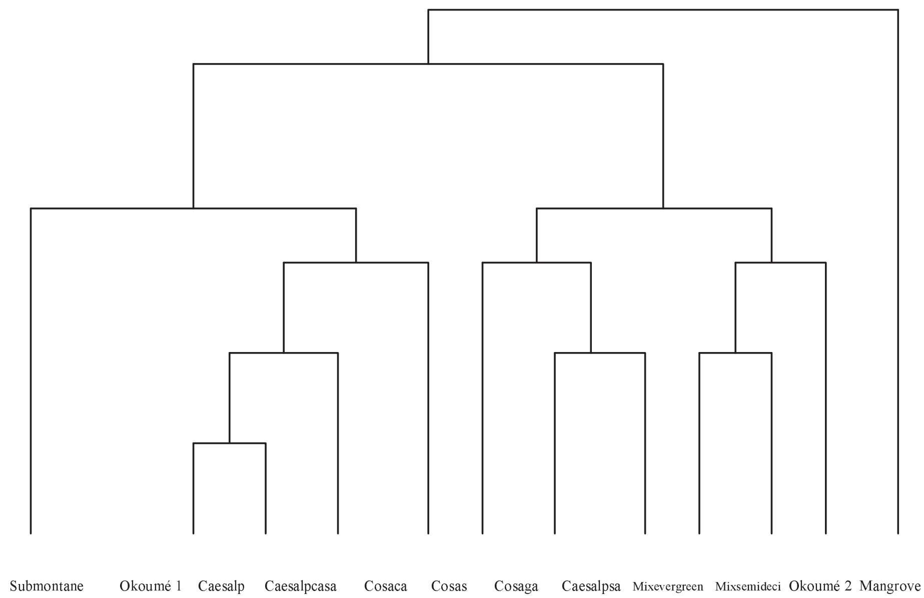

Figure 2.1 TWINSPAN dendrogram of 958 species of vascular plants with DBH ≥ 1 cm recorded in 147 plots of 0.1 ha each in the Campo-Ma'an rain forest. TWINSPAN groups: Submontane: Submontane forest on hill tops; Okoumé 1&2: Okoumé forest; Caesalp: Lowland evergreen forest rich in Caesalpinioideae; Caesalpcasa: Lowland evergreen forest rich in Caesalpinioideae with *Calpocalyx heitzii* and *Sacoglottis gabonensis;* Cosaca: Coastal forest with *Sacoglottis gabonensis* and *Calpocalyx heitzii*; Cosas: Coastal forest on sandy shorelines; Cosaga: Coastal forest with *Sacoglottis gabonensis*; Caesalpsa: Lowland evergreen forest rich in Caesalpinioideae and *Sacoglottis gabonensis*; Mixevergreen: Mixed evergreen and semi-deciduous forest with elements of evergreen forest predominant; Mixsemideci: Mixed evergreen and semi-deciduous forest with semi-deciduous elements predominant; Mangrove: Mangrove forest.

Diogoa zenkeri, Greenwayodendron suaveolens, Santiria trimera, Strombosia grandifolia, S. pustulata and *Tetraberlinia bifoliolata.* The understorey is about 10 m high, discontinuous, and consists of immature trees of the upper strata and other small trees and shrubs. They include species such as *Diospyros preussii*, *Jollydora duparquetiana, Lasianthera africana, Massularia acuminata, Podococcus barteri, Asystasia macrophylla,* and *Cola, Crotonogyne, Diospyros, Drypetes, Psychotria, Rinorea* and *Scaphopetalum* species. Beneath the tree and shrub layers is the ground layer that is dominated by seedlings of the above layers and many herbaceous species such as *Costus englerianus, Marantochloa monophylla, Microcalamus barbinoides, Palisota barteri, Puella schumanniana* and *Stylochaeton zenkeri*. Common large woody liana species are *Agelaea pentagyna, Neuropeltis incompta* and many species of the genera *Combretum, Dichapetalum, Millettia, Salacia* and *Strychnos*.

2. Lowland evergreen forest rich in Caesalpinioideae, with Calpocalyx heitzii and Sacoglottis gabonensis (Caesalpcasa).

This forest type is unique in Cameroon and only occurs in the Campo area between 50-200 m above sea level (Letouzey, 1985; Kaji, 1990; Thomas & Thomas, 1993; Sunderland *et al.*, 1997). Although it is similar in structure and composition to the lowland evergreen forest rich in Caesalpinioideae, it is characterised by its abundance in Caesalpinioideae, *Calpocalyx heitzii* and *Sacoglottis gabonensis.* These species often occur in association with *Alstonia boonei, Calpocalyx dinklagei, Desbordesia glaucescens, Greenwayodendron suaveolens, Irvingia gabonensis, Meiocarpidium lepidotum, Piptadeniastrum africanum, Ochthocosmus calothyrsus*, and *Terminalia superba*.

Table 2.1 Vegetation types derived from multivariate analyses with map code, altitudinal range, annual rainfall and degree of disturbance.

Map code	Vegetation types	Altitudinal range (m)	Rainfall (mm/year)	Degree of disturbance*
Caesalp	Lowland evergreen forest rich in Caesalpinioideae	100-700	1750-2000	a, b, c & d
Caesalpcasa	Lowland evergreen forest rich in Caesalpinioideae with *Calpocalyx heitzii* and *Sacoglottis gabonensis*	50-200	2200-2800	b, c & d
Caesalpsa	Lowland evergreen forest rich in Caesalpinioideae with *Sacoglottis gabonensis* and other coastal indicators	50-350	2600-2950	b, c & d
Cosaga	Coastal forest rich in *Sacoglottis gabonensis*	0-100	2800-2950	b, c & d
Cosaca	Coastal forest rich in *Sacoglottis gabonensis* and *Calpocalyx heitzii*	0-100	2700-2800	b, c & d
Mixevergreen	Mixed evergreen and semi-deciduous forest, with elements of evergreen forest predominant	100-700	1750-2000	a, b, c & d
Mixsemideci	Mixed evergreen and semi-deciduous forest, with semi-deciduous elements predominant	100-700	1670-1750	b, c & d
Submontane	Submontane forest on hilltops	800-1100	1800-2000	a
Swamp	Seasonally flooded and swamp forests	0-500	1670-2950	a & b
Mangrove	Mangrove rich in *Rhizophora racemosa* and *Pandanus* species	0-30	2800-2950	a & b
Cosas	Coastal vegetation on sandy shorelines	0-20	2800-2950	d & e
Hevecam	Industrial rubber plantation	0-100	2600	e
Socapalm	Industrial oil palm plantation	0-100	2950	e

* Where, a: virtually undisturbed except for hunting and the collection of non timber forest products; b: small patches (<25%) of human disturbance; c: significant areas (25-50%) of forest degradation; d: large areas (>50%) of forest degradation; and e: no natural vegetation left. Cosas forms a narrow strip along the coast that cannot be depicted on the vegetation map because of its scale.

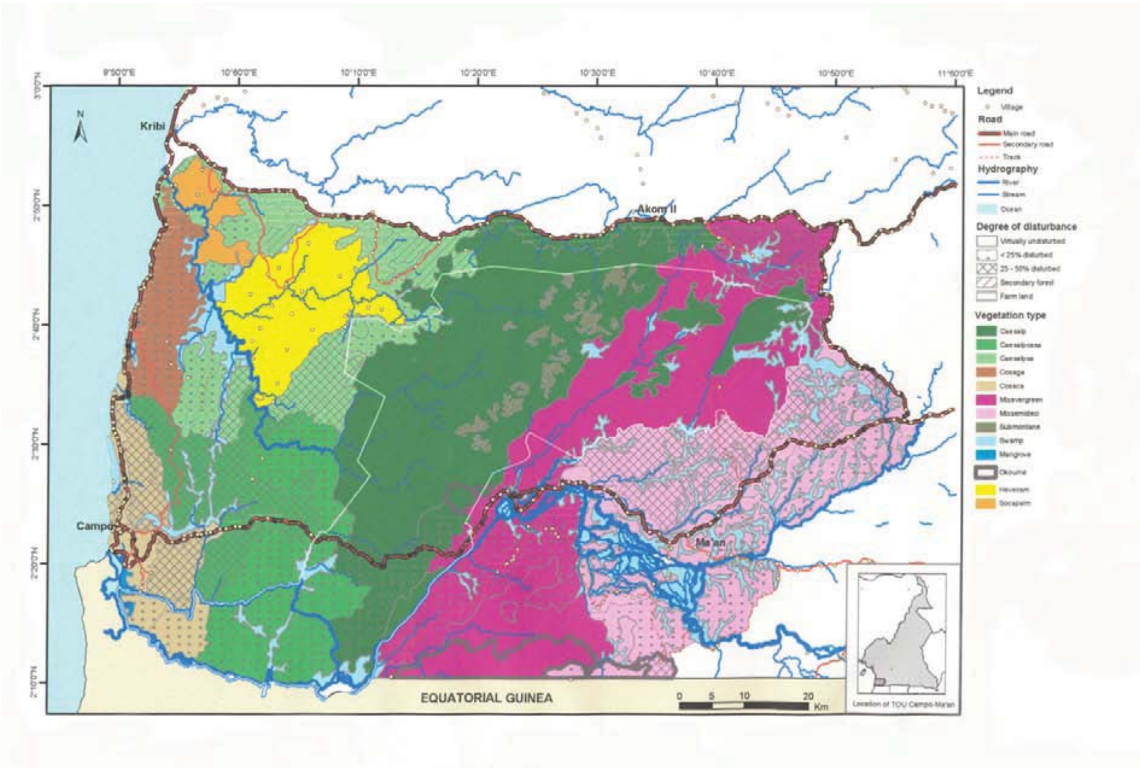

Figure 2.2 Vegetation map of the Campo-Ma'an area (Annex 5)

3. Lowland evergreen forest rich in Caesalpinioideae, with Sacoglottis gabonensis and other coastal indicators (Caesalpsa).

Generally, these are found along the coast and around Massif des Mamelles, Mont d'Eléphant, Nyete and Lobe between 50-350 m above sea level. The forest is characterised by its richness in Caesalpinioideae and the presence of many coastal indicators amongst which *Sacoglottis gabonensis* is the most frequent. They are often associated with other tree species such as *Anthonotha fragrans, Brachystegia cynometroides, Coelocaryon preussii, Coula edulis, Dichostemma glaucescens, Leonardoxa africana, Lophira alata, Ochthocosmus calothyrsus, Odyendeya gabonensis, Scyphocephalium mannii, Strombosia pustulata* and *Tetraberlinia bifoliolata*. The understorey is dominated by shrub and herb species such as *Allexis cauliflora, Asystasia macrophylla, Crotonogyne manniana, Diospyros obliquifolia, Jollydora duparquetiana, Lasianthera africana, Massularia acuminata, Palisota ambigua, Rinoria albidiflora* and *Scaphopetalum blackii.*

4. Coastal forest rich in Sacoglottis gabonensis (Cosaga)

These forests are predominantly found along the coast between Kribi and Campo at altitudes between 10-100 m above sea level. This forest type is similar to the lowland evergreen forest rich in Caesalpinioideae with *Sacoglottis gabonensis,* but it contains many more coastal indicator species and less Caesalpinioideae than the former. It is characterised by the frequent occurrence of *Sacoglottis gabonensis* that occurs in association with other tree species such as *Coula edulis, Cynometra hankei, Lophira alata, Ochthocosmus calothyrsus* and *Pycnanthus angolensis*. This forest type is heavily affected by human activities such as agriculture, logging, road construction, and urbanisation. It is rather difficult to find traces of undisturbed forest of this type despite its primary appearance in some areas.

5. Coastal forest rich in Calpocalyx heitzii and Sacoglottis gabonensis (Cosaca).
This vegetation type occurs in the Campo area between 0-100 m above sea level and represents a transitional zone where the evergreen forest rich in Caesalpinioideae, *Calpocalyx heitzii* and *Sacoglottis gabonensis* mixes with the coastal forest. As a result, it contains many more coastal indicator species and much less Caesalpinioideae than the latter. In addition to *Calpocalyx heitzii* and *Sacoglottis gabonensis,* the forest is dominated by tree species such as *Alstonia boonei, Calpocalyx dinklagei, Coelocaryon preussii, Desbordesia glaucescens, Distemonanthus benthamianus, Greenwayodendron suaveolens, Lophira alata, Ochthocosmus calothyrsus, Pterocarpus soyauxii, Staudtia kamerunensis* var. *kamerunensis* and *Terminalia superba*.

6. Coastal vegetation on sandy shorelines (Cosas).
It occurs along the coastline between Kribi and Campo, supporting a species-poor belt of low-canopy woody vegetation, often with herbaceous and shrubby maritime plant species. The foreshore is dominated by the typical Atlantic shore species *Ipomea pes-caprae* spp. *brasiliensis* that occurs on a low sandy coastline. Additional species are *Andira inermis* ssp. *inermis, Remirea maritima, Dioda serrulata, Canavalia rosea, Ipomea cairica, Flagellaria guineense, Cassytha filiformis* and *Stylosanthes erecta*. The seaward side bordering this formation is rich in maritime tree species such as *Terminalia catappa, Syzygium guineense* var. *littorale, Phoenix reclinata, Chrysobalanus icaco* spp. *icaco, Manilkara obovata, Calophyllum inophyllum, Carapa procera,* and *Cocos nucifera. Hibiscus tiliaceus*, a species characteristic of tropical shores also occurs here in association with other coastal species such as *Dodonaea viscosa, Craibia atlantica, Lonchocarpus serieus, Dalbergia ecastaphyllum, Mucuna flagellipes* and *Tetracera alinifolia*.

7. Mixed evergreen and semi-deciduous forest, with elements of evergreen lowland forest predominant (Mixevergreen).
This vegetation type occurs mostly in the western part of Ma'an, and in the eastern part of the Campo-Ma'an National Park at altitudes between 100-700 m. Here the forest has a fairly closed canopy though, patches of open areas are occasionally found where the forest is poorly developed. It contains many more elements of the lowland evergreen forest rich in Caesalpinioideae and the canopy is dominated by tree species such as *Anthonotha fragrans, Calpocalyx dinklaigei, Canarium schweinfurthii, Erythrophleum ivorense, Plagiostyles africana, Petersianthus macrocarpus, Pycnanthus angolensis, Santiria trimera, Strombosiopsis tetrandra, Tabernaemontana crassa*, *Stachyothyrsus staudtii* and *Uapaca guineensis*. The understorey is dominated by shrub species such as *Alchornea floribunda*, *A. hirtella*, *Asystasia macrophylla, Haumania danckelmaniana, Heisteria parviflora,*

Microdesmis puberula, Palisota ambigua, Podococcus barteri, Scaphopetalum blackii and *S. thonneri*.

8. *Mixed evergreen and semi-deciduous forests, with semi-deciduous elements predominant* (Mixsemideci).

This forest type which occurs in the south and eastern parts of Ma'an is similar to the forest type described above, but it contains many more semi-deciduous elements than the former. The forest is characterised by a discontinuous canopy with considerable patches of open forests covered by *Haumania danckelmaniana* and rattan species such as *Calamus deerratus, Laccosperma opacum, L. robustior, L. secundiflorum,* and *Oncocalamus mannii*. The forest canopy is irregular with scattered tree species such as *Alstonia boonei, Celtis milbraedii, C. tessmannii, Coula edulis, Dacryodes buettneri, D. macrophylla, Dichostemma glaucescens, Distemonanthus benthamianus, Erythrophleum ivorense, Lophira alata, Pentaclethra macrophylla, Petersianthus macrocarpus, Pterocarpus soyauxii, Pterygota macrocarpa, P. mildbraedii, Pycnanthus angolensis, Stachyothyrsus staudtii, Tabernaemontana crassa* and *Triplochiton scleroxylon*.

9. Submontane forest on hilltops (Submontane).

It occurs mainly between 800-1100 m on Nkolmedjabambon and Ongongo hills south of Akom II, on the Nkolebengue Hills west of Ebianemeyong, and on other hills northeast of Biwome. The lowland forest rich in Caesalpinioideae gradually gives way to the submontane forest, which occurs on steep slopes with distinctive ridge top and slope communities. It is characterised by a low canopy (25-30 m high) with scattered large trees (up to 35 m tall). Common tree species include *Afrostyrax lepidophyllus, Anisophyllea polyneura, Aphanocalyx hedinii, A. microphyllus, Dacryodes macrophylla, D. klaineana, Endodesmia calophylloides, Fillaeopsis discophora, Garcinia gnetoides, G. mannii, Klaineanthus gaboniae, Leonardoxa africana, Newtonia duparquetiana, Plagiosiphon emarginatus, Protomegabaria stapfiana, Santiria trimera, Scorodophloeus zenkeri, Syzygium staudtii, Tetraberlinia bifoliolata* and *Uapaca guineensis*. Between 900 and 1100 m, trees are densely covered by bryophytes (mosses) and vascular epiphytes including ferns and orchids.

10. Seasonally flooded and swamp forests (Swamp).

They are found throughout the Campo-Ma'an area along rivers, in river basins and creeks in areas which are permanently or seasonally inundated. Many species have breathing or aerial roots that give a conspicuous physiognomy to this vegetation when combined with the unusual architecture of other species such as *Lasiomorpha senegalensis*, a giant spiny aroid, *Ficus vogeliana* with long sinuous spreading buttresses bearing flagelliform infructescences and the sprawling, highly thorny *Pandanus*. Others common species include *Berlinia bracteosa, Cola hypochrysea, Gilbertiodendron dewevrei, Hallea stipulosa, Homalium longistylum, Lasiodiscus mannii, L. marmoratus, Pachypodanthium barteri, Plagiosiphon multijugus, Spondianthus preussii, Sclerosperma mannii* and *Uapaca guineensis.* Some swamps are dominated by *Raphia* species. Riparian forest communities are mostly found on seasonally exposed rocks along riverbanks that are seasonally submerged. Their species composition includes normal forest species and species adapted to a seasonally high water table. Common tree species found include *Aphanocalyx* *hedinii, Anthonotha macrophylla, Diospyros gracilescens, Ficus vogeliana, Gilbertiodendron demonstrans, G. dewevrei, Millettia griffoniana, Neolemornniera batesii, Spondianthus preussii, Synsepalum brevipes, Syzygium guineense* var. *littorale, Uapaca guineensis, U. heudelotii, U. staudtii,* and *Vitex doniana*. Narrow-leaved rheophytic shrubs such as *Alsodeiopsis zenkeri, Ixora fastigata, Garcinia sp., Ouratea dusenii,* and *Rinorea sp.* nov. are commonly found along the Ntem and Bongola rivers.

11. Mangroves

There are many small creeks, sometime with small estuaries and wetlands in the Campo-Ma'an area. Occasionally, these habitats either support a few clumps of tall mangroves dominated by tall *Rhizophora racemosa* and *Pandanus candelabrum* species or a population of short mangroves dominated by small *Rhizophora racemosa* and *Pandanus satabiei*. These mangrove trees (20-30 m tall) bear spectacular aerial roots forming a dense matrix on which one can cross the mangrove one or two metres above the mud during dry seasons. More often short mangroves are fringed by seasonally flooded forests which are dominated by *Crudia klainei, Guibourtia demeusei*, *Hallea stipulosa, Hibiscus tiliaceus, Lonchocarpus sericeus, Phoenix reclinata, Syzygium guineense* var. *littorale, Raphia* and *Uapaca* species.

12. Aucoumea klaineana forest (Okoumé 1&2)

Although Okoumé communities do not form a vegetation type per se in the Campo-Ma'an area, it is worth mentioning its occurrence in Cameroon since *Aucoumea klaineana* is reaching its northern limit of distribution in the area. It only occurs in small patches around Ebianemeyong on exposed steep hills or to the south of Ma'an close to the border with Equatorial Guinea around Nsengou and Ngo'ambang. In Ebianemeyong, the forest is opened and dominated by *Aucoumea klaineana* sometimes forming a distinctive near mono-dominant stands on exposed steep hills. In the Ma'an area, small clumps of Okoumé occur in open areas dominated by species of *Haumania danckelmaniana* and many rattans species. Despite the apparent virgin nature of this forest type, it has a strong secondary character in terms of species composition.

In addition to these vegetation types, degraded coastal forest, lowland evergreen rain forest or mixed evergreen and semi-deciduous forests are mostly found along roads and logging paths, near settlements and industrial sites. Secondary forests are often dominated by pioneer trees species such as *Albizia adianthifolia, Alchornea cordifolia, Anthocleista schweinfurthii, Bridelia micrantha, Cleistopholis patens, Dichaetanthera africana, Harungana madagascariensis, Musanga cecropioides, Rauvolfia caffra, R. vomitoria, Trema orientalis,* and *Macaranga* species.

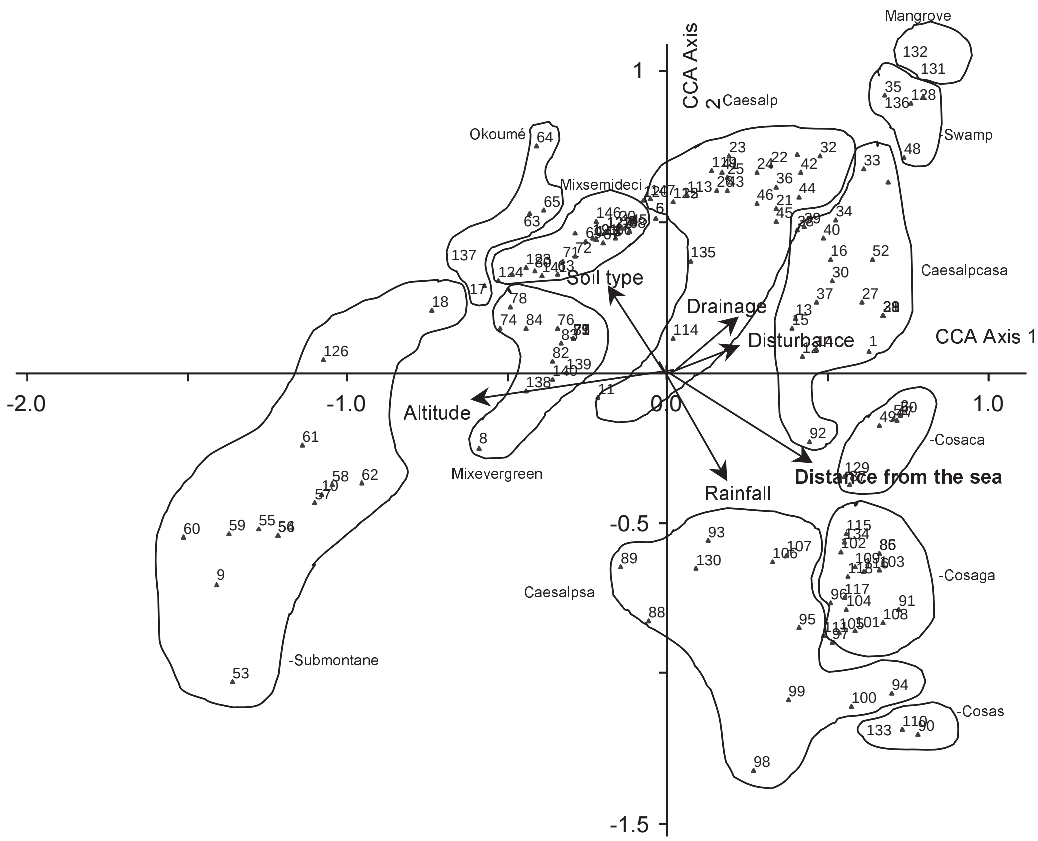

Figure 2.3 CCA ordination graph based on 958 vascular plant species with DBH ≥ 1 cm recorded in 147 plots showing the influence of environmental variables such as rainfall, altitude, distance from the sea, main soil type, drainage and human disturbance on the various vegetation types. Environmental factors with long arrows are more closely correlated in the ordination than those with short arrows and therefore are more important in influencing the vegetation groupings

In some areas where degradation is very severe, only few trees are left standing in a secondary vegetation consisting of pioneer woody and herbaceous species such as *Chromolaena odorata, Lycopodiella cernua, Nephrolepis bisserata*, *Selaginella myosurus* and *S. kraussiana.* Marantaceae and Zingiberaceae forests are mainly found along abandoned logging paths. They form thickets of about 2-3 m high and are generally dominated by Marantaceae species such as *Haumania danckelmaniana, Marantochloa leucantha, Megaphrynium macrostachyum, Sarcophrynium prionogonium* and many species of *Aframomum, Renealmia* and *Costus* of the Zingiberaceae and Costaceae families respectively. This vegetation type also supports scattered small and medium sized pioneer tree species such as

Alchornea cordifolia, Anthocleista schweinfurthii, Bridelia micrantha, Harungana madagascariensis, Musanga cecropioides, Trema occidentalis and *Macaranga* species. This forest association appears to be the main habitat for forest elephant, buffalo, gorilla, chimpanzee and many other large primates because of its good cover and high food production.

DCA and CCA analyses

The species-environment biplot from the CCA analysis is presented in Figure 2.3. As shown in Table 2.2, the first two axes of the DCA and CCA analyses of the data set have eigenvalues above 0.5, which denotes a good separation of the species along these axes despite a low amount of species variance explained. TWINSPAN and correspondence analyses have produced a similar classification since most of the plots that were found together in the various TWINSPAN groups were also put together in the CCA classification groups.

Table 2.2 Summary table of DCA and CCA of 147 plots recorded in the Campo-Ma'an area.

	Axis 1	Axis 2	Axis 3	Total inertia
DCA				20.83
Eigenvalues	0.92	0.74	0.66	
Lengths of gradient	9.38	4.35	4.71	
Cumulative percentage variance of species data	17.26	4.75	4.73	
CCA				20.83
Eigenvalues	0.68	0.61	0.54	
Species-environment correlation (Pearson correlation)	0.97	0.95	0.95	
Cumulative percentage variance of species data	3.4	6.2	8.8	

Table 2.3. CCA canonical coefficients of 10 important environmental variables recorded in 147 plots distributed over the Campo-Ma'an area.

Environmental factors	Axis 1	Axis 2	Axis 3
Mean annual rainfall (mm.y-^{1})	0.13	-0.60	-0.21
Altitude (m above sea level)	-0.76	0.38	-0.12
Distance from the sea (km)	-0.01	-0.62	-0.14
Disturbance	0.34	0.10	0.09
Soil characteristics			
Main soil type	0.07	0.02	-0.36
Parent material	-0.03	-0.10	-0.09
Drainage	0.07	-0.03	-0.61
Top soil texture (0-10 cm)	-0.06	-0.02	-0.04
PH ($H_2$0) of the top soil (0-10 cm)	-0.04	-0.09	-0.11
Electricity conductivity of top soil (0-10 cm)	0.03	-0.01	0.10

Environmental factors such as rainfall, proximity to the sea and altitude are more closely correlated with the vegetation ordination than soil characteristics. Almost all the coastal plots (Cosaca, Cosaga and Cosas), mangrove, swamps and lowland evergreen forest rich in Caesalpinioideae (Caesalp, Caesalpcasa and Caesalpsa) are negatively correlated with altitude and positively with increasing rainfall. Plots that were located in the rain shadow in the Ma'an area (Mixevergreen and Mixsemideci) are characterised by a lower rainfall. The effect of altitude is also well illustrated by all high altitude plots grouped together (submontane). The relative importance of environmental variables is shown in Table 2.3. Altitude (-0.76) and disturbance (0.34) are highly correlated with the first axis, distance from the sea (-0.62) and mean annual rainfall (-0.60) with the second axis, and drainage (-0.61) and soil type (-0.36) with the third axis.

Soils

Following the FAO classification system, soils in the Campo-Ma'an area were generally classified as Ferrasols and Acrisols (Franqueville, 1973; Muller, 1979; van Gemerden & Hazeu, 1999). They are strongly weathered, acid and low in nutrients with pH (H_2O) values generally around 4 (Annex 2). The soils are deep to very deep and clayey in texture, except at the seashores and river valleys where they are often sandy. Based on drainage characteristics and texture, four major soil types can be distinguished in the area. Poorly drained soils that are commonly found in the river valleys and adjacent swamp areas throughout the Campo-Ma'an area. They were classified as Dystric Fluviosols or Gleyic Cambisols. The texture is often sandy to gravely with clay interlayer. Moderately well to well drained soils are frequent in other parts of the research area. The dominant soils in the coastal plain are Plinthic Ferrasols, with patches of Haplic Acrisols and Acri-Xanthic Ferrasols. They are sandy clay loam soils developed on granites and gneiss with high pyrocene content. In the eastern part of the Campo-Ma'an area, soils are developed on ectinites including gneiss, micaschist and quartzite. Xanthic Ferrasols are predominant though Ferralic Cambisols and Ferric Acrisols are also found around the Massif des Mamelles. In the mountainous area, soils are developed on migmatites and granites and are mostly classified as Acri-Xanthic Ferrasols and Xanthic Ferrasols. They are deep clay soils with a sandy clay loam to sandy clay topsoil.

Forest structure and floristic composition

Diameter class distribution and basal area

In total 78086 trees, shrubs, climbers and other vascular plants with DBH ≥ 1cm in 147 plots (14.7 ha) were recorded in the various vegetation types (Table 2.4). They belonged to 1116 species, 421 genera and 98 families. Of all the records 75% were identified at species level, 23% at generic level and 2% at family level. The diameter distribution pattern of stems was similar among the various vegetation types and all plots were characterized by a high density of stem 1-30 cm DBH and a paucity of trees above 50 cm DBH, with a tendency of smaller canopy trees in the submontane forest, mangrove and swamps. As shown in Table 2.4, the mean number of stems/ha for all vascular plants ≥ 1cm DBH varies from 4380 in the lowland evergreen forest rich in Caesalpinioideae to 8630 in the mangrove. The mean basal area/ha varies from 49.86 in the coastal forest on sandy shorelines to 88.73 in lowland evergreen forest rich in Caesalpinioideae with *Calpocalyx heitzii* and *Sacoglottis gabonensis*. In general, the area is characterized by a high mean basal area/ha because of the high frequency of canopy trees with large buttresses.

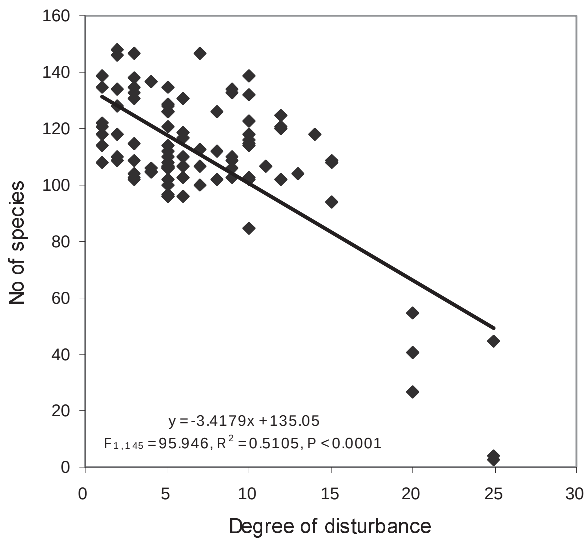

Figure 2.4 Correlation between the degree of human disturbance (% of degraded forest) and the number of species recorded in 147 plots of 0.1 ha each.

Floristic composition and species richness

As shown in Table 2.4, the number of species for all vascular plants ≥ 1cm recorded varies from 4 in the mangrove to 557 in the lowland evergreen forest rich in Caesalpinioideae. The mangrove, swamps and coastal forest on sandy shorelines were species poor and less diverse than the other forest types. Overall, the Rubiaceae family has the highest number of species (159 species of vascular plants with DBH ≥ 1cm), followed by Euphorbiaceae (80 species), Leguminosae-Caesalpinioideae (72 species), Annonaceae (61 species), Sterculiaceae (50 species), Sapindaceae (37 species), Apocynaceae (34 species), Ochnaceae (28 species), Sapotaceae (26 species), Ebenaceae, Guttiferae and Meliaceae (25 species each), Dichapetalaceae and Leguminosae-Papilionoideae (22 species each).

Generally, the Campo-Ma'an area is characterized by a rich and diverse flora. The Shannon diversity index was relatively high and varied from 0.12 in the mangrove to 5.33 in the submontane forest. Results from the enumeration of all vascular plant species showed and confirmed that the lowland evergreen forest rich in Caesalpinioideae is characterized by its abundance in Caesalpinioideae (72 species).

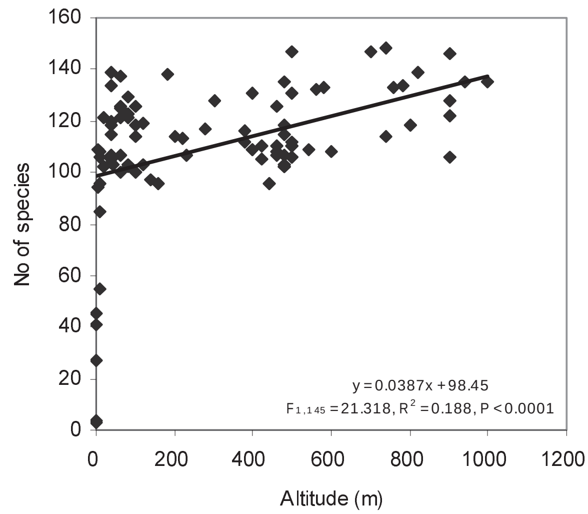

Figure 2.5 Correlation between altitude and the number of species recorded in 147 plots of 0.1 ha each.

The important value index (IVI) of the Caesalpiniaceae was high in most of the vegetation types encountered and varied from 38.09 in lowland evergreen forest rich in Caesalpinioideae to 14.01 in the lowland evergreen forest rich in Caesalpinioideae with *Sacoglottis gabonensis*. In terms of species richness, there was a strong significant negative correlation between the number of species recorded in the various plots and the level of human disturbance (Figure 2.4) and a relatively weak correlation with rainfall ($F_{1,\ 145}$ = 10.094, R^2 = 0.099, P = 0.002), altitude (Figure 2.5), and distance from the sea ($F_{1,\ 145}$ = 10.797, R^2 = 0.105, P = 0.001), or pH ($F_{1,\ 145}$ = 7.200, R^2 = 0.073, P = 0.009).

Table 2.4 Summary of the number of species, number of stem/ha, mean basal area/ha, canopy height and Shannon diversity index (H') of the various vegetation types for all plants with DBH ≥ 1 cm recorded in the Campo-Ma'an area. Minimum and maximum values are given between brackets.

Vegetation types	No of plots	No of species	Average No of stems/ha	Mean basal area/ha	Height of upper canopy	Shannon diversity index (H')
Caesalp (2.3 ha)	23	557 (75-128)	4380 (2500-5750)	75.89 (37.95-121.90)	50 (40-55)	5.12
Caesalpcasa (2.5 ha)	25	555 (93-139)	5326 (3120-7020)	88.73 (41.00-146.75)	50 (40-55)	5.01
Caesalpsa (1.4 ha)	14	474 (86-138)	5935 (4350-7120)	85.73 (58.94-161.98)	45 (40-50)	5.09
Cosaga (0.9 ha)	9	303 (81-140)	5810 (4940-8010)	86.1 (35.82-113.67)	45 (40-50)	4.58
Cosaca (0.9 ha)	9	326 (78-108)	5864 (4740-7570)	87.69 (32.40-140.31)	45 (40-50)	4.38
Cosas (0.4 ha)	4	100 (27-55)	4710 (3630-5700)	49.86 (34.88-65.08)	30 (25-35)	3.54
Mixevergreen (2.1 ha)	21	523 (63-135)	4983 (3890-6980)	78.22 (45.36-135.03)	45 (40-50)	4.70
Mixsemideci (1.6 ha)	16	481 (86-147)	5460 (4390-6340)	69.73 (68.88-131.25)	45 (40-50)	4.59
Submontane (1.4 ha)	14	499 (79-148)	6094 (3680-8449)	57.66 (40.74-67.90)	30 (25-35)	5.33
Swamps (0.5 ha)	5	246 (18-108)	4276 (2070-5960)	62.77 (41.15-100.01)	30 (25-35)	4.35
Mangrove (0.2 ha)	2	4 (3-4)	8630 (8150-9100)	75.16 (66.03-84.30)	30 (20-35)	0.12
Okoumé forests (0.5 ha)	5	234 (18-107)	4802 (3720-5800)	64.28 (42.47-91.95)	40 (30-45)	4.10
Total for the Campo-Ma'an area (14.7 ha)	147	1116 (3-148)	5312 (2070-9100)	76.71 (34.88-161.98)	50 (20-55)	5.54

2.4. DISCUSSION

General vegetation patterns

There is a good correspondence between the TWINSPAN, DCA and CCA classifications and the comparable outputs from these analyses efficiently illustrate the influence of the main environmental factors on the various vegetation types. This probably indicates that all relevant environmental variables were included in the analyses and that the sampling design, based on small plots of 0.1 ha in which all vascular plants with DBH ≥ 1 cm are recorded, may be successfully applied in detecting species environment relationships in a tropical rain forest (Hall & Swaine, 1976; Gartlan *et al.*, 1986; Duivenvoorden & Lips, 1995; Newbery *et al.,* 1996). However, the data presented some difficulties to TWINSPAN and CCA analyses because some species were commonly found throughout the area thus resulting in the presence of a few outlying plots.

The vegetation in the Campo-Ma'an area falls within the Lower Guinea subdivision of the Guineo-Congolian rain forest region and is part of the Biafran forest type that extends from Southeast Nigeria to Gabon and the Mayombe area in Congo (White, 1983; Letouzey, 1968 & 1985). The Campo-Ma'an forest is situated in the middle of this belt and shares with other sites the overall characteristic of the Atlantic Biafran forest mainly with evergreen but also some semi-deciduous elements. Although this vegetation type is widespread, there is a considerable variation in dominant species and species composition between localities. This study demonstrated that the area has a diverse and rich forest with more than 10 vegetation types and sub-types that include the coastal vegetation, lowland evergreen forest rich in Caesalpinioideae, mixed evergreen and semi-deciduous forest, mangroves, seasonally flooded and swamp forests, riparian vegetation and secondary forests (Figure 2.2). The Campo area was dominated by the lowland evergreen forest rich in Caesalpinioideae and the Ma'an area by the mixed evergreen and semi-deciduous forest.

In terms of relative density, the Caesalpinioideae was the dominant sub-family throughout the area. Its species were co-dominant and their abundance varied within the various vegetation types. Some of them were gregarious with a high regeneration capacity and many juvenile trees. Many species were emergent or big canopy trees with large buttresses that partly account for the high basal area recorded in the area. More than 65% of the forest types recorded have at least 250 species with a Shannon diversity index > 4. Moreover, 56% of all the plots recorded have more than 100 species/0.1 ha for all vascular plants above 1 cm DBH. The submontane forest has the highest frequency of species-rich plots (93% of all plots recorded has more than 100 species/0.1 ha). Other rich vegetation types include the lowland evergreen forest rich in Caesalpinioideae with *Calpocalyx heitzii* and *Sacoglottis gabonensis* (81%), the lowland evergreen forest rich in Caesalpinioideae with *Sacoglottis gabonensis* (78%), the lowland evergreen forest rich in Caesalpinioideae (76%) and the mixed evergreen and semi-deciduous forest (67%). The mangroves, swamps and the coastal vegetations on sandy shorelines were species-poor.

The impact of environmental and human factors

Rainfall and proximity to the sea

There was a strong positive correlation between the various vegetation types, rainfall and proximity to the sea. These three factors were highly correlated with the first two axes of the CCA ordination graph. The average annual rainfall generally decreases with increasing distance from the sea, ranging from 2950 mm/year in Kribi to 2000 mm around Akom II and 1670 mm in the Ma'an area (Olivry, 1986). The Ma'an area has significant less rainfall than other areas. This is probably due to a rain shadow effect caused by the range of hills that start from Ebianemeyong to Akom II and which forms a substantial upland block between Ma'an and the ocean. As a result the vegetation changes from the mangrove or coastal forest with many coastal indicator species, through the lowland evergreen forest rich in Caesalpinioideae to the mixed evergreen and semi-deciduous forest in the drier Ma'an area. The number of species recorded was relatively influenced by the proximity of the sea and rainfall, thus resulting in a gradual variation in dominant species and an increase in species richness with increasing distance from the sea and decreasing annual rainfall. The submontane forests and the Caesalpinioideae forests of the interior were more diverse and species rich than the coastal forests (Table 2.4).

Altitude

Altitude also had a positive influence on the general vegetation patterns and species composition in the area (Figure 2.5). It is worth mentioning that the effect of altitude on the vegetation is less pronounced in the Campo-Ma'an area than in others mountainous areas in Cameroon. This is partly due to the fact that Campo-Ma'an is not a mountain and the hills found here are low (up to 1100 m above sea level) and do not show a clear altitudinal gradient in the vegetation from sea level to the top. On these hills the forest composition was almost the same on both sides of the slope. Generally, on high mountains, the number of species tends to decrease with increasing altitude. But in the Campo-Ma'an area, there was rather a relative increase of species richness with increasing altitude. High altitude forest appeared to be relatively more species-rich than the lowland and coastal forests. In the submontane forest, more than 93% of the plots had at least 100 species/0.1 ha. Furthermore, the structure and composition of the forest, as well as the physiognomy of the species change progressively as one moves from the lowland to the submontane forest. In the lowland forest, trees were taller (up to 50 m) and a considerable number of emergent and canopy trees have large buttresses. Many small trees and shrubs bear their flowers and fruits directly on the trunk or large branches. The submontane forest was lower (25-35 m) than the lowland forest and between 900-1100 m many trees were covered with bryophytes and vascular epiphytes. Furthermore, special physiognomic features characteristic of the lowland forest such as large woody lianas, buttressing and cauliflory were less common.

Soils

The relationships between soil characteristics and the vegetation types was less clear than other environmental variables such as rainfall, proximity to the sea and altitude, though soil type showed highest correlation with the third axis of the CCA result. Mangroves and swampy forests on hydric soils with poor drainage conditions have low nutrient concentrations and are species-poor. This must stem partly from the fact that, in exception to mangrove and swamps that are characterised by a distinctive edaphic condition, soils in the research area are well drained, strongly weathered, and acid with pH (H_2O) values generally around 4. However, soil type and drainage were correlated with plots recorded in mangrove and swamps forests (Figure 2.3). Gartlan *et al.* (1986) and Newbery *et al.* (1996) undertook similar analyses in Korup National Park and the Douala-Edea Forest Reserve in Cameroon and found that the main environmental factors affecting vegetation were rainfall, altitude, slope, drainage, and potassium and phosphorus concentrations in the soil. They argued that rainfall and seasonality are likely to lead to stronger distributional gradients than soil nutrients in equatorial Africa rain forests. Although we did not carry out soil nutrient analyses, we found that in addition to rainfall, proximity to sea and altitude, human disturbance, drainage and soil type are the most important characteristics influencing the vegetation types in the Campo-Ma'an area. However, it is noteworthy to mention that many of the present-day distributions of plant species in the tropical Africa region are also dependent on the Pleistocene history and the continuing influence of Quaternary glacial and inter-glacial periods (Hamilton, 1982; White, 1983; Maley 1987, 1989, 1993, 1996 & 2001; Sosef, 1994 & 1996).

Human disturbance

The vegetation patterns as well as the forest composition and species richness were strongly influenced by the degree of human disturbance. Disturbance was positively correlated with the first axis of the CCA ordination graph and the number of species recorded in the various plots (Table 2.3 and Figure 2.4). Coastal forests appeared to be more disturbed with many secondary species, less species-rich and less diverse than other forest types recorded. This is mainly due to the fact that the replacement of the Campo-Ma'an rain forests into other land use types began centuries ago, and the coastal area is more degraded. So far, large tracts of the primary lowland forests have been affected by agriculture, shifting cultivation, urbanisation and more recently by logging. Clearance of natural vegetation to provide land for settlements and subsistence agriculture (28% of the total area) and commercial agriculture (7.5%) is the biggest threat to the lowland forests and its unique vegetation. Timber exploitation is the main economic activity in the area and logging concessions cover 31.4% of the area. It is rather difficult to find undisturbed forest of this type, despite its primary appearance in some areas (Table 2.1 and Figure 2.2). Particularly, the coastal forest and the lowland evergreen forest rich in Caesalpinioideae suffered from logging and agricultural activities. Pockets of undisturbed primary forest mainly remain on hills and gentle slopes because of difficult access.

Long before these recent human activities on the Campo-Ma'an rain forests, man has had a marked influence on the coastal vegetation (Reynaud & Maley, 1994; Oslisly, 2001; Maley & Brenac, 1998; Maley 1999, 2001 & 2002). Recent archeological exploration in the area has identified village sites located along the coast (Bwambé, Bwendjo, Campo, Ebodje, Lobé and Lolabé) and within the forest (Biyan, Efoulan II, Nemeyong, Nkoelon, Nkolebengue and Nkolmekok) dated 3.000-2.500 years BP (Kuete, 1990; Ossa Mvondo, 1994 & 1998; Oslisly *et al.*, 2001). This has brought several authors to argue that the coastal forests and the mixed evergreen and semi-deciduous forests in the Ma'an area may have undergone a great change in the past that is probably caused by man. A strong indication of past human disturbance is the frequent occurrence of *Alstonia boonei, Ceiba pentandra, Lophira alata, Pycnanthus angolensis* and *Terminalia superba* which are characteristic of mature secondary vegetation. Letouzey (1968 & 1985) classified most of the coastal forest as "Forêts atlantiques littorales à *Lophira alata* et *Sacoglottis gabonensis*" because of the abundance of *Lophira alata.* Today it is very difficult to find a mature stem of *Lophira alata* in these forests since they have been selectively logged at least twice during the past 30 years. Logging also accounts for the low density of mature timber tree species recorded in the coastal and lowland forest rich in Caesalpinioideae. However, despite this human influence on the Campo-Ma'an rain forest, there is still a considerable portion of rich and diverse forest in the Campo-Ma'an National Park and its surroundings. Furthermore, recent studies carried out by van Gemerden *et al.* (2003) in the Bipindi-Akom II-Lolodorf forests adjacent to the Campo-Ma'an area has shown that vegetation recovery in gaps caused by selective logging is relatively quick (5-14 years after logging) in Central African rain forest.

2.5. CONCLUSION

There was a good correspondence between the TWINSPAN, DCA and CCA classifications and the analyses illustrated the influence of the main environmental factors on the various vegetation types. The present study demonstrated that the vegetation of the Campo-Ma'an area is determined by rainfall, the proximity to the sea, altitude, soils and human disturbance. There was a strong impact of rainfall, proximity to the sea and human disturbance on the various vegetation types. As a result the vegetation changes from the coastal forest on sandy shorelines, through the lowland evergreen forest rich in Caesalpinioideae to the mixed evergreen and semi-deciduous forest in the drier Ma'an area. There is also a gradual variation in dominant species and an increase in species richness from the coast to the interior. Altitude and slope factors seem to have less influence on the general patterns of the vegetation distribution and species composition in the Campo-Ma'an area than rainfall and proximity to the sea. The overall relationship between soil characteristics and the various vegetation types was less clear than other environmental variables. However, drainage and soil type were the most important soil characteristics. Soil texture, pH and electricity conductivity values had less impact on the forest composition. The strong relationship between human disturbance and the vegetation patterns has implications on the floristic composition and species richness of various forest types. Coastal forests appeared to be more disturbed with many secondary species, less species-rich and less diverse than other forest types recorded.

Photo: Large buttress of *Desbordesia glaucescens* (Engl.) Tiegh. (Irvingiaceae) (Tchouto, M.G.P.)

Chapter 3

DIVERSITY PATTERNS IN THE FLORA OF THE CAMPO-MA'AN RAIN FOREST, CAMEROON: DO TREE SPECIES TELL IT ALL?

Gildas Peguy Tchouto Mbatchou [1]

With W.F. de Boer [2], de Wilde J.J.F.E. [3], and van der Maesen L.J.G. [3]

[1] Limbe Botanic Garden, BP 437, Limbe, Cameroon; e-mail: peguy2000@yahoo.com
[2] Tropical Nature Conservation and Vertebrate Ecology Group, Wageningen University, Bornsesteeg 69, 6708 PD, Wageningen, the Netherlands; e-mail: fred.deboer@wur.nl
[3] Biosystematics Group, Wageningen University, Generaal Foulkesweg 37, 6703 BL, Wageningen, the Netherlands; e-mail: jos.vandermaesen@wur.nl