A STUDY TO INVESTIGATE THE FACTORS AFFECTING THE DISTRIBUTION OF *Cola usambarensis*, AN ENDANGERED ENDEMIC TREE OF THE EAST USAMBARA MOUNTAINS, TANZANIA

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September 1998

A dissertation submitted to the Ecology and Conservation Unit, Department of Biology, University College London, in partial fulfillment of the requirement for the Degree of Master of Science in Conservation

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ACKNOWLEDGEMENTS

This study was undertaken with the approval of the East Usambara Catchment Forest Project (EUCFP) in Tanga, Tanzania. I am most grateful to all the EUCFP personnel, in particular Mr Nashanda, Dr Stig Johannson, Shedrack Mashauri, Mr Sawe and Mama Beda who imparted useful knowledge of the area, provided essential logistical support, and permitted the use of field equipment, as well as library and email facilities. Most importantly they arranged for a botanist, Mr Iddi Rajabu, to assist with plant identification throughout the survey.

My mission to find the *Cola usambarensis* tree would not have been possible without Iddi's botanical expertise, patience and enthusiasm. He identified the tree in the densest of forest and never tired of teaching me about the flora of the East Usambaras. He also taught me a great deal about Tanzanian culture and helped to improve my *Kiswahili*. To him I am most grateful.

Special thanks are due to Dr Mike Maunder and Dr Clare Hankamer of the Conservation Projects Development Unit at the Royal Botanic Gardens, Kew, who highlighted the importance of this species and spared enormous amounts of time guiding me before, during and after the field work. Also to Dr Martin Cheek at the Kew Herbarium and Leonard Mwasumbi and Frank Mbago at the University of Dar es Salaam, for their patience in helping me to identify *C. usambarensis* from voucher specimens. Mr Charles Kweyunga kindly analysed the soil samples.

Frontier agreed to let me join the Frontier-Tanzania East Usambara Forest Research Programme and have use of their volunteer research assistants. I am most thankful to the Director, Eibleis Fanning and Leigh Stubblefield from the London office. In Tanzania, I could not have managed without the support of the excellent field staff: Nike Doggart, Liana Joseph, James Davey, Kathryn Doody, Martin Guard and Matt Willson. The volunteers deserve mention for their assistance and motivation in very difficult conditions. They are: Dan Bridges, Clare Bullen, Michael Cheetham, Duncan Ellis, Helen Goddard, Sally Huband, Ed Mannsaker, Barry Marsden, Andy Marshall, Paul Monteith, Clare Percy, Albert Salu, Olivia Scholtz, Richard Silcock, Vicky Stanley, Jon Stokes and Sam

Thompson. The transect cutters were inspirational and my thanks to Hassani Maingo, Gaston, Dismus, Ayubu and James, the askari.

Mr Magange and Alex Hipkiss of the Tanzania Forest Conservation Group were helpful in setting up interviews with traditional herbalists in Kwamtili and Churwa.

I am also most grateful to my supervisor, Dr Barrie Goldsmith who assisted with data analysis and made helpful comments on my draft. The Natural Environment Research Council (NERC) provided financial assistance with field work and I am grateful for their support.

Finally, thanks go to my long-suffering family who provided constant encouragement during moments of despair and to my friends who were always there when needed.

ABSTRACT

Cola usambarensis is a small forest tree endemic to the East Usambara Mountains in north-east Tanzania. At a Conservation Assessment Management Plan (CAMP) workshop held in March 1998, this species was classified as Endangered as a result of habitat destruction, fire and non-commercial harvesting.

In order to investigate the factors affecting its distribution, a study of the key habitat requirements, threats and regeneration dynamics was carried out in July 1998 in four protected forests areas.

Separate data, from the Frontier-Tanzania East Usambara Forest Research Programme in 8 Forest Reserves, were used to estimate population density and distribution pattern.

In total, 12 1ha plots were sampled. Adult trees (dbh >4cm) and saplings were recorded and estimates of percent canopy closure were made in each 20m x 20m sub-plot and above each tree and sapling. Evidence of fire disturbance and human-induced tree damage was documented and soil samples were collected for analysis. Interviews were held in villages surrounding Kwamgumi and Segoma Forest Reserves to assess resource use.

Cola usambarensis populations are now known to exist in seven forest reserves. The spatial distribution was found to be non-random (clumped). This pattern is believed to be caused by gravity-dispersed seeds germinating close to the mother trees.

The key habitat requirements are believed to be undisturbed moist (riverine) forest with a high canopy cover of over 70% and soils with good drainage, aeration and water retention capacity.

Cola usambarensis was not recorded in the six plots disturbed by fire. As such, fire may have an adverse effect on the survival of this species because of high vulnerability to direct heat damage, and because it invariably leads to a reduction in canopy cover thereby creating conditions unfavourable for growth.

To a lesser degree, felling of large timber trees is also believed to be a threat.

Harvesting for rope and medicinal purposes does not appear to be a threat. However, coppicing for building poles, although sustainable at the current level, may pose a threat if intensified because it might reduce the regeneration potential of the species.

Cola usambarensis was observed to be regenerating although mortality appears to be high in the early growth stages.

Recommendations include: further research (including a genetic study); establishment of permanent 1ha monitoring plots; greater control of illegal activities such as fire and logging; and production of a field tree identification guide.

1. INTRODUCTION

Cola usambarensis (Family: *Sterculiaceae*) is a small understorey tree first described by the German naturalist, Engler, in 1907. Of the six *Cola* species found in the intermediate rain forest of the East Usambara Mountains, two (*Cola usambarensis* and *Cola scheffleri*) are endemic to this area. In June 1997, the East Usambara Catchment Forest Project (EUCFP) identified *C. usambarensis*, along with 11 other species, as of conservation concern and recommended that its conservation status be formally assessed as part of a collaborative Conservation Assessment and Management Plan workshop held in 1998 facilitated jointly by the EUCFP, the National Museums of Kenya and the Royal Botanic Gardens, Kew (Mwasumbi *et al*., in press).

1.1 Background

1.1.1 Eastern Arc Mountains

The East Usambara Mountains, in north-east Tanzania, form part of the Eastern Arc crescent of isolated mountain forest blocks stretching south-west across the country from southern Kenya to northern Malawi (Figure 1).

The Eastern Arc crystalline mountains were formed over 30 million years ago and harbour forests of a similar age, representing one of the oldest and most stable ecosystems on the African continent. The Eastern Arc covers less than 2% of Tanzania's land area but its forests contain 30-40% of the country's species of flora and fauna (Hipkiss, 1997). As such, these forests are a globally known biodiversity "hotspot" (Myers, 1998) and have recently been listed in the "Global 200", (a representative approach to conserving the Earth's distinctive ecoregions), as one of the world's most outstanding, yet critically endangered, examples of tropical moist broadleaf forest (Olson and Dinerstein, 1998).

1.1.2 East Usambara Mountains

The East Usambara mountains, which rise abruptly from the coastal plain to an altitude of 1500m, support both lowland (<850m) and submontane (> 850m) forest types (Lovett & Wasser, 1994). The climate is humid or perhumid throughout the year with a mean annual rainfall of 1919mm (Rodgers & Homewood, 1982). Rainfall is bimodal with peaks between April and June and in November. The eastern (windward) side of the East

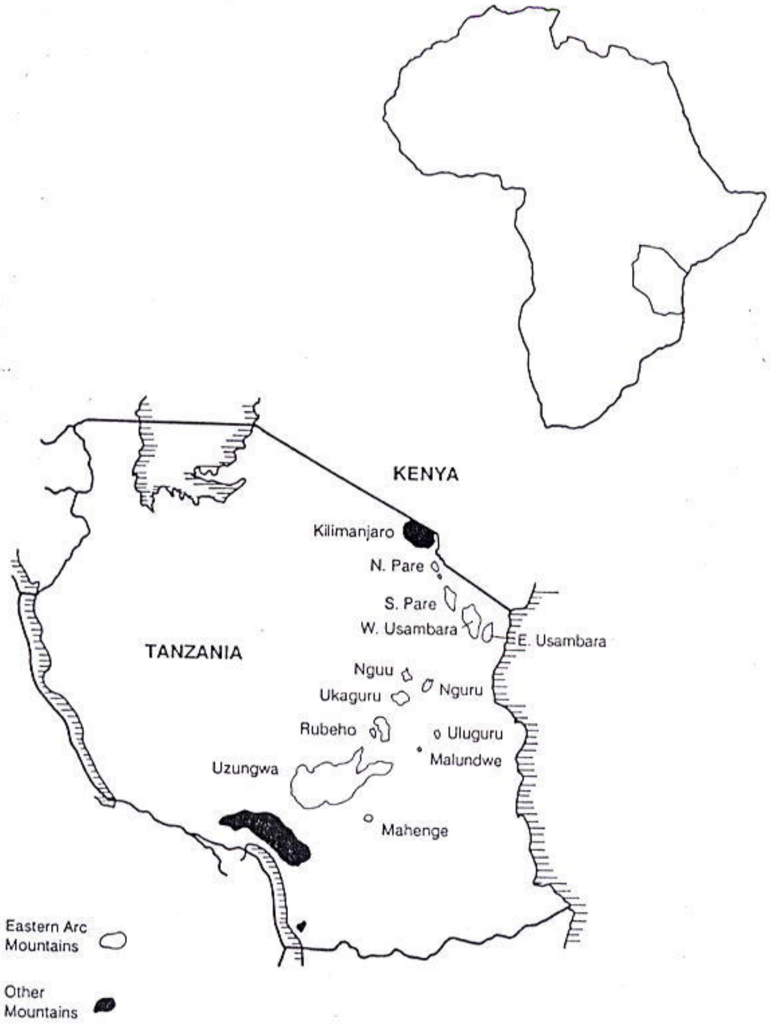


Figure 1. The Eastern Arc Mountains in Tanzania. The East Usambara Mountains are situated in the north-east close to the Kenyan border

Usambaras receives more rainfall than the western side which is in the rain shadow from warm moisture-bearing air from the Intertropical Convergence Zone in the India Ocean (Lovett & Wasser, 1994). Soils are described as humic ferralsols which have been derived from acid rocks. Above 850m, soils are red-brown with little inherent fertility whilst the lower altitude soils are more fertile grey-black sandy clays (Hamilton, 1989a).

In terms of biodiversity richness, the forests of the East Usambaras boast the greatest level of endemism and species richness in the Eastern Arc Mountains, and have been likened in biological importance to the Galapagos Islands (Rodgers & Homewood, 1982). With regard to plant diversity specifically, the forests are an IUCN-recognised Centre of Plant Diversity (WWF & IUCN, 1994). Out of a total of 2,855 plant taxa in the Usambaras, 25% are estimated to be endemic (Iversen, 1991). Of these, 276 are forest species, 50 of which are endemic or near-endemic (Rodgers & Homewood, 1982). The high degree of endemism is believed to be the result of a relatively stable geological and climatic environment, combined with long periods of isolation from the larger African forest blocks (Rodgers & Homewood, 1982). Aside from the biological importance, the forests have important catchment value, supplying vital water to urban and rural populations in Tanga Region (Stocking and Perkin, 1992; Bjorndalen, 1992).

There is evidence of human disturbance in the East Usambara forests dating back to the Early Iron Age (Hamilton, 1989b). Consequently it is believed that few areas of forest have escaped disturbance by man at one time or another during the past 2000 years. More recently, since 1954, forest utilisation and clearance has led to a 70% decline in forest cover (Kikula, 1989; Iversen, 1992). What was formerly a continuous forest block is now a fragmented network of forest reserves covering an area of 33,500ha (Johannson et al., 1997). The major threats to the forest ecosystem include agricultural encroachment, pit-sawing, logging, cash crop cultivation (tea, coffee, sisal and cardamom) and commercial harvesting (Kilahama, 1998).

The forests of the East Usambaras are managed by the EUCFP, which is implemented by the Forestry and Beekeeping Division. The EUCFP is responsible for establishing and protecting forest reserves, protecting water sources, sustaining forest benefits for local communities and rehabilitiating the Amani Botanical Garden which is one of the largest in Africa (Johannson et al., 1997).

1.2 Rationale

In March 1998, the National Museums of Kenya-Darwin Plant Conservation Techniques Course for East Africa Programme held a seven day Conservation Assessment and Management Plan (CAMP) training workshop in Amani Nature Reserve, East Usambaras. The CAMP process serves as a tool to hasten the development of scientifically-based management strategies for threatened species which are both realistic and achievable (Ellis & Seal, 1995) and uses methodologies developed by the Conservation Breeding Specialist Group (IUCN/SSC). It is intended as a bottom-up approach which, in theory, generates political and social support for conservation actions by local people because all stakeholders including reserve managers, scientific experts and local resource-users are involved in decision-making.

Information on the distribution, uses and threats of 11 plant species of conservation concern, including *Cola usambarensis*, were presented at the workshop and a summary taxon sheet completed for each species (Mwasumbi et al., in press). Recommendations for management and further research were also discussed and agreed.

The current status of *C. usambarensis* was evaluated using existing data from Frontier baseline biological surveys (e.g. Cunneyworth et al., 1996, Cunneyworth, 1997), informal field sightings and herbarium records. The findings are summarised below:

- It is a rare evergreen tree occurring on steep hilly slopes and has a fragmented distribution in six protected areas (Amani Nature Reserve, Bamba Ridge, Kambai, Kwamarimba, Kwamgumi and Mtai Forest Reserves), occupying an area of less than 10,000 ha.
- It is estimated that the population of *C. usambarensis* has declined by 50% over the past 100 years.

- *C. usambarensis* is threatened primarily by habitat destruction and forest fragmentation but also from fire and local harvesting for rope and building poles.
- No ex-situ or in-situ conservation programme currently exists for *C. usambarensis.*
- Because very little is known about its ecology, recommendations for research highlighted the need for survey and monitoring, life history studies and habitat management.
- Management recommendations likewise stipulated surveying and monitoring of remaining forest reserves to ascertain where the main reproducing and regenerating populations of *C. usambarensis* are located, as well as providing more protection to the existing populations and initiating an ex-situ conservation programme.

In light of this information, the New IUCN Red List category of threat assigned to *C. usambarensis* at the CAMP Workshop was "Endangered" (criteria B1, 2b,c). As a result of the workshop, the EUCFP recognised the need to develop single species recovery plans as part of the Amani Nature Reserve Management Plan. The research required to collect the necessary information prompted the current study, at the invitation of the EUCFP. It is the first project of this kind for the EUCFP and the field methodology will provide a template for future single species recovery research.

1.3 Objectives

The overall aim of this study was to investigate the factors affecting the distribution of *Cola usambarensis* in the East Usambara Mountains as a first step in understanding the ecology of and threats to this species.

More specifically, the objectives were to:

- identify the key habitat factors determining the distribution of *C. usambarensis;*
- investigate whether its distribution is affected by fire disturbance and current levels of local harvesting;
- study the regeneration dynamics of *C. usambarensis*; and
- make recommendations based on this data for in-situ management of populations.

2. METHODS

Fieldwork was carried out from 4 to 31 July 1998. Assistance with plot demarcation and data collection was provided by Volunteer Research Assistants from the Frontier-Tanzania East Usambara Forest Research Programme (F-T EUFRP).

2.1 Density and Pattern

Prior to field work, the Frontier data were analysed firstly to obtain a measure of density of *C. usambarensis* (dbh >10cm) per hectare and secondly to detect non-randomness using the Poisson series and chi-squared test for goodness-of-fit (Kershaw & Looney, 1985).

2.2 Species identification

A total of six *Cola* species (*C. usambarensis, C. greenwayi, C. scheffleri, C. clavata, C. microcarpa* and *C. stelacantha*) have been recorded in the East Usambara Mountains (see Cunneyworth *et al*., 1996; Doggart & Dilger, 1997). Herbarium specimens were examined at the Royal Botanic Gardens, Kew and the University of Dar es Salaam (UDSM) prior to fieldwork in order to identify distinguishing characteristics of *C. usambarensis* as compared to the other species in the *Cola* genus. An identification key (Brenan, 1956), and a bark identification key (Junikker, in press) further facilitated identification. Voucher specimens of *C. usambarensis*, together with *C. greenwayi* and *C. clavata* were collected during the course of the study and deposited at Amani Botanical Garden, and the Herbariums at Kew and UDSM. Furthermore, the EUCFP assigned a Tanzanian field botanist, Mr Iddi Rajabu, to assist with in-situ plant identification.

2.3 Selection of sampling areas

In view of the size of the East Usambaras and the problems of accessibility, it was impractical, in the time available, to survey *C. usambarensis* throughout its range (as recommended by Given (1994)). Therefore a stratified random sampling method was employed using existing information on its distribution.

The main source of baseline data is from the findings of the biodiversity surveys which have been carried out in 11 forest reserves since 1994 by the F-T EUFRP (Cunneyworth *et al*., 1996; Cunneyworth, 1997; Doggart & Dilger, 1997, Doggart *et al*., 1997). Systematic vegetation surveys involve the division of each forest reserve into 450m x 450m grid squares. In the south-east corner of each grid, a 50m x 20m plot is sampled and every tree with a dbh (diameter at breast height) of 10cm or over is recorded, marked and identified. Of the 347 50m x 20m plots surveyed, *C. usambarensis* has been recorded in 28, in five Forest Reserves. The general plot characteristics in which *C. usambarensis* was found were then compared to see if a pattern emerged (see Appendix 1). 68% of plots contained mature mixed forest, mostly with mid-slope or gentle lower slope topography. Altitude ranged from 160m – 650m and slope angle and aspect varied considerably.

The other source of information on the distribution of *C. usambarensis* stems from work undertaken by Sawe (1996), Mashauri (1997) and Junikker (in press) in submontane forest in Amani Nature Reserve.

For the purpose of this study, two discrete forest blocks were chosen, representing submontane (Amani Nature Reserve) and lowland (Bamba Ridge/Kwamgumi/Segoma Forest Reserve complex) forest types. Within the boundaries of the reserves, aerial photographs (from 1992) and vegetation maps were examined to identify areas of mature mixed forest. Within this vegetation stratum sample positions were selected randomly

2.4 Survey method

A number of survey techniques were considered to take into account the low density and rarity of *C. usambarensis* as well as the fact that unskilled Frontier volunteers would be assisting with the field activities. It was important, therefore, that the method was simple and covered as large an area as possible. Random meanders and timed meander searches (Given, 1994) were considered but in view of the limitations, namely that some areas may be covered more than once and others not at all, and the lack of reliable statistical procedures that can be applied to the results, a 1ha plot methodology was ultimately selected. The reasons for this were twofold: first 1ha plots are considered to be appropriate for tropical forest studies, and second this method is used by the Smithsonian Institution-Man and Biosphere Programme (Dallmeier, 1992) for long-term monitoring in tropical forests.

In the stratified study areas, 1ha plots were positioned randomly. In total 12 plots were sampled: two at Amani, two in Segoma FR, and four in both Bamba Ridge and Kwamgumi FRs (Figure 3).

The outer boundary of the plot was measured and tagged at 20m intervals. The plot was then divided into 25 quadrats 20 x 20m in size (Figure 2). The quadrats were numbered consecutively, starting at the baseline of the plot, and the tag in every quadrat corner labelled with a letter and number to differentiate its location in the plot. Every quadrat was surveyed for *C. usambarensis*. All data were recorded on a Recording Form (see Appendix 2)

Figure 2. The 1 ha plot is divided into 25 quadrats (20 x 20m), each with an identification code.

100m x 100m (1ha)

A5	B5	C5	D5	E5
A4	B4	C4	D4	E4
A3	B3	C3	D3	E3
A2	B2	C2	D2	E2
A1	B1	C1	D1	E1

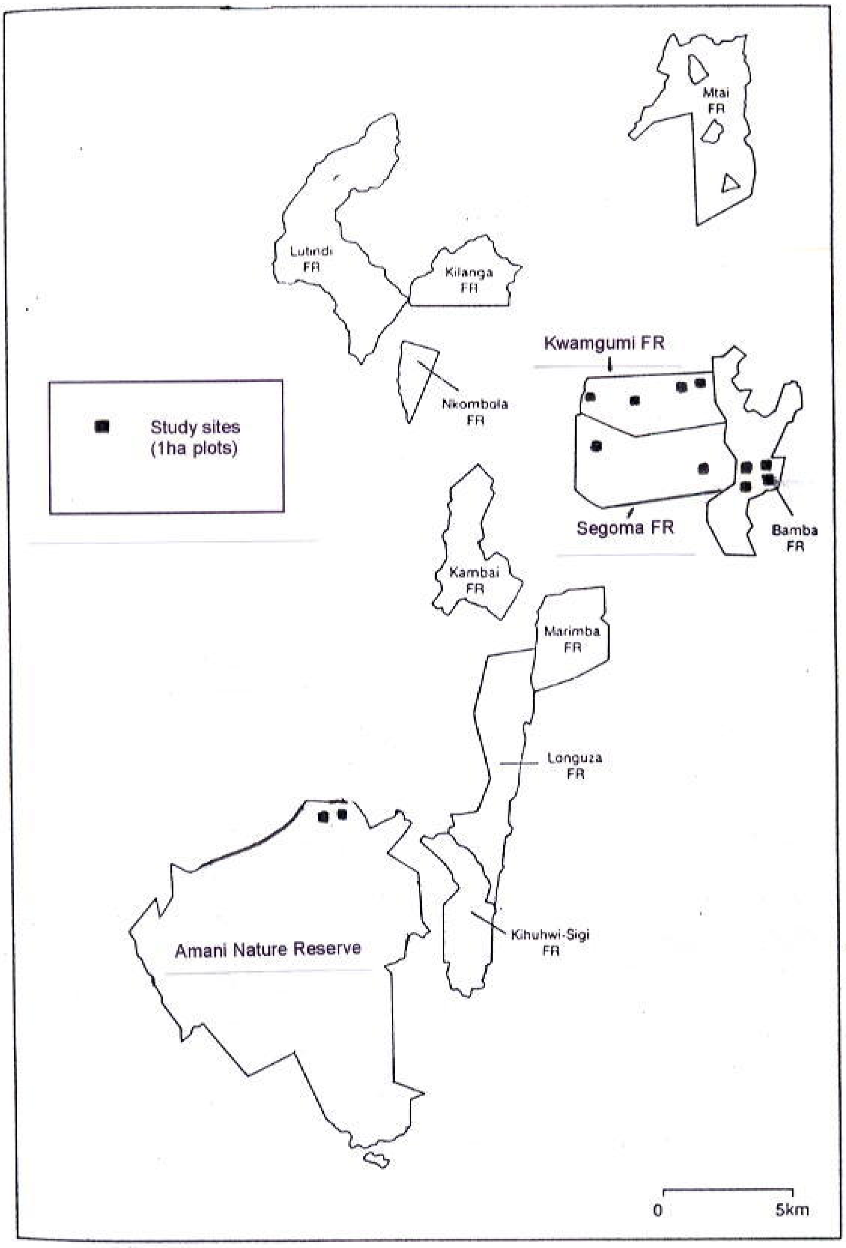


Figure 3. The East Usambara Mountains showing protected forest areas and location of study sites

2.5 Plot characteristics

In every plot, general characteristics were noted. These included altitude (using an altimeter), slope angle (using a standard forestry clinometer), topography, canopy height, vegetation type, vegetation condition and evidence of disturbance (e.g. fire). In each 20 x 20m quadrat, the canopy closure (%) was estimated and any areas with tree fall mapped. The dominant trees and shrubs were also recorded, and the nearest trees/shrubs within a 6m radius of every *C. usambarensis* tree were identified.

One soil sample was taken from each plot and analysed at the University of Dar es Salaam for organic matter content, soil texture, exchangeable bases, cation exchange capacity (CEC), total Nitrogen and available Phosphorus. Methods used are described by Allan (1989).

2.6 *Cola usambarensis* distribution and regeneration

An intensive search for *C. usambarensis* was carried out in each quadrat (starting in A1 and working systematically to E5). The height and dbh (>4cm) of all trees encountered were measured. A dbh of 4cm was observed to be the minimum for flowering trees and was used as to distinguish mature individuals from juveniles. The % canopy closure was estimated above each tree. Since the majority of trees were multi-stemmed, the cross-sectional area at breast height (csabh) was later calculated from dbh. This alternative measure allows a standardised trunk size to be calculated for trees with more than one stem at breast height, by summing the csabh for all stems. Observations were made of trees that were flowering or fruiting and damage to individual trees was recorded.

A 6m circular plot was established around each adult tree. Within this area, *C. usambarensis* seedlings and saplings (dbh <4cm) were recorded together with % canopy closure directly above the individual plants. The height of each sapling and distance from the mother tree were measured, using a tape measure, and any evidence of leaf damage noted.

All trees (adults and juveniles) encountered were mapped in relation to two adjacent corner tags.

2.7 Socio-economic survey

Socio-economic surveys were carried out in three villages (Kwamtili, Churwa and Segoma) surrounding the Bamba/Kwamgumi/Segoma forest complex. Due to logistical constraints, it was not possible to conduct interviews with herbalists operating within villages adjacent to Amani Nature Reserve. Interviews were held with traditional herbalists/medicinal practitioners to ascertain the extent and types of use of *C. usambarensis*, as it was known to be important for tool handles (Ruffo, 1989) and as a remedy for stomach complaints (Woodcock, 1995). The questionnaire is shown in Appendix 3. Iddi Rajabu acted as interpreter. Interviews were either conducted in *Kiswahili* or the local dialect, *Kisambaa*.

3. RESULTS

3.1 Density

The average density of *C. usambarensis* (dbh >10cm) was 2.19/ha, calculated from the existing Frontier data (see Table 1).

Table 1. Density of *C. usambarensis* (from Frontier systematic surveys)

Forest Reserve	Area (ha)	Total no. of 50m x 20m (0.1ha) plots surveyed	No. of 0.1ha plots in which *C. usambarensis* recorded	No. of individuals recorded	Density/ha
Bamba Ridge	1,131	33	8	26	7.87
Kambai	1,000	51	10	32	6.27
Kwamarimba	887	54	2	2	0.37
Kwamgumi	1,148	54	6	14	2.59
Mtai	2,985	110	2	2	0.18
Mlungui	200	10	0	0	0.00
Longuza	1,579	20	0	0	0.00
Semdoe	900	15	0	0	0.00
Total		**347**	**28**	**76**	**2.19/ha**

The density figures for *C. usambarensis* are relatively low when compared with other species. For example, the densities for *Leptonychia usambarensis* and *Funtumia africana* in Mtai Forest Reserve were 17/ha and 22/ha respectively. This compares with 0.18/ha for *C. usambarensis.*

3.2 Distribution pattern

There was a significant difference ((^{2} = 934.61, df = 5, p<0.001) between the Poisson series (expected) and the observed data (ie a non-random distribution) for *C. usambarensis* in the 0.1ha Frontier plots. This was verified by calculating the variance to mean ratio which was 8.8 (SE = 0.076; t = 115.78; p < 0.001). A variance:mean ratio of <1 indicates a regular distribution, 1 indicates a random distribution and >1 indicates a contagious distribution. Therefore, this result shows that *C. usambarensis* has a contagious (or clumped) distribution pattern.

3.3 Plot characteristics

C. usambarensis was located in 6 out of the 12 1ha plots surveyed. The general plot characteristics are detailed in Table 2. The photographs in Plates 1 and 2 give an indication of the forest type and condition.

3.3.1 Altitude and aspect

Table 2 shows that *C. usambarensis* was recorded at a range of altitudes (120m – 950m) in both lowland and submontane forest on east, north and west-facing slopes.

3.3.2 Hydrology and topography

All of the plots, with the exception of Am1, were dissected by or adjacent to seasonal or permanent river courses. The topography varied from steep upper to gentle lower slopes.

3.3.3 Vegetation type

The vegetation type was classified as either submontane or lowland forest. The floristic composition of the forest types are described by Hamilton et al. (1989). The species that were most commonly associated with *C. usambarensis* in both submontane and lowland forest types are listed in Appendix 4.

The submontane forest plots (Am1 and 2) were dominated by *Allanblackia stuhlmannii*, *Newtonia buchananii* and *Maesopsis eminii* which are all large trees, reaching heights of up to 60m and providing a dense canopy cover. The latter species has been introduced into the East Usambaras and has rapidly become naturalised through invasion of gaps in indigenous forest (Binggeli & Hamilton, 1993). The dominant shrubs were *Alchornea hirtella* and *Whitfieldia elongata* which are both indigenous species. *Clidemia hirta* and *Lantana camara* were abundant in gaps. These are likely to have been introduced as exotics to Amani Botanical Garden as they are common on logging tracks and roadsides (Pocs, 1989). The tree species most commonly associated with *C. usambarensis* (within a maximum distance of 6m) were *Allanblackia stuhlmannii*, *Alchornea hiltara*, *C. usambarensis*, *Cephalosphaera usambarensis, Maesopsis eminii, Mesogyn insignis* and *Sorindeya madagascariensis*.

Table 2. General plot characteristics with number of *C. usambarensis* adults and saplings

Location	Plot Code	No. adults (dbh>4cm)	No. saplings	Mean canopy closures (%)	Veg type	Veg condition	Altitude (masl)	Topography	Slope angle (°)	Aspect	Canopy ht (m)	Human disturbance	Fire Disturbance
Amani NR	**Am1**	**40**	**37**	**57.6**	**SM**	**F**	**950**	**SU**	**28**	**E**	**60**	✓	**x**
	Am2	**42**	**78**	**62.8**	**SM®**	**F**	**900**	**SM**	**30**	**NE**	**60**	✓	**x**
Bamba FR	Bam1	0	0	30.4	L®	ODF	300	SM	32	W	25	x	✓
	Bam2	0	0	38.0	L®	ODF	320	SM	30	SW	20	✓	✓
	Bam3	0	0	28.4	L®	ODF	380	SM	35	SW	30	✓	✓
	Bam4	0	0	30.8	L®	ODF	400	SU	30	SE	30	✓	✓
Kwamgumi FR	Kwam1	0	0	50.8	L®	ODF	345	SM	35	NW	30	X	✓
	Kwam2	**14**	**74**	**64.4**	**L®**	**F**	**120**	**GL**	**12**	**W**	**20**	**X**	**x**
	Kwam3	**22**	**82**	**63.6**	**L®**	**F**	**350**	**SM**	**32**	**N**	**25**	✓	**x**
	Kwam4	0	0	30.0	L®	ODF	350	SM	22	NW	25	✓	✓
Segoma FR	**Seg1**	**6**	**44**	**72.0**	**L®**	**F**	**220**	**SM**	**23**	**NE**	**25**	✓	**x**
	Seg2	**7**	**20**	**65.6**	**L®**	**F**	**240**	**SM**	**28**	**W**	**20**	**x**	**x**

Plots containing C. usamabarensis are in **bold**

KEY

Vegetation type:
SM® Submontane forest (riverine)
L® Lowland forest (riverine)

Vegetation condition:
F Mature mixed
ODF Open disturbed forest

Topography:
SU Steep upper
SM Steep middle
GL Gentle lower

Plate 1. View of Kwamgumi Forest Reserve from surrounding farmland

Plate 2. Fire disturbed plot (Bam3) in Bamba Ridge Forest Reserve

Common species in the lowland forest plots included *Antiaris toxicaria, Bombax rhodognaphalon* and *Terminalia sambesiaca*. *C. usambarensis* occurred in association with both large and small lowland forest species, in particular *Antiaris toxicaria* and *Leptonychia usambarensis*. *Antiaris toxicaria* is a riverine species (Hamilton *et al*., 1989). *Alchornea hirtella, Whitfieldia elongata* and the grass *Olyra latifolia* were abundant in tree fall gaps and fire disturbed areas.

3.3.4 Vegetation condition

3.3.4.1 Fire disturbance

Six plots, four in Bamba Ridge Forest Reserve and two in Kwamgumi Forest Reserve, had been disturbed by recent fires (January 1997). The plots were characterised by a relatively low mean percent canopy closure which is shown in Figure 4, and large tree fall gaps, dominated by colonising shrubs and herbs (e.g. *Alchornea hirtella* and *Lantana camara*) and dry friable soil. No *C. usambarensis* trees were recorded in these plots. Interestingly, *C. clavata, C. greenwayi* and *C. scheffleri* were recorded in the fire disturbed plots which suggests that these species are more resistant to the effects of fire damage or favour slightly drier forest which is therefore more fire-prone.

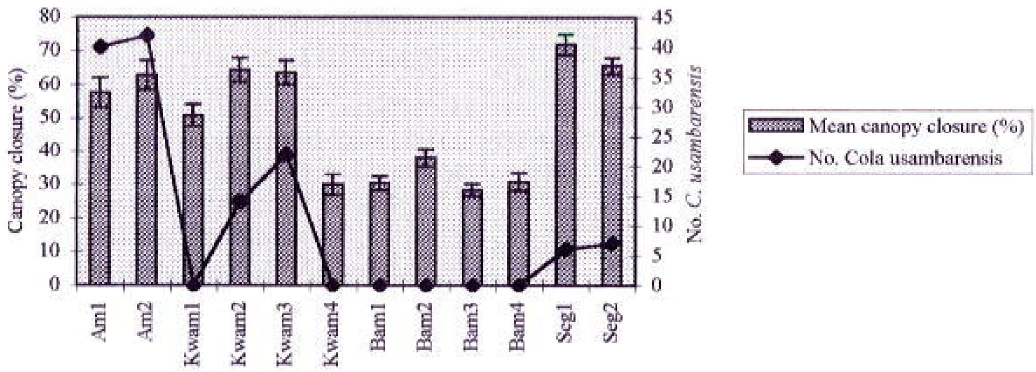
3.3.4.2 Natural tree fall and canopy closure

Natural tree fall was evident in all of the plots (Figure 5). *C. usambarensis* was generally not found in tree fall gaps. The strength of this negative association was calculated using a chi-squared test and found to be highly significant ($\chi^2 = 15.744$, $p < 0.001$).

The % canopy closure was estimated in every 20m x 20m quadrat, regardless of whether *C. usambarensis* was present, in order to determine whether this was a factor affecting its distribution.

One-way analysis of variance (ANOVA) was performed to test for variation in % canopy cover. There was no significant difference in canopy closure in the plots where *C. usambarensis* was present. It was therefore assumed that the different forest reserves exert no ‘treatment’ effects on the data. Consequently the canopy closure data was tested for variation between all of the plots. The results showed a significant variation in mean canopy closure between the plots in which *C. usambarensis* was present (higher canopy cover) and those in which it was absent (F: 27.68, $p < 0.01$). The mean % canopy closure (standard error bars shown) and number of trees in each plot are presented in Figure 4.

Figure 4. Relationship between number of *C. usambarensis* trees and mean canopy closure in each plot



3.3.5 Soils

The results of the soil analysis are presented in Table 3. The samples from Plots Bam1 and 2 had low levels of total Nitrogen (N) and all the Bamba plots had low levels of potassium (K). High % available Phosphorus (P) levels were recorded from the plots in which *C. usambarensis* was absent with the exception of Seg2. Two samples had a low cation exchange capacity (CEC) (Kwam2 and Bam1) which is attributed to the high sand content in the soil. Exchangeable sodium was very low in all the soil samples.

The soil samples from the Amani plots contained the highest levels of organic matter, exchangeable bases and N and K.

Independent *t* tests were performed to compare the means of the various soil properties between the plots in which *C. usambarensis* was present and absent to investigate whether soil fertility was affecting its distribution.

Table 3. Results of soil analyses

Plot	Soil Texture			Classification based on ISSS	OM %	Exchangeable Base Meq/100g				CEC Meq/100g	Total N %	Available P %
	% Sand	% Silt	% Clay			Na	K	Ca	Mg			
Am1	**10**	**20**	**70**	**Clay loam**	**9.00**	**0.13**	**4.96**	**63.00**	**16.64**	**98.06**	**2.10**	**0.031**
Am2	**15**	**21**	**64**	**Clay loam**	**13.38**	**0.14**	**5.00**	**62.10**	**16.50**	**98.14**	**2.11**	**0.032**
Kwam1	8	32	60	Loam	3.66	0.16	1.40	24.13	10.41	51.31	1.61	1.28
Kwam2	**55**	**15**	**30**	**Sand loam**	**4.98**	**0.14**	**1.11**	**5.14**	**3.20**	**18.34**	**2.31**	**0.16**
Kwam3	**10**	**35**	**55**	**Loam**	**7.08**	**0.16**	**1.52**	**24.11**	**10.17**	**51.28**	**1.14**	**0.01**
Kwam4	10	15	75	Clay loam	6.78	0.16	5.33	62.30	16.60	98.17	1.68	1.64
Bam1	55	15	60	Sand loam	2.80	0.01	0.45	7.20	3.30	13.40	0.23	3.80
Bam2	10	20	70	Clay loam	4.80	0.09	0.50	8.80	2.80	23.60	0.31	6.80
Bam3	10	30	60	Loam	3.27	0.16	0.10	6.52	10.58	58.26	1.64	2.90
Bam4	10	20	70	Clay loam	3.82	0.16	0.88	5.24	4.50	51.08	1.15	3.10
Seg1	**10**	**30**	**60**	**Loam**	**5.00**	**0.12**	**5.16**	**42.00**	**13.11**	**73.20**	**1.63**	**0.041**
Seg2	**10**	**25**	**65**	**Loam**	**3.66**	**0.11**	**1.32**	**24.11**	**10.28**	**51.26**	**2.20**	**1.60**

Plots in which *C. usambarensis* were recorded are in **bold**.

The results showed that there was no significant difference in organic matter content, sodium (Na), potassium (K), calcium (Ca), magnesium (Mg) or cation exchange capacity (CEC) between the plots.

However, there were significant differences in the means of total N ($t = 2.461$, $df = 10$, $p < 0.01$) and available P ($t = 3.867$, $df = 10$, $p < 0.01$) which are both important macro-nutrients. The % total N was greater in the plots in which *C. usambarensis* was present. Conversely, with the exception of Plot Seg2, there was a higher percentage of available P in the soil samples taken from the plots in which *C. usambarensis* was absent. High available P levels may be a consequence of fire rather than a factor controlling *C. usambarensis* distribution.

The density of adult trees was then correlated (Spearman's Correlation Coefficient) with the soil properties. There was a significant positive correlation between tree density and % organic matter ($p < 0.001$) and a negative correlation with available P ($p < 0.01$). There was no correlation between density and total N, Mg, K, Ca or CEC.

3.4 *Cola usambarensis* distribution and regeneration

Maps showing the exact location of *C. usambarensis* trees and saplings by plot are shown in Figure 5. Features of interest such as river courses, tree fall and footpaths are also displayed.

3.4.1 Size Classes of mature trees

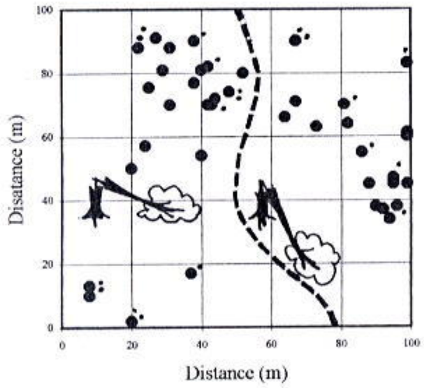
3.4.1.1 Height

The trees were small with a mean height of 7.67m (SD: 3.0, SE: 0.267). Few reached a height of over 10m. The mean tree height in each plot, and the height classes for all trees, are displayed in Figure 6 and 7 respectively. The histograms show that i) the submontane forest plots contained trees with the greatest height variation about the mean indicating a wider range of height classes (immature and mature trees) than the lowland plots (e.g. Seg2); and ii) overall there were very few tall trees (maximum height of 20m).

Figure 5. Spatial maps of 1ha plots in which *C. usambarensis* were recorded

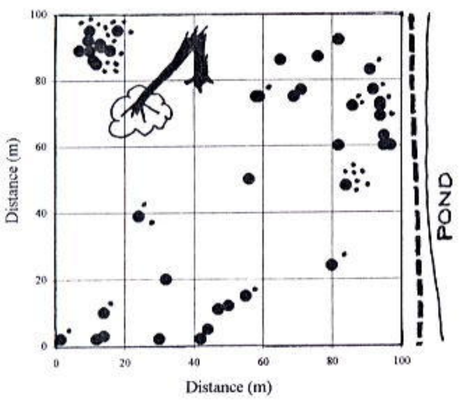
N

Plot Am1



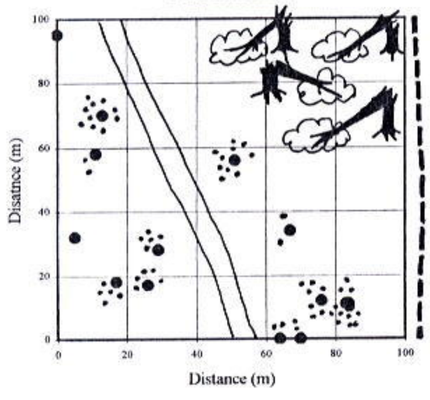
Location: Amani Nature Reserve
Grid Reference: 38°32'E, 04°48'S
Altitude: 950m
Vegetation type: forest
Canopy ht: 50m
Topography: steep mid-slope
Slope angle: 28 degrees
Aspect: E

Plot Am2



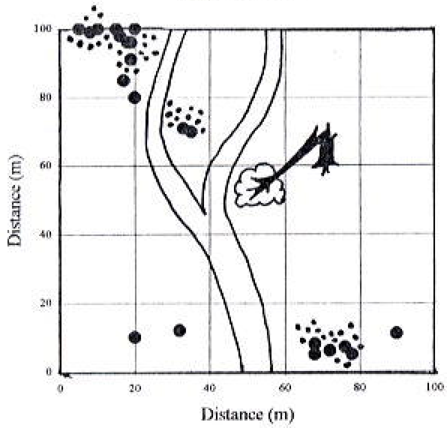
Location: Amani Nature Reserve
Grid reference: 38°48'E, 04°48'S
Altitude: 900m
Vegetation type:riverine forest
Canopy height: 50m
Topography: steep lower-slope
Slope angle: 30 degrees
Aspect: NE

Plot Kwam2



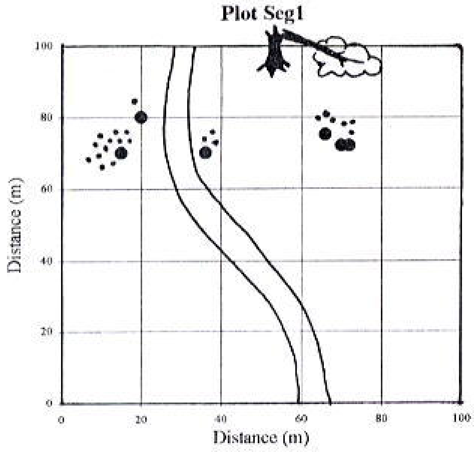
Location: Kwamgumi FR
Grid reference: 38°45'70E, 05°00'54S
Altitude: 120m
Vegetation type: riverine forest
Canopy height: 20m
Topography: gentle lower slope
Slope angle: 12 degrees
Aspect: W

Plot Kwam3



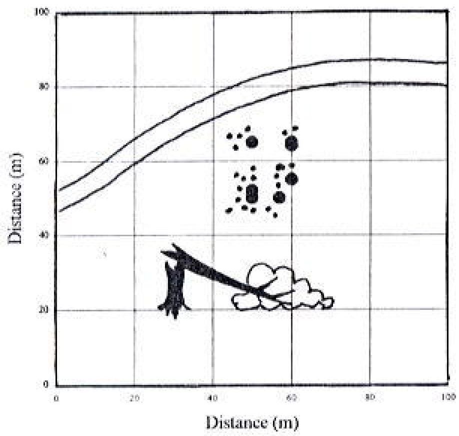
Location: Kwamgumi FR
Grid reference: 38°45'74E, 05°00'54S
Altitude: 350m
Vegetation Type: riverine forest
Canopy height: 20-30m
Topography: steep mid-slope
Slope angle: 32 degrees
Aspect: N

Plot Seg1



Location: Segoma FR
Grid reference: 38°45'75E, 05°00'51S
Altitude: 220m
Vegetation Type: riverine forest
Canopy height: 25m
Topography: gentle lower slope
Slope angle: 23 degrees
Aspect: NE

Plot Seg2



Location: Segoma FR
Grid reference: 38°45'71E, 05°00'52S
Altitude: 240m
Vegetation type: riverine forest
Canopy height: 20m
Topography: steep middle slope
Slope angle: 28 degrees
Aspect: W

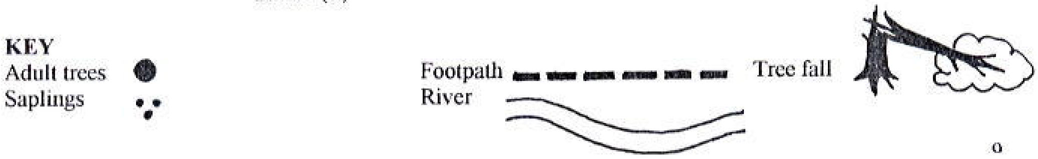


Figure 6. Mean tree height by plot

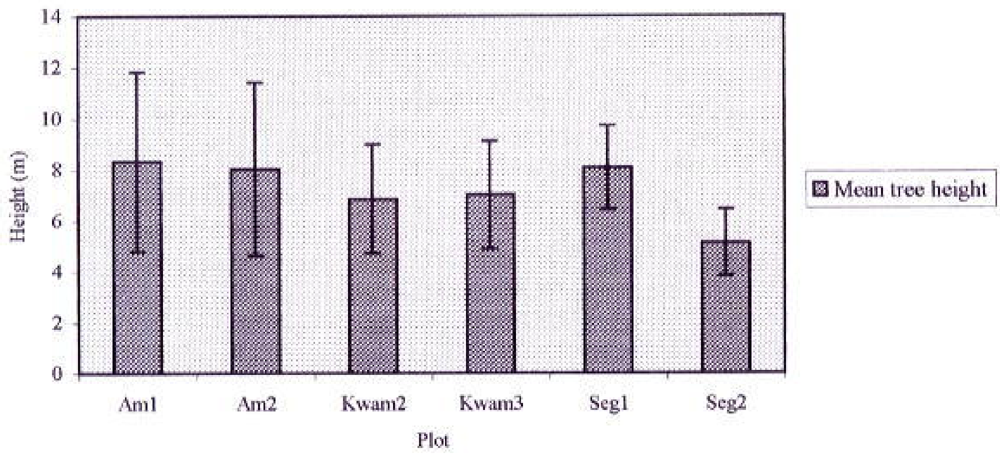
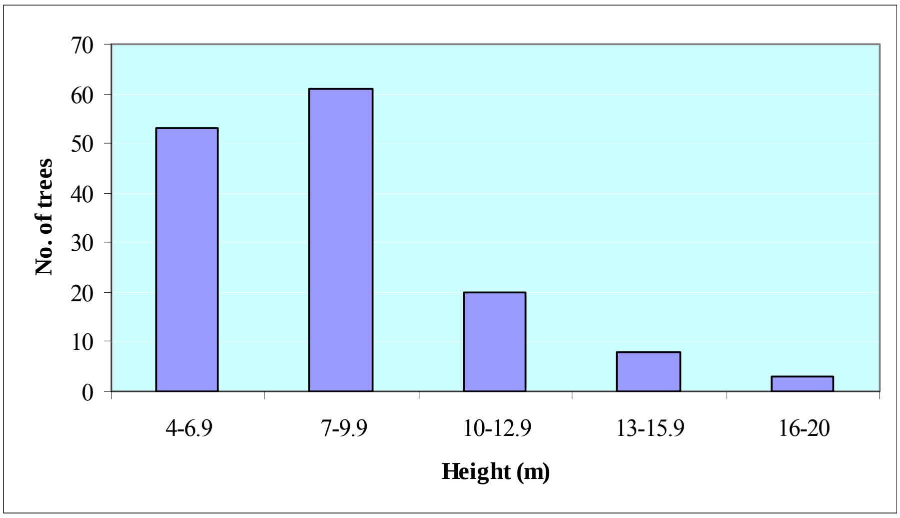


Figure 7. Height classes of *C. usambarensis*



3.4.1.2 Area at breast height

The area at breast height (m^2/ha) was calculated from dbh measurements or from the csabh for trees that were multi-stemmed. The area at breast height (abh) of *C. usambarensis* in each plot is shown in Figure 8 and, as expected, is higher in the plots with a higher density of trees. The mean basal area per tree was $0.0044m^2$ which is very low indicating that on average the stems were thin.

Figure 8. Area at breast height (m2/ha) by plot

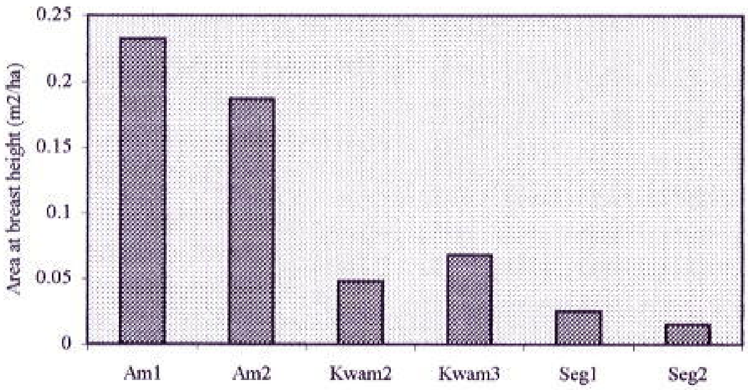


Table 4 below shows the number of trees in each plot and the average stem size (column 4). When compared with the histogram in Figure 7, it is possible to infer the age of tress. For example, in Plot Seg1, only 6 trees were recorded but they were above average height and had a relatively large abh. This suggests that the trees are more mature than those found in for instance Plot Seg2.

Table 4. Area at breast height (abh) per plot and per tree

Plot	No. of trees	Abh (m^2/ha)	Abh (m^2)/tree
Am1	40	0.23	0.005
Am2	42	0.18	0.004
Kwam2	14	0.05	0.004
Kwam3	22	0.06	0.002
Seg1	6	0.03	0.005
Seg2	7	0.01	0.001

There was no significant correlation between tree height and basal area ($p > 0.1$) when tested using Spearman's correlation coefficient.

3.4.2 Regeneration

3.4.2.1 Coppicing

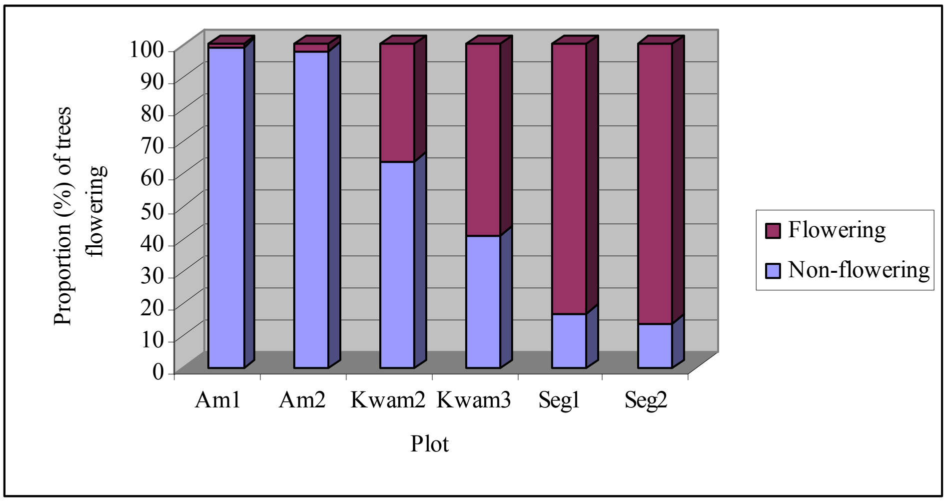
87 (66%) of the trees coppiced, producing thin straight stems from the base of the main trunk (ideal for building poles). The greatest number of stems recorded from a single individual was 11 whilst the average number of stems per tree was three.

3.4.2.2 Flowers and fruits

Past field observations (Sawe, 1996), have shown that the fruiting and flowering period for *C. usambarensis* occurs between October and December. The collection dates for all fertile herbarium specimens examined prior to field work were also within this period.
The observations of both flowering and fruiting trees made during this study (in July) may be the result of the early and prolonged monsoon rains between February and June 1998 inducing early flowering.

30 adult trees were in flower. All but one of these was located in lowland areas in Kwamgumi and Segoma FRs. Flowering trees were particularly abundant in moist riverine forest where numerous buds were also observed. Figure 9 shows the proportion of flowering trees by plot.

Figure 9. The proportion (%) of flowering trees in plots in each forest reserve



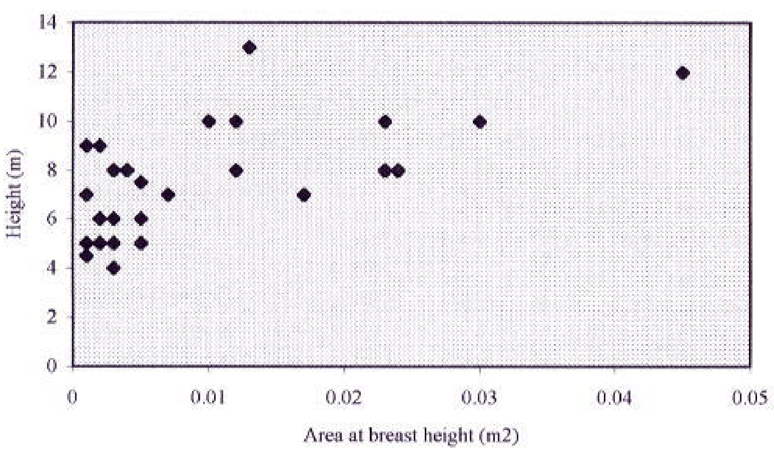
The flowers are cauliflerous. They are small (< 1cm in diameter) and creamy-brown in colour (see Plate 5). In Plot Kwam2, a pollinator which looked like a wasp (possibly

Hymenoptera) was observed on a flower. It was not possible to collect a specimen for identification.

The minimum height and area at breast height of flowering trees was 4m and 0.0007m² respectively. The size classes are displayed in Figure 10. 11 (37%) of the flowering trees were single-stemmed (min. dbh: 4cm) and 19 (63%) were coppiced (min. mean dbh: 2.5cm).

Only trees that had not been harvested were observed to be flowering. However, there was evidence of regeneration close to trees that had been cut.

Figure 10. Size classes of flowering trees



Only one tree in Plot Am1 was fruiting. The tree was single-stemmed (dbh = 36cm) and 10.5m tall. The drupe fruits were unripe and pale yellow in colour (fruits turn dark red when ripe) and the fruits were observed along the stem and branches.

3.4.2.3 Saplings

A total of 335 saplings were recorded (Plate 4). The height classes were plotted (Figure 11) to give a typical reverse J-shaped curve or Type III survivorship curve (Begon et al., 1996). Over 50% of saplings were less than 50cm high and within this size class 31% were less than 10cm high which indicates extensive mortality in the early growth stages.

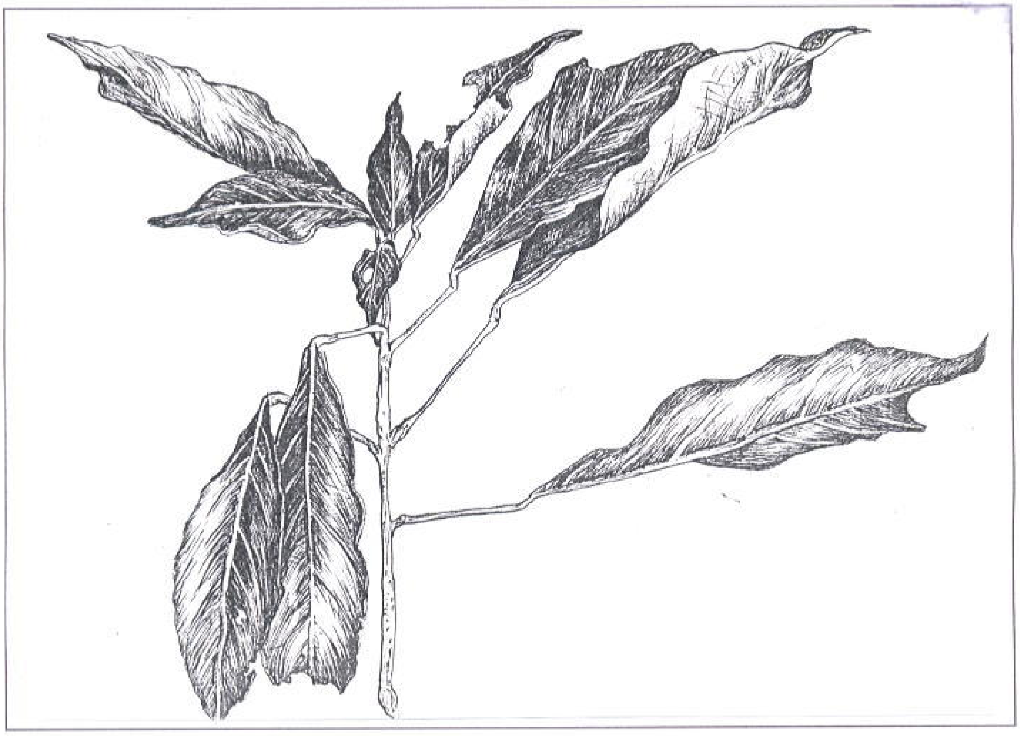


Plate 3. Illustration of a leaf specimen from an adult *Cola usambarensis* tree (illustration by Barry Marsden)

Plate 4. *Cola usambarensis* sapling (Plot Kwam3)

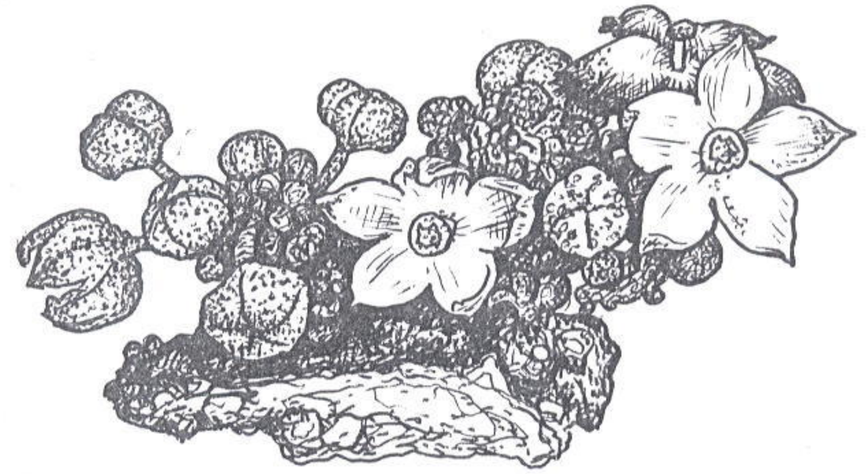


Plate 5. *Cola usambarensis* flowers – growing on the main stem and in close up (illustration by Barry Marsden)

Figure 11. Height classes of saplings

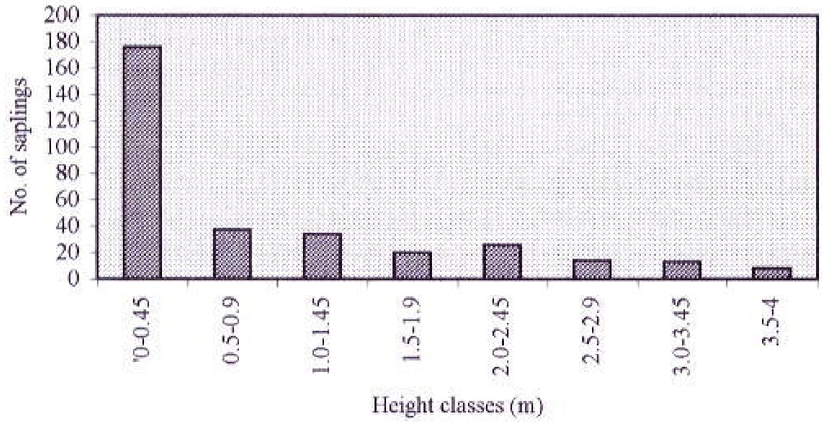
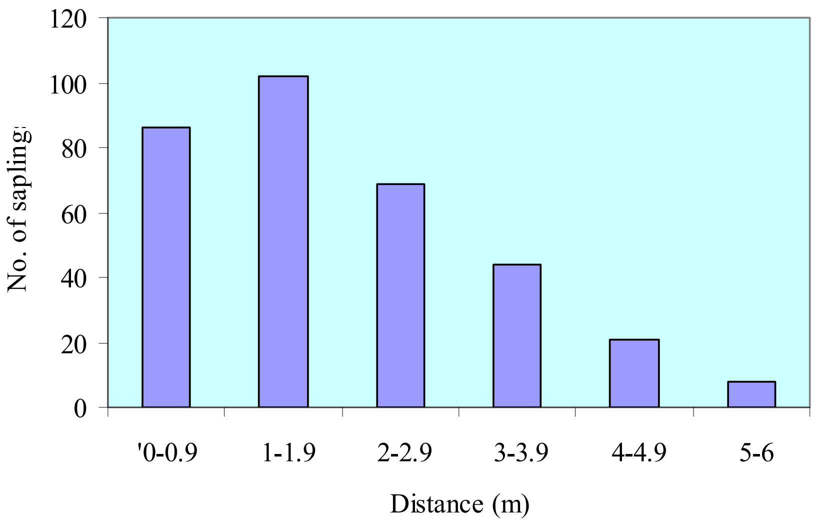


Figure 12. Distance of saplings from mother tree



The regeneration density decreased with distance from the mother tree with the highest density occurring between a distance of 0.1 – 1m (Figure 12). *C. usambarensis* has a small crown diameter of about 3-5m and it is possible that the high seed shadow provided by the mother tree contributes to higher regeneration within this area.

3.4.2.4 Sapling Damage

Leaf damage was recorded on 164 saplings. Since herbivores were not observed, it is difficult to know what was grazing them but the type of damage suggests that it was lepidoptera (caterpillars), rather than duiker or hyrax.

3.5 Adult tree damage

Evidence of pole cutting was observed in four out of six plots in Amani Nature Reserve, Kwamgumi and Segoma FRs. Table 5 below shows the number, and percent, of trees in each plot that were damaged naturally or from harvesting for building poles. De-barking for rope was only observed on one tree (Plot Am2).

Table 5. Number of trees damaged in each plot

Plot	**No. trees damaged**			
	Harvested	**%**	**Insect/ fungi**	**%**
Am1	2	5	4	10
Am2	17	40	14	33
Kwam2	-	-	-	-
Kwam3	4	18	-	-
Seg1	1	17	-	-
Seg2	-	-	-	-
Total	**24**	**80**	**18**	**43**

The level of harvesting was in part related to accessibility. For instance, one side of Plot Am2 bordered a well-used footpath and most of the trees that had been cut were adjacent to this access route (see Figure 5). Plot Am1 was dissected by a footpath but this is rarely used by local villagers. As such, the level of harvesting was low.

No damage was recorded in Plot Kwam2. This is surprising because it bordered a path and was only a short distance from Kwamtili village. Plot Kwam 3 was accessible from a nearby path whilst both plots in Segoma FR were relatively inaccessible.

Plot Am2 contained the greatest proportion of trees damaged by insects/fungi. It is possible that this “natural” damage is in fact secondary infection caused by past harvesting for building poles.

Flowering was not observed on trees that had recently been harvested. However, regeneration was evident close to these trees.

3.6 The effect of canopy closure

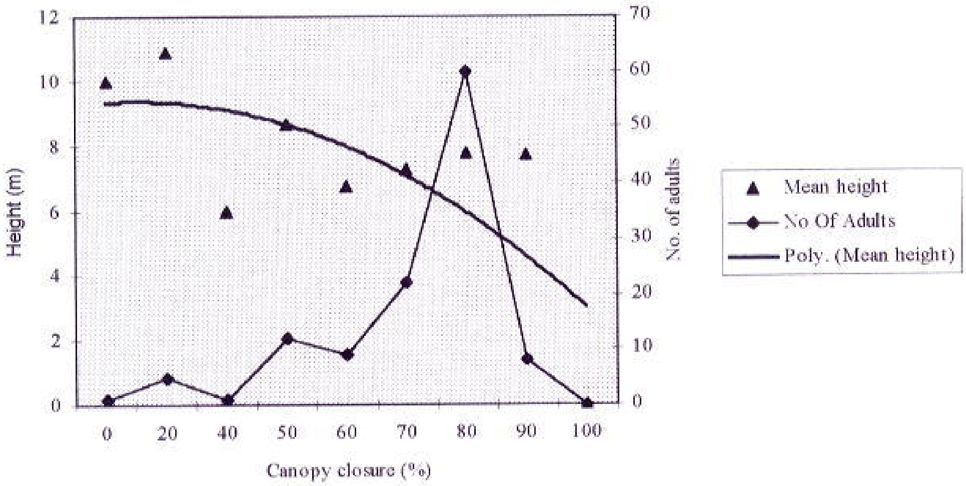
Regression analysis was carried out to test the significance of the association between the level of light intensity (independent variable) and the number and height of both adults and saplings (dependent variable). Separate measurements of canopy closure directly above trees and saplings were used for these tests.

The results are presented below:

3.6.1 Number & height of adults related to canopy closure

Figure 13 shows that there was a significant positive relationship between the frequency of adults and % canopy closure ($y = -0.41 + 0.025x$, $p < 0.001$). In other words, one would predict a greater number of adults in areas with a canopy closure of between 60-80% (ie low light intensity).

Figure 13. The number and height of adult trees related to canopy closure

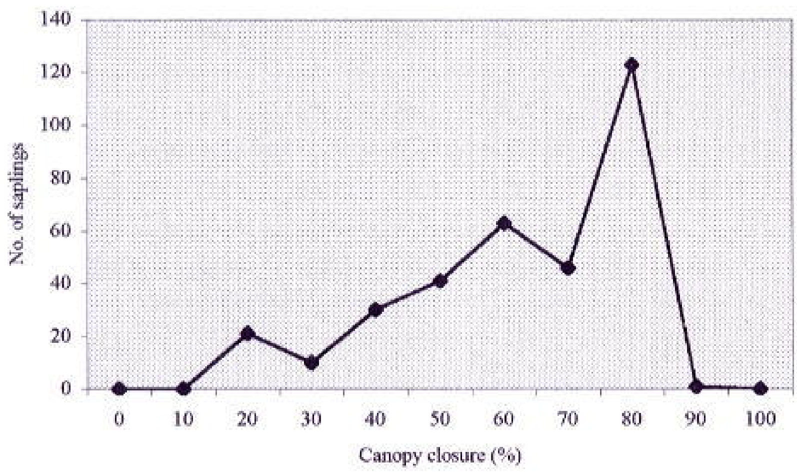


The relationship between tree height and canopy closure was not significant when tested by a linear regression ($p > 0.5$). However a negative relationship was observed when the variables were tested by a quadratic regression ($p < 0.5$) (see Figure 13 above). When comparing the two graphs (frequency and height) an inverse relationship is apparent. In other words, only a few tall trees (mean height >10m) were growing under canopy of less than 30%, most trees of average height were present in forest with a canopy closure of between 50-80%, and none were recorded in complete closed canopy.

3.6.2 Number & height of saplings related to canopy closure

There was a significant positive relationship between the number of saplings and canopy closure ($y = -1.64 + 0.016x$, $p < 0.01$) with the greatest number occurring under canopy cover of 60-80%. Few were observed in areas of very high closure above 80%. This is illustrated in Figure 14.

Figure 14. Number of saplings related to canopy closure



The relationship between sapling height and % canopy closure was not significant ($y = 81.4 + 0.081x$, $p > 0.5$) when tested for a linear or quadratic regression.

3.7 Socio-economic survey

Interviews were conducted in three villages close to Kwamgumi and Segoma FRs. Specimens of both *C. usambarensis* and *C. clavata* were shown to the interviewees in order to compare uses and verify identification. The uses of both species are detailed in Table 6.

The vernacular names (*Kisambaa*) for *C. usambarensis* were "*Muungu*", which is used as a general name for a number of species in the Sterculiaceae family (including *C. clavata*), or more specifically, "*Muekei*" which translates as "leave him".

Table 6. Local non-commercial uses of *C. usambarensis* compared with *C. clavata*

Species	Uses					Parts used	Source
	Poles	Rope	Tool/spoon handles	Bows	Medicinal		
C. usambarensis	✓	✓	✓	x	Headache, backache, stomach ache, scabies, madness	Stem, leaves, bark	Forest Reserves only
C. clavata	✓	x	x	✓	x	Stem	Forest Reserves & farmland

C. usambarensis is used for building poles, rope and medicine. Stems, bark and leaves are utilised but the whole tree is always left intact. It also has important spiritual value and is used to rid people of evil spirits (Mashetani). The seeds are not eaten/chewed because, unlike other species of *Cola*, *C. usambarensis* seeds do not contain caffeine (Mitchell-Watt & Breyer-Brandwijk, 1962).

Trees were only known to be growing within the nearby forest reserves. The collection frequency was 2/3 times a month or whenever a new house or particular ailment demanded it. Whilst *C. clavata* was common and cultivated in farms (shambas), *C. usambarensis* was considered rare and was becoming increasingly difficult to find.

According to local superstition, *C. usambarensis* can bring both good and bad luck. By carrying a small peg cut from the tree, travelers are believed to be protected (he/she will be left alone). However, if part of a tree is left inside, or grown near a house, then the occupants will be avoided by their neighbours and hence suffer in times of need. On-farm cultivation of *C. usambarensis* may therefore not be acceptable or appropriate in some villages.

4. DISCUSSION

The aims of this study were to: i) identify the key habitat factors controlling the distribution of *Cola usambarensis*; ii) investigate whether fire and non-commercial harvesting are threats; and iii) stydy the regeneration dynamics. The ultimate goal was to collect information necessary for the development of a species recovery plan. The results are discussed below and recommendations for research and management are proposed in Section 5.

4.1 Distribution and status

C. usambarensis was recorded in three out of the four protected areas surveyed. These were Amani Nature Reserve, and Kwamgumi and Segoma Forest Reserves. Documentation of this species in Segoma increases the number of protected areas in which it is now known to occur from six to seven (see Section 1.2).

No recordings were made in Bamba Ridge Forest Reserve where *C. usambarensis* had been identified by the Frontier programme in July 1995. Extensive fires in early 1997 damaged large tracts of forest in this reserve so it is possible that the population recorded in 1995 has suffered high mortality as a consequence of fire.

However, some doubt as to the correct identification of *C. usambarensis* by the Frontier programme was raised when a number of tagged *C. usambarensis* trees in two of the Frontier 01.ha plots were checked and found to be *Cola clavata*. While the Frontier data as a whole is believed to be sufficiently accurate, in view of the fact that different field botanists are involved in species identification in the 0.1ha plots both within and between forest reserves, it is not inconceivable that data for the other 6 plots in Bamba Ridge was also inaccurate. Thus a population of *C. usambarensis* may not have existed before the fire (see Table 1).

The data generated by the Frontier surveys, in combination with these results, show that *C. usambarensis* occurs at low densities in the East Usambara Mountains with sub-populations in only a handful of protected forests. Within these forest fragments, there is a tendency for *C. usambarensis* trees to clump together. This pattern may be a reflection of poor dispersal ability, which is a common feature of rare species (Hubbell, 1979; Rabinowitz, 1981;

Gaston, 1994) or it might be that its micro-habitat is local and rare. The possible cause will be intimated during the discussion. Whatever the underlying reason, a contagious distribution pattern can increase the vulnerability of a species to seed predation (Janzen, 1970), stochastic events such as fire or storms, and inbreeding depression (Kunin & Gaston, 1993) thereby increasing the risk of extinction. If the species is also at risk from human disturbance which increases the rates of mortality or decreases the rates of natality, the species is then subject to double jeopardy (Begon et al., 1996).

4.2 Key habitat factors

4.2.1 Altitude and aspect

The general plot characteristics detailed in Table 2 show that *C. usambarensis* has the potential to regenerate in both submontane (up to 950m asl) and lowland forest types implying that altitudinal gradient is not a factor controlling its distribution. Higher tree density in the Amani plots, however, suggests that wetter, cooler conditions may be more favourable for tree growth and development.

Aspect did not appear to be a key factor affecting distribution because *C. usambarensis* was recorded on north, east and west facing slopes.

4.2.2 Topography and soils

Topographic variation is thought to be a major factor influencing forest variation because it is closely correlated with soil moisture availability and aeration (Newbery & Proctor, 1984). Table 2 shows that five plots where *C. usambarensis* was found were on steep slopes (23-32°). This topographic position tends to have well-drained and aerated soils and may indicate that this species is intolerant of water-logged conditions. This supposition is supported by the results of the soil analysis shown in Table 3. The analysis reveals that soil texture, which influences the amount of moisture held in the soil in forms available for plant uptake, in the steep plots was clay loam or loam. The predominance of silt means that the soil water retention capacity is relatively high and thus moisture is available for plant uptake. On the other hand, in the only low-lying plot (Kwam2), the soil texture was sand loam. The relatively high proportion of sand allows water to percolate more freely so reducing the risk of water-logging.

The organic matter content in all the plots containing *C. usambarensis* was high. The proportion of organic matter in the soil is influenced by the amount of leaf litter and soil faunal activity. High levels tend to increase the cation exchange capacity and increase the amount of nutrients available for plant uptake. There was a positive correlation between tree density and organic matter content suggesting that this soil property is an important requirement for tree growth.

The results showed that the available phosphorus was significantly higher in the plots in which *C. usambarensis* was not recorded suggesting that this important macronutrient might be a factor limiting growth. However, these plots had been disturbed by fire. It is known that the percentage of available phosphorus in the topsoil is raised substantially following burning because the bulk of available phosphorus and most of the cationic nutrients are contained in the ash (Richards, 1996). Since the phosphorus level was also high in Seg2, in which *C. usambarensis* was recorded, it intimates that fire, as opposed to phosphorus levels, accounts for it absence.

Very little is known about the nutritional requirements of *C. usambarensis*. There data, although inconclusive, show that soils supporting *C. usambarensis* had good levels of nitrogen and potassium, a high cation exchange capacity and relatively high organic matter levels. Further investigation on the nutrient requirements of *C. usambarensis* seedlings may provide information useful for the development of ex-situ conservation programmes such as on-farm cultivation. Experiments to test the effect of soil texture and nutrient levels on the growth of dipterocarp seedlings have proved to be important for forest rehabilitation and enrichment planting in degraded habitats in Malaysia (Nussbaum et al., 1996).

4.2.3 Vegetation type and condition

With the exception of Am1, all the 1ha plots were dissected by or adjacent to seasonal or permanent streams. The location of water courses in relation to the distribution of this species are shown in Figure 5. As discussed above, *C. usambarensis* may be intolerant of poorly drained and aerated soils. However, the association with riverine areas suggests that it is also intolerant of moisture deficiency. Thus, the moist conditions and relatively high water table probably reduces the risk of moisture stress, particularly during dry spells.

C. usambarensis was closely associated with tall trees (e.g. *Allanblackia stuhlmannii* and *Leptonychia usambarensis*) that provided a dense canopy layer in the upper storey. As an understorey tree, the assumption is that it is shade-demanding and therefore sensitive to intense light and solar radiation levels. Figure 4 shows that this species was not recorded in the plots with an average canopy closure (over an area of 1ha) of less that 55% suggesting that this assumption is correct.

The results of the canopy closure measurements made directly above each *C. usambarensis* tree strengthens this argument because, as shown in Figure 13, they were found to be most abundant in shaded areas with a canopy cover of 80%. Fewer trees were recorded to be growing in forest with a more open canopy and none were recorded when the canopy was completely closed. The results also showed that trees were of average height in low light level (Figure 13). However, taller trees were reported in areas with lower cover and thus higher light levels. This may be explained by different light wavelengths. Compared with diffuse light, sunlight contains a greater proportion of red light which can be used in photosynthesis (diffuse light contains more blue, green and near-infra-red light which is not used in photosynthesis (Richards, 1996)). When a gap is opened and the tree is exposed to direct light, the rate of photosynthesis is likely to increase causing the tree to "bolt" upright. Because high solar radiation and light levels are unfavourable, few may survive.

When the number of saplings was related to canopy closure, a similar pattern to that of adults emerged with the highest abundance occurring under cover of 80% (Figure 14). It was observed that the leaves of saplings were several times larger than the adult leaves providing a greater surface area for photosynthesis in the shaded understorey during early growth stages.

The evidence from this survey suggests that the key habitat factors determining the distribution of *C. usambarensis* are moist (riverine) forest with a relatively high canopy closure and soils with good drainage, aeration and water retention capacity.

4.3 Threats

4.3.1 Fire

Extensive fires occurred in many of the lowland forest reserves in the East Usambaras between January and March 1997, following a prolonged period of drought. Fires may have been started naturally, but it is belied that the careless extinguishing of camp fires by illegal hunters and pit-sawers exacerbated the extent of damage (A. Salu, Catchment Officer, *pers. comms.*) Fire disturbance was recorded in six of the plots surveyed, four in Bamba Ridge Forest Reserve and two in Kwamgumi Forest Reserve.

Despite extensive searches, *C. usambarensis* was not recorded in these plots. This may be coincidental, but in light of the fact that it was recorded in both Bamba and Kwamgumi by Frontier in 1995 and 1996 respectively and in two undisturbed plots in Kwamgumi during this survey (Kwam2 and Kwam3), it is reasonable to suppose that *C. usambarensis* is sensitive to fire disturbance. As already mentioned above, trees are typically small, in terms of height and stem diameter and the bark is thin and smooth (*pers. obs.*). These characteristics may make it more vulnerable to flames and intense heat than larger trees which are less likely to be severely damaged. The other *Cola* species (*C. scheffleri, C. clavata* and *C. greenwayi*) observed in these plots were larger than their relative and their size may explain why they have persisted.

The incidence of tree fall was high in fire damaged plots compared to the undisturbed plots and large canopy gaps had been colonsied by fast-growing herbs, shrubs and pioneer species to form a dense understorey layer (Plate 2). Consequently, the mean canopy closure was relatively low as illustrated in Figure 4. The importance of dense canopy cover to the survival and growth of this species has already been demonstrated. Disturbance leading to a reduction in the canopy cover and the creation of gaps appears to have a negative effect on its distribution. Since fire alters the forest structure, it follows that fire will pose a threat to its survival. Furthermore, in view of the fact that *C. usambarensis* has a clumped distribution pattern, even small localized fires may threaten its survival.

4.3.2 Logging

The maps in Figure 5 show that *C. usambarensis* did not occur in tree fall gaps. This negative association was found to be significant when analysed using chi-squared contingency test and relates again to the fact that *C. usambarensis* is a shade-demanding species. It demonstrates that gap microclimates, which have a greatly increased amount of solar radiation, higher air and soil temperatures and reduced humidity compared with the microclimate beneath a closed canopy, are not ideal for growth.

The negative association with natural tree fall suggests that felling of large forest trees for timber will have a similarly detrimental effect on the distribution of *C. usambarensis*. Signs of illegal pit-sawing activities were observed in Kwamgumi Forest Reserve near plot Kwam3,

4.3.3 Non-commercial harvesting

The results of this study revealed that *C. usambarensis* is an important local resource used primarily for building poles and medicine. De-barking for rope was only observed on one tree in Amani Nature Reserve and as such does not warrant discussion here.

4.3.3.1 Pole-cutting

According to the forest reserve regulations which currently govern the management of the East Usambara forests, entry to the reserves by local people is prohibited except for access for fuelwood collection from dead branches and collection of traditional medicines (Kessy, 1998). Despite these restrictions, illegal exploitation for timber and building materials continues within the reserve boundaries (Johansson et al., 1997). This is verified by the fact that *C. usambarensis* trees in four out of six plots surveyed had been harvested. Previous studies have shown that demand for building materials in the East Usambaras is high with 80% of local communities using fresh poles from the forest reserves to build their houses (in Sawe, 1996). Kessy (1998) estimates that to supply adequate building materials for the population of 7 villages in the Kwamkoro area alone, 39,300 cubic meters would be required over the next ten years.

C. usambarensis is a particularly valuable source of building poles because it produces epicormic (coppice) shoots at the base when the main trunk has died or been injured. The thin stems are straight, strong and light and are resistant to termite damage (I Rajabu, *pers. comms*.) The coppicing habit of certain species is regarded as a kind of vegetative reproduction and is thought to be related to difficulties in seed establishment (Richards, 1996). It was not possible to tell whether *C. usambarensis* self-coppices or coppices only as a result of human-induced damage. What looked like natural coppicing (insect/fungi damage) may in fact have occurred as an indirect result of harvesting leading to secondary infection and then death of the main trunk.

Either way, pole cutting did not appear to cause severe damage or tree mortality. If properly managed (low frequency and intensity), pole cutting may favour tree regeneration. Barik *et al*. (1996) have shown that if the frequency and intensity of human-induced tree damage is not high, the germination and recruitment of certain species may be enhanced through the increased availability of light, soil temperature and nutrient availability. Figure 5 and Table 5 show that the two plots with the highest level of human-induced tree damage (Am2 and Kwam3) also had the highest density of saplings (see below).

Although flowering was not observed on *C. usambarensis* trees that had recently been cut for poles, regeneration was evident in the 6m plots circling these parent trees. It is possible, therefore, that damage may decrease the reproductive potential of the individual tree in the short term (perhaps two or three flowering seasons) whilst resources are channeled into producing new shoots. This hypothesis is supported by the fact that flowers were observed on the stems of trees that appeared to coppice naturally (or may have been harvested in the past). In view of the high density of regeneration beneath the crown of the mother tree (see Section 4.4 below), reduced flowering and hence germination may serve to increase regeneration by decreasing intra-specific competition between saplings for light and space in this confined seed shadow area. However, if there is indeed a time lag between cutting and flowering, harvesting may not be sustainable if trees are damaged persistently because they will never have the opportunity to fully recover.

The evidence above suggests that the level of harvesting observed during this study does not appear to be having a particularly adverse effect on survival and reproduction. However, further investigation is necessary to ascertain to what extent, if any, pole cutting reduces reproductive capacity and to determine more precisely what level of harvesting is sustainable.

4.3.3.2 Medicinal and other uses

The bark and leaves of *C. usambarensis* are used by traditional herbalists for treating a variety of ailments such as headaches, scabies and madness (Table 6). It is also used to cure menstrual pain and intestinal worms (Woodcock, 1995). The results of the socio-economic survey suggest that non-destructive harvesting for medicinal purposes is not a threat.

C. usambarensis is a sacred tree and according to traditional belief, must never to cut down (Kessy, 1998). This obviously has positive implications for its conservation.

However, as results of this study show, in some villages *C. usambarensis* is believed to bring bad luck. Whilst domestication might be acceptable in other areas of the East Usambaras (Kessy, 1998), this superstition (in villages surrounding Segoma and Kwamgumi Forest Reserves) would prevent cultivation on farmland and thus hinder potential ex-situ cultivation initiatives.

4.4 Regeneration

There was evidence of regeneration in all the plots in which mature *C. usambarensis* trees were recorded. As Figures 5 and 12 show, the density of saplings decreased with distance from the mother tree. This pattern supports the findings of Sawe (1996) and Mashauri (1997) who recorded the greatest number of *C. usambarensis* saplings within a distance of 1-5m from the mother tree. This suggests that the main seed dispersal mechanism is by gravity which would explain the high sapling density directly below the parent tree crown when the heavy drupe-type fruits fall to the ground.

Colobus monkeys, blue monkeys and squirrels are reported to be the main post-dispersal seed predators (Sawe, 1996) and therefore one would expect to observe evidence of regeneration in areas where mature trees were absent. Since this was not apparent, it is possible that the seeds are totally destroyed during passage through the intestine and when expelled are unable to germinate. The inefficient dispersal ability of *C. usambarensis* is the most likely factor causing its contagious distribution pattern.

Evidence of germination close to the parent tree conflicts with Janzen's (1970) escape hypothesis which postulates that the probability of germination increases if the seeds are transported far from the parent trees, thus escaping the higher chance of predation near the parent tree. In this context, it was interesting to observe that the main stem of many tall *C. usambarensis* trees (>10m), particularly on steep slopes and adjacent to river courses, had bent over thus enabling fruits to disperse longer distances downhill or downstream. These observations were merely opportunistic but further study during the fruiting season to record the number of fruits dispersed by water and the number of those successfully germinating would provide useful data on dispersal mechanisms.

Figure 11 shows that most of the saplings recorded were less than 50cm high. The numbers were found to decrease in progressively larger size classes. If height is used as an indication of age, these data suggest high rates of mortality in the early growth stages. This may be a result of herbivory by caterpillars as almost half (49%) of the saplings had damaged leaves or high intra-specific competition for resources.

The pollination ecology of *C. usambarensis* has not been studied. The sighting of a wasp-like insect suggests that it is insect-pollinated. Further investigation is clearly needed and this inference is merely conjecture.

4.5 Conclusions

C. usambarensis has a small geographic range restricted to (endemic to) the East Usambara Mountains in north-east Tanzania, a narrow habitat specificity (moist undisturbed forest) and a small fragmented population. These characteristics conform to one classification of rarity in Rabinowitz's (1981) typology of rare species.

It is a small tree with a contagious distribution pattern. The evidence suggests that it is shade-demanding and intolerant of water stress and water-logged conditions. As such, the optimum conditions for growth appears to be forest that provides a dense canopy cover (ideally between 60-80%), which is moist (riverine) but well-drained (steeply sloped).

With regard to threats, the results indicate that fire has an adverse effect on the survival of this species because of high vulnerability to direct heat damage, and because fire disturbance invariably leads to a reduction in canopy cover thereby creating conditions unfavourable for growth.

To a lesser degree, logging activities may also pose a threat.

Non-commercial harvesting for building poles appears to be sustainable at the levels observed during this study. However, if the frequency and intensity of cutting is not carefully controlled, the reproductive potential of this species might be reduced or in the worse case scenario lost altogether. It is therefore considered a potential threat.

Cola usambarensis is regenerating although mortality appears to be high in the early stages of growth. This could be a result of leaf damage or may be due to high intra-specific competition in the vicinity of the mother tree.

In conclusion, the risk category Endangered, assigned at the CAMP workshop, is considered to be appropriate.

5. RECOMMENDATIONS

It is hoped that the recommendations listed below will facilitate the development of a recovery plan for *C. usambarensis* and be considered for possible integration in the Amani Nature Reserve and the Amani Botanical Garden Management Plans which are currently being developed by the East Usambara Catchment Forest Project. However, it should be emphasized that they are made tentatively in recognition of the fact that there by be important political and social issues which have remained outside the scope of this study.

5.1 Research

5.1.1 Further research and genetic analysis

- A longer-term research study (possibly a 3 year PhD study), concentrating effort in key habitat sites identified in this study, to further investigate the distribution of this species, to substantiate and improve the information that already exists and to help to prioritise conservation resources in forests most at risk.

- As part of the longer-term study recommended above, an assessment of the genetic variation within and between sub-populations of *Cola usambarensis* is proposed in order to establish whether in-breeding is a threat. A technique which can be applied to previously unstudied taxa is random amplified polymorphic DNA (RAPD) analysis which uses leaf material (Williams et al., 1990). This technique has been used to assess genetic variation in *Prunus africana*, an endangered medicinal Afromontane tree and was found useful for devising optimum genetic management strategies for its conservation and sustainable utilization (Dawson & Powell, in press).

5.1.2 Long-term monitoring programme

- The establishment of permanent plots for the long-term monitoring of *Cola usambarensis* in order to:
  - Provide critical autecological information on life history, phenology, population flux, survivorship and the causes of mortality. These data could then feed into the population viability analysis software, RAMAS/stage in order to simulate the effect on the viability of *Cola usambarensis* populations of stochastic events such as fire and different management scenarios, such as controlled harvesting

- Investigate the effects of different treatments or experiments (e.g. light intensity, nutrient levels) on *Cola usambarensis*, in order to understand the mechanisms by which it copes with environmental stresses such as drought or fire;
- If appropriate, initiate seed germination trails for ex-situ conservation in farmland surrounding forest reserves.

- A 1ha plot size is recommended for monitoring, positioned in natural forest within the Amani Botanical Garden which is easily accessible and where a population of *Cola usambarensis* is already known to exist.

5.2 Management

5.2.1 Fire and logging control

- Greater control of illegal logging activities and awareness raising of the consequences of fire disturbance as part of the EUCFP village extension activities.

5.2.2 Rotational harvesting system

- Establish a rotational harvesting pilot programme at Amani where the level of harvesting for poles appears to be the highest, and which would be organized and managed by recognized village institutions. This may help reduce the potential risk of over-utilisation.

5.2.3 Field identification materials

- In view of the highly diverse flora in the East Usambaras and the confusion about the identification of *C. usambarensis* in Bamba Forest Reserve by the Frontier programme, it is recommended that resources be made available for the production and acquisition of identification material specifically for use in the field. A guide to tree identification using bark is currently being developed for the Amani Nature Reserve (Junikker, in press) which will be invaluable to field botanists. In addition, the availability of cibachromes (color photographs of herbarium specimens) from the National Herbarium in Arusha or through the Royal Botanic Garden, Kew, would further facilitate taxonomy in the field.

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APPENDIX I

FRONTIER DATA

0.1ha plots in which *c. usambarensis* recorded

Forest Reserve	**Plot no.**	**Veg Type**	**Veg condition**	**Alt (m)**	**Top**	**Slope angle (°)**	**Canopy ht (m)**	**No. individuals**
Bamba	2	F	M	350	SM	30	40	3
	6	F	M	300	SL	36	>40	2
	13	F	M	360	SM	18	20-30	1
	15	F	M	305	GL	21	20-30	4
	18	F	M	560	SU	40	>30	1
	20	F	P	440	SM	16	20-30	1
	23	ODF	P	500	SM	22	>30	13
	32	F	M	630	SM	32	20-30	1
Kambai	2	F	M	300	SM	25	20-30	1
	7	F	M	400	SM	25	10-20	1
	16	F	M	340	SM	27	>30	1
	22	ODF	EC	390	SU	25	<10	1
	23	ODF	EC	320	SM	25	10-20	2
	25	F	M	650	SU	20	10-20	19
	26	F	M	650	SM	25	20-30	1
	35	F	M	700	SU	25	10-20	2
	40	F	M	400	SM	20	10-20	3
	45	ODF	B	400	SM	30	<10	1
Kwamarimba	37	F	M	205	GL	5	10-20	1
	38	ODF	P	210	GL	10	10-20	1
Kwamgumi	4	F	M	350	SM	30	20-30	2
	14	ODF	P	210	SM	25	20-30	1
	31	F	M	300	GL	20	>30	3
	32	F	P	160	GL	5	10-20	3
	38	F	P	210	GL	10	10-20	3
	46	ODF	M	225	SM	30	20-30	2
Mtai	78	F	M	400	GL	5	10-20	1
	82	F	M	490	GL	20	10-20	1

KEY

Vegetation type:

F Forest
ODF Open disturbed forest

Vegetation condition:

M Mature mixed
P Disturbed primary/secondary
EC Ex-encroachment/colonising
B Bushland/thicket

Topography:

SU Steep upper
SM Steep middle
SL Steep lower
GL Gentle lower

APPENDIX II

COLA USAMBARENSIS RECORDING FORM

Date: Forest Reserve: Grid Reference: Recorders:

Plot Code:

General plot characteristics:

Altitude: Vegetation Type: Vegetation Condition: Topography:

Slope Angle: Aspect: Fire disturbance: Y/N Hydrology:

Sub-plot ID code	Tree no.	Tree ht (m)	dbh	Dist from corners of quad	Damage (cut/insect)	Flowers/ Buds/fruit	Tree fall (Y/N)	Canopy closure (%)	Associated species	Saplings			Misc
										Ht (cm)	Dist.	Leaf damage (Y/N)	

APPENDIX III

QUESTIONNAIRE on the uses of *C. usambarensis*

Date:
Name of village:
Nearest Forest Reserve:
Name of interviewee:
Profession:

Do you recognise *C. usambarensis?*: Y/N

If Y,
What is the vernacular name? Does this have a meaning?

What are the uses of *C. usambarensis*? Poles/Rope/F'wood/Medicine/Misc.
Give details. E.g. part of tree used (e.g. bark, leaves), what is it used to cure etc.

Where is it found? FR/Shambas

Are there specific areas in which it is found?

Is it common? Y/N

How far do you travel to harvest *C. usambarensis*? No. of hours.

How many times a month do you collect?

Is it cultivated? Y/N

If Y, where?

If N, do you think it would be a good idea to cultivate it in view of its uses?
Y/N.

If N, give reasons.

APPENDIX IV

Species associated with *C. usambarensis*

Forest type	Dominant tree(s)	Dominant shrub(s)	Species most commonly assoc. with Cola usambarensis	Number of times recorded	Description
Submontane	*Allanblackia stuhlmannii*	*Alchornea hirtella*	*Allanblackia stuhlmannii*	25	Common lrg submontane forest tree
	Newtonia buchananii		*Alchornea hirtella*	27	Small tree/shrub
	Maesopsis eminii		*Cephalosphaera usambarensis*	10	Lrg submontane forest tree
			Cola usambarensis	15	Understorey tree
			Maesopsis eminii	11	Large exotic submontane forest tree
			Mesogyn insignis	25	Common small submontane tree
			Myraithus holstii	9	Common submontane tree
			Schefflerodendron usambarense	10	Mdm submontane forest tree
			Sorindeia madagascariensis	24	Common sm. s'montane forest tree
Lowland	*Antiaris toxicaria*	*Alchornea hirtella*	*Anglocalyx braunii*	5	Small lowland forest tree
	Drypetes natalensis	*Whitfieldia elongata*	*Antiaris toxicaria*	9	Common large lowland forest tree
	Leptonychia usambarensis		*Celtis mildbraedii*	8	Common large lowland forest tree
			Cola usambarensis	10	Understorey tree
			Diospyros natalensis	8	Small lowland lowland forest tree
			Leptonychia usambarensis	15	Common small lowland forest tree
			Rinorea ferruginea	6	Small lowland forest tree
			Rinorea albersii	5	Small lowland forest tree
			Tabernaemontana ventricosa	5	Common small lowland forest tree
			Diospyros natalensis	5	Small lowland forest tree