Mapping of the Kabo River Forest Reserve in Ghana towards Community-Based Fire Management

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Abstract

Post-fire restoration and vegetation management in a fire-prone area, where 'no burning' practice is a policy, could subsequently result in severe burning when fuel-load builds up. In line with the Ghana National Wildfire Management Policy objectives, that seek to promote basic and applied user-focused research in wildfire management [Section 3.3 (iv)], and the suggested strategies for effective prevention and control [Section 3.4.1 (Bullet 5 & 6)], an analog map of portions of the Kabo River Forest Reserve (KRFR) in the Kadjebi District of the Volta Region was transformed into digital spatial data, using Landsat ETM+ December 2000 satellite imagery. With available ground data sets, the December 2000 pictorial result of processed Landsat ETM+ imagery was corroborated with plant species diversity indices for systematic vegetation analysis to provide the necessary baseline for community-based fire management. The resultant vegetation-type maps derived is used to provide a spectral signature guide on potential ground areas likely to suffer wildfire occurrences, hence strategizing for fire-fighting during the dry season. It is recommended that the quality of other sites of the KRFR and seriously degraded forest reserves in Ghana be assessed, using similar methodological approach, to enable numerous fire-prone forest sites to be consistently monitored and compared through time or between sites/treatments, if the relationship between future fire and restoration success has to be measured.

Introduction

The idea of mapping vegetation quality in order to classify a site or establish a baseline dataset is not new. Mapping provides pictorial results for direct examination and analysis for relating the slightest phenomena. With remotely sensed data and the application of Geographic Information System (GIS), mapping generates statistical estimates for modeling as well as monitoring and detection of change (Morain & Klankamsorn, 1978; Lanley, 1982; Woodwell *et al.*, 1984; Myers, 1988; Sader & Joyce, 1988; Gilruth *et al.*, 1990; Blasco & Achard, 1990; Green and Sussman, 1990; Campbell & Bowder, 1992). At present, the Joint Research Centre of the European Union (JRC/EU), in collaboration with the United Nations Food and Agricultural Organization (UN/FAO), has pioneered the use of Landsat imagery for mapping and monitoring deforestation in the tropics (FRA, 2009).

Generally, many disaster-prone areas, particularly fire prone forests, when digitally mapped, provide statistical estimates for quantifying complex mosaics of vegetation that provide useful community-level parameters for future monitoring and management strategizing (Whitmore, 1990; Aber & Melillo, 1991; Whelan, 1997). Therefore, to address meaningful decision-making and policy matters on potential future disasters due to predicted climate change on, for example, fire prone areas, it is crucial to establish ground data measurement of key vegetation variables to match remotely-sensed data analysis.

There is a death of studies on forest vegetation in Ghana to generate appropriate ground data and remotely sensed imagery for spatio-temporal evaluation either for risk or early warning (Swaine & Hall, 1988; Hawthorne, 1993). It has, therefore, become increasingly necessary to reduce the extent of species diversity loss. This is because the country's floral and genetic diversity is protected in the forest reserves, yet species richness and diversity, biomass and percent cover and dominance characteristics for monitoring change in the event of a disaster is non-existent. Even though the extent of cover and accumulated biomass during the wet season provides sufficient organic matter that burns in the dry season, information on the contribution of plant cover to understorey debris that influences fire is unavailable to influence management decisions during the fire season.

Combined afforestation and natural regeneration practices are being implemented in various parts of the country by governmental and non-governmental organizations (NGOs) to reverse forest degradation trends on the environment due to predicted climate change and its consequent negative impacts (MLF, 2004). Even though a lot of effort and resources are being put into bush- and forest-fire disaster education programmes, bush/forest-fire updates, which appear as headlines in Ghana's media, seem to be totally forgotten, when the risk disappears with the onset of the rains. This attitude undoubtedly undermines the ability to follow methodically through the prevention, control and management of wildfire disasters in Ghana.

As far back as 1909, Ghana has had a forest management plan that manifested in 241 forest reserves under the Ministry of Lands and Forestry (MLF) (Amoako-Atta, 1998). Today, many of these reserves have been reduced to 'empty shells' implying that in terms of tree species content and vegetation luxuriance, the country's forest physiognomy is spatio-temporally unsatisfactory (Chachu, pers. comm.). Hawthorne & Abu-Juam (1995) identified a few of such seriously degraded forest reserves (SDFRs) in almost all the ecological zones of the country. The FAO's forest statistics in relation to the varying levels of degradation around the same time also indicated that approximately 2% of Ghana's GDP was annually lost to fires which, when weighed against the more than 6% that forest resources contributes, make it obvious that bush- and forest-fire disasters reduce the country's real GDP (Orgle, 1998).

In the past two decades, for example, from the early 1980s to 2002 (i.e. particularly for 1982/1983), Ghana lost over 50% of its vegetal/vegetation cover to bush- and forest-fires in the dry season. Consequently, a regional distribution analog map on bushfire outbreaks, indicating total numbers and intensities for the country, was developed (Ampadu-Agyei, 1988). Ten years after the 1982/1983 bush- and forest-fires, between 1992–1996, fire damage accounted for an economic loss of more than GH¢0.1 billion (Orgle, 2000). Unfortunately, the actual amount of biodiversity loss was unaccountable. With a consistent and intensified fire disaster education campaign, however, available records relating total fire incidence to total forest cover, including other wooded land areas burnt in Ghana, suggest that there is a decreasing trend of wildfire incidence (Agyeman *et al*., 2005).

As part of other measures to address the fire disaster problem, two key CBFiM activities have been identified as being effective for prevention and control of wildfires in fire-prone forests and zones. These include (i) construction of fire observation towers to cover fire-prone forest reserves and (ii) construction of lookout towers to be manned by community members (Fire Volunteer Squads) on a 24-hour basis at 40 sites in 28 forest and wildlife reserves, as part of a natural resource management project (Wildfire Management Policy, 2005). These efforts are meant to complement the National Wildfire Management Policy objectives, that seek to promote user-focused research (i.e. basic and adaptive research) in wildfire management and, the suggested strategies for effective prevention and control [i.e., introduction and promotion of Fire Danger Rating Systems (FDRS)]. This is to provide signals on potentials for wildfire occurrences, and appropriate fuel treatment procedures and technologies to reduce combustible residue in the environment (Wildfire Management Policy, 2005).

The primary objective of the paper is to apply spatio-temporal analysis to the KRFR Forest Resource Utilisation and Management (FORUM) project, located in the Kadjebi District of the Volta Region. Thus, the 15-year (1993–2008) joint Government of Ghana and Germany collaborative project aimed at the re-establishment of this fire-prone forest reserve to near historic levels. Specifically, the paper sought to (i) provide suggestions for addressing danger rating and early warning, and (ii) provide baseline information for the needed action and strategy to effectively manage and prevent future fires in the KRFR, a core community-based fire management (CBFiM) practice.

Materials and methods

Study area

The Kabo River Forest Reserve (KRFR) falls within the south-eastern dry semi-deciduous fire prone zone of Ghana (Hall & Swaine, 1976), (Fig. 1). It occupies a total land area of 13,598 ha and extends approximately 38.1 km. The KRFR assumes the shape of a horseshoe or question mark (Fig. 1). This stretch of forest land is an IUCN Category VI Protected Area that is divided among the six stool-lands of Asatu, namely Okoe-South, Okoe-North, Kabetu, Gyeamonoma, Ketepii, Wawaso and Akpesokubi in the Kadjebi District of the Volta Region of Ghana (FORUM, 1993; IUCN & UNEP-WCMC, 2010). In the past, portions of the reserve were admitted farms and, therefore, were very prone to fires. Following the February 1983/1984 and March 1988/1989 fires, therefore, the entire forest was demarcated into various silvicultural compartments for direct afforestation and natural regeneration (Sharma, 1987).

Three sites in KRFR, each up to 5 km apart, were selected for the study and designated, B23, B24 and B25. They were located between latitudes 7^{o} 33-342 N and longitude 0^{o} 252 E (Fig. 1). The rational for selecting these sites were (i) proximity and ease of access, and (ii) vegetation at these sites constituting part of the reserve expected to be less sensitive to fire outbreak if enforcement of the regulations on protected areas is strictly adhered to. Unfortunately, these sites were greatly degraded by past fires, possibly because they constituted a forest-farm interphase, 'edge-effect', along

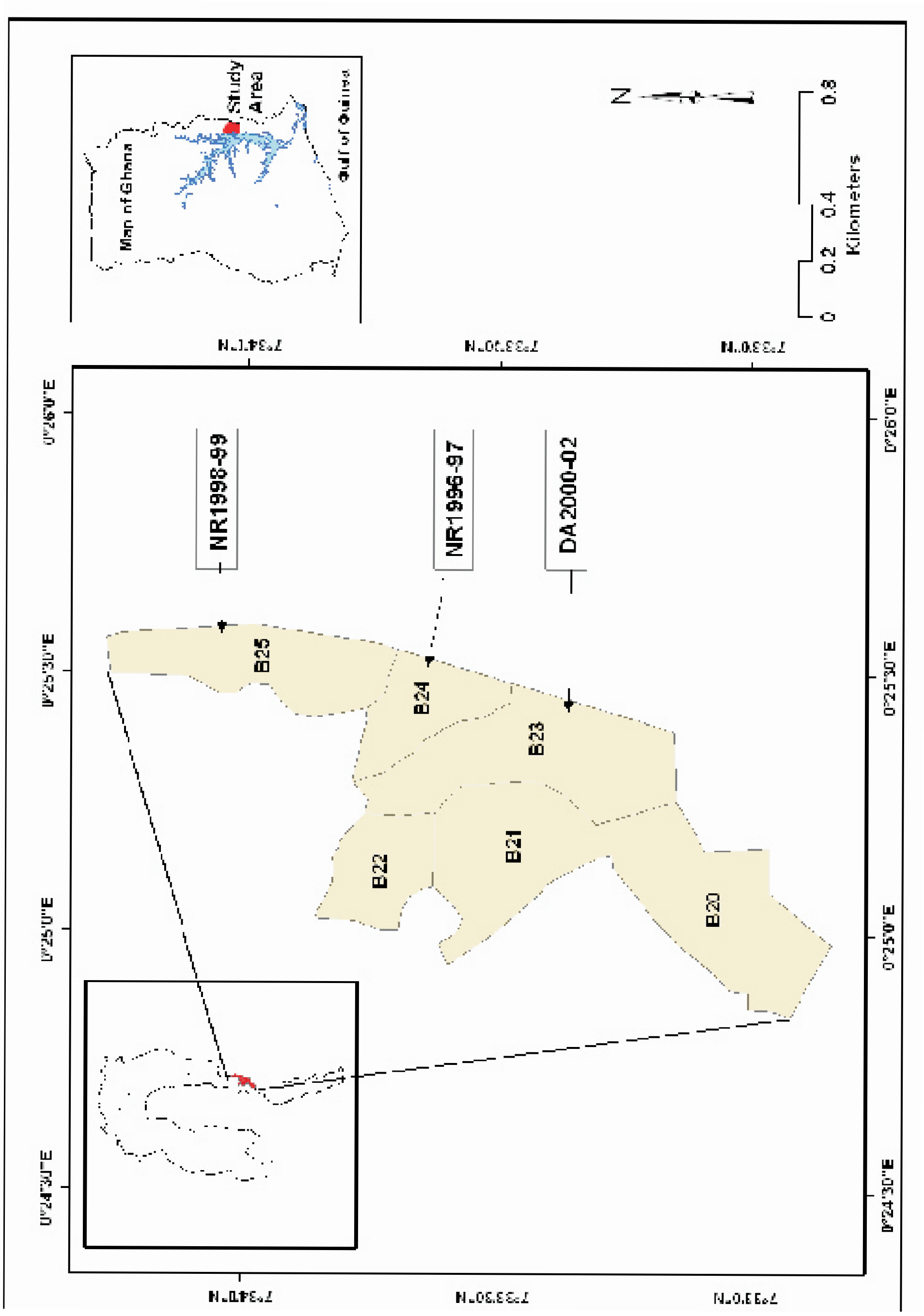

Fig. 1. Study area showing selected sites in KRFR.

the hill slope of the reserve. All the three sites, including all other areas of the reserve, are currently under complete exclusion from fire, and, hence, there is gradual accumulation of combustible matter. For the purposes of this paper, the vegetation at these sites was re-categorized into NR1996-97, NR1998-99 and DA2000-02 establishments to show the period within which they were silviculturally established post-fire.

Remote sensing/GIS application

On-screen digitization and geometric transformation: A scanned analog map of the silvicuturally managed KRFR was first geometrically transformed by on-screen digitization, followed by assigning attribute values (i.e. estimated hectares) and colour symbols to the corresponding layers. False colour digital vector data on each FORUM Project-based compartment was derived. Next, the spatial data was imported into a geodatabase and with the appropriate ArcGIS version 9 Desktop tool (Verbyla & Chang, 1997), was projected to real-world coordinates for the Ghana zone, the WGS_1984, to establish the land use land cover (LULC) of KRFR.

Derivation of normalized difference vegetation index (NDVI) values. Landsat-TM December 2000 coverage for the study area downloaded from the United States Geological Survey (USGS) website was converted to NDVI with the in-built module COVER in the Conversion Tools in ArcToolbox. B23, B24 and B25 with their adjoining compartments, were then clipped with the appropriate in-built module. The NDVI point features (i.e. the spectral response of vegetation above-ground) for the three re-classed sites; NR1996-97, NR1998-99 and DA2000–02, were specifically queried to sort their radiance statistic, hence, pattern and extent of vegetation radiance (greenness).

Derivation of slopes from digital elevation module (DEM). The digitized elevation and terrain data (DEM) of the study area derived from the Ghana Survey Contour map (1975 Base Map) in accordance with Hardy & Burgan (1999) was then re-classed into three slope layers using natural breaks as follows:

Class	*Slope (^{O})*	*Description of elevation*
1	00.0-34.2°	Low
2	34.2-58.7°	Middle/Medium
3	58.7-79.1°	High/Upper

Next, NDVI and SLOPE geodata were brought together by overlaying the former on the latter, using the image multiplication operation to derive pictorial result on the radiance of vegetation along the different toposequence in NR1996-97, NR1998-99 and DA2000-02, respectively, for December 2000.

A very low radiance statistic (0.1 and below) corresponds to moribund vegetation or dry litter, barren areas, rock and sand, while moderate values (0.2 to 0.3) represent grass and shrub areas. High radiance values (0.6 to 0.8) indicate luxuriant forest areas (Hardy & Burgan, 1999).

Groundthruth data collection

Transect-and-quadrat sampling of re-categorized vegetation sites. Between the periods 2004/2005 and 2006/2007, three line-transects oriented in an east-west direction along the toposequence at NR1996-97, NR1998-99 and DA2000-02 selected sites were each sampled with a $14.4 \times 7.2\ m^2$ rectangular quadrat at intervals of 30 m from the lower limit to the hill summit at each site. As in the case of the DEM, the steep and, undulating nature of the terrain in the NR1996-97 alone was divided into three slope layers, namely upper/high, middle/medium and low/lower slopes, to harmonize ground data with remotely-sensored data. Thus, sampling involved demarcating; 1. Twenty-five alternating quadrats in the NR1996-97 area. 2. Ten alternating quadrats in the NR1998-99 area. 3 Ten alternating quadrats in the DA2000-02 area, respectively. 4. For the lower hill slope, however, 10 contiguous quadrats of the same size and at the same interval as in the NR1996-97, and other establishments were sampled following Krebs's (1998) suggested method for such corridors. Altogether, 54 quadrats were sampled out of the proposed 55.

Floral data collection

Each sample quadrat was thoroughly inventoried by spot identification of plant species during the periods 2004/2005 and 2006/2007. Several botanical guide-books (Hepper, 1976; Hawthorne, 1993; Hawthorne & Gyakari, 2006; Hawthorne & Jongkind, 2006) were employed for correct citation and spell-checks of scientific names. Presence/absence of species, abundance count, estimated tree height and girth-at-breast height, as well as bark thickness measurements were all determined.

Statistical analysis

Non-parametric measures of heterogeneity (Simpson, 1949; Williams, 1964; MacArthur, 1972) in Biodiversity Professional (Biodiversity ProII) developed by McAleece (1997), that readily compares the characteristic assemblages of samples in the different conservation management areas based on different indices of diversity, were used. The derivation of some of these indices (Margaleff and Simpson's) is provided by Magurran (1988). In certain cases, parametric measures and simple histograms for comparative description were employed. Complexity of vegetation or crowdedness was derived as follows:

C_i = [No. of species] × [Coverage of sampled species (m^2/0.1ha)] × [Maximum tree height (m) in sampled field] × [No. of tree stems per 0.1ha × 10^{-3}] × [Allometric classes of woody stem thicknesses in sampled field], to probe whether all three sampled sites had the same susceptibility to fire.

But, Coverage of sampled species (m^2/0.1ha) is expressed as

[Total quadrat area sampled on ground (m^2)]/
[Habitat area from satellite imagery (0.1ha)].

Results

Remote sensing/GIS application

Based on the geometric transformation of the analog to digital map, relatively half the size of admitted farms (i.e. 5% of the forest) constituted much of the initial plantation development (Fig. 2). Fifty seven percent of the forest, prior to commencement of the FORUM Project, was 'seriously degraded' with about 4% and 12% constituting closed and cleared high-forest patches, respectively (Hawthorne & Abu-Juam, 1995).

Open and dense savanna areas constituted 5.4% and 2.6%, respectively while degraded savanna areas added up to 4.1% of the forest reserve. Altogether, 12.1% of KRFR was

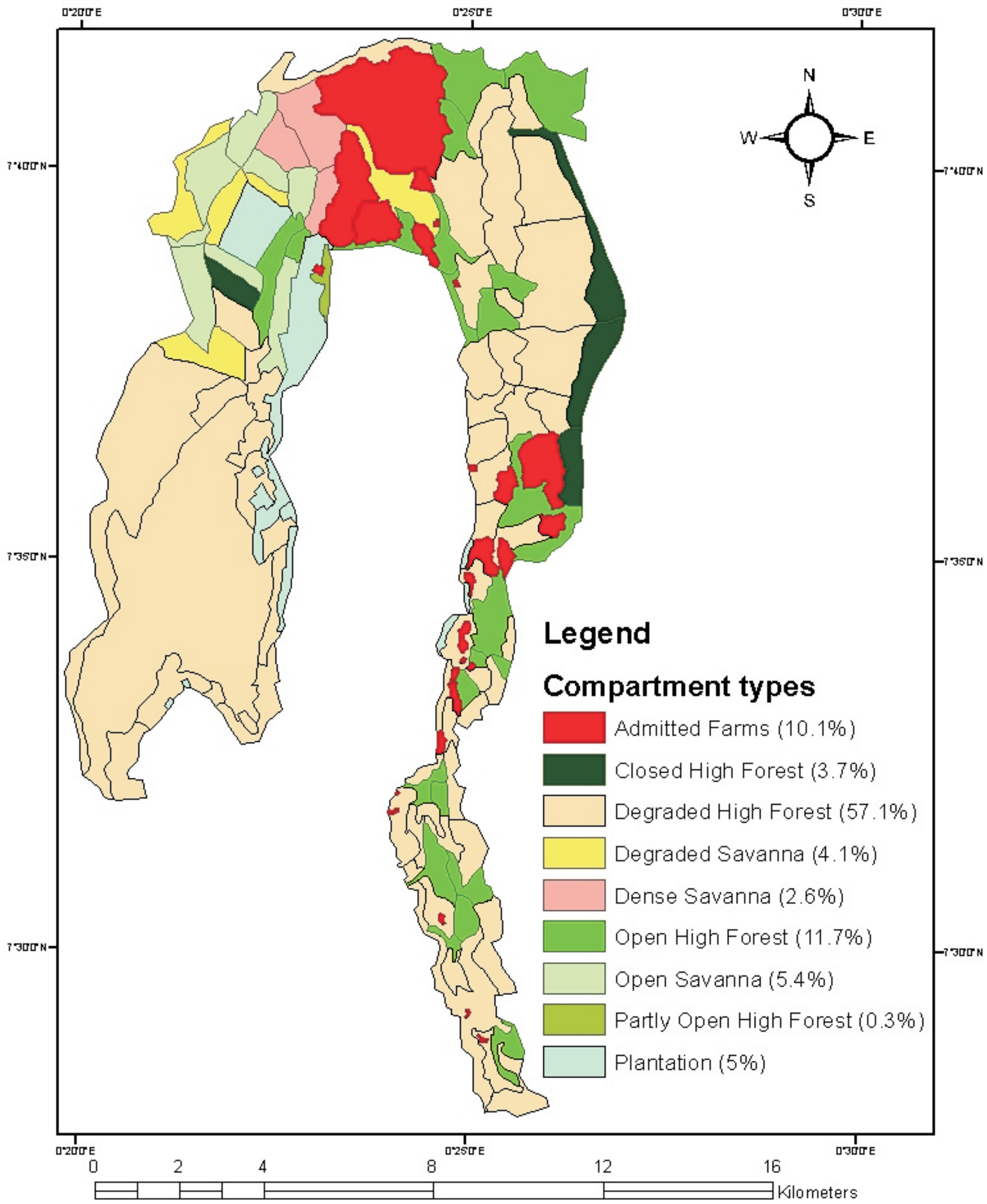

Fig. 2. Land use and cover of KRFR based on FORUM's Silviculture Plan

composed of grassland. The spectral response of vegetation in these sampled sites around December due to the satellite swath (i.e. Landsat TM, December 2000) showed a significant difference in NDVI values (${}^{2}_{\text{crit.(8)}} = 31.83 < {}^{2}_{\text{calc.(8)}} = 770.57, P >$ 0.0001), implying that varying degrees of physiological species status existed among the establishments (Fig. 3) around that period. Thus, around December 2000, the vegetation radiance showed increasingly low statistic, indicating that the vegetation was relatively dry, hence, the probable season for fires.

Moribund vegetation areas and potential bare and exposed rocky surfaces (i.e., brown colour areas) are most noticeable on the middle (medium) hillslopes than on the upper (high) and low hillslopes (Fig. 4a–c). A large proportion of the middle slopes (Fig. 4b) in the NR1996–97 and DA2000–02 establishments comprised a mosaic of forest, shrub and grass patches. Only few pixels displayed any such vegetation types on the high/upper hillslopes (Fig. 4a). Open high forest patches are more prevalent in NR1996-97 and DA2000–02 than NR1998–99 areas. A distinct narrow continuum of mixed vegetation, forming a belt on either side of NR1996–97 on the low hillslope, separates it from the other silviculturally managed areas (Fig. 4c).

Floral diversity (Margalef index, M_g) ranking and plant family composition of sampled transect-and-quadrats

In terms of species richness standing, the NR1996-97 is ranked highest (M_g = 52.233) followed by the NR1998-99 (M_g = 50.982), with the DA2000-02 (M_g = 43.316) being the least ranked (Table 1). In spite of the average richness ranking of species in these establishments, more than 50 plant families were altogether inventoried. Of these plant family numbers, the Euphorbiaceae-Mimosaceae and Annonaceae-Moraceae-Papilionaceae-and-Sapindaceae, respectively, constituted the major plant families of the vegetation. Along the low and upper hillslopes, as well as the 'edge effect' of the NR1996-97 establishment, 96, 83 and 95 plant species, respectively, were recorded but the middle slopes of NR1996-97 and DA2000-02 both had a close yet lesser richness of species (Table 1).

Based on the corroboration of radiance characteristic (Fig. 4) to ground data analysis, NR1998-99 and DA2000-02 are noted to exhibit similarly high evenness of distribution of plant species (i.e. Simpson's D or 1/D = 43.5) compared to NR1996-97 that recorded less evenness (i.e. 1/D = 28.4) in distribution of species (Table 1). To ascertain the effectiveness of the vegetation sampling techniques employed to these establishments; i.e the combined linear and contiguous transect-and-quadrat sampling, a plot of the cumulative species richness to the cumulative area sampled (Fig. 5) show that a reasonably sufficient assessment of the three establishments was undertaken.

Percent recurrence of species

A total of 172 species (i.e. about 32 species/0.10 ha) in the NR1996-97, NR1998-99 and DA2000-02, respectively, were inventoried (Table 2). In all three establishments, the frequently occurring plant species in each quadrat sampled included *Albizia zygia*, *Chromolaena odorata*, *Ficus exasperata* and *Griffonia simplicifolia*. However, most other plant

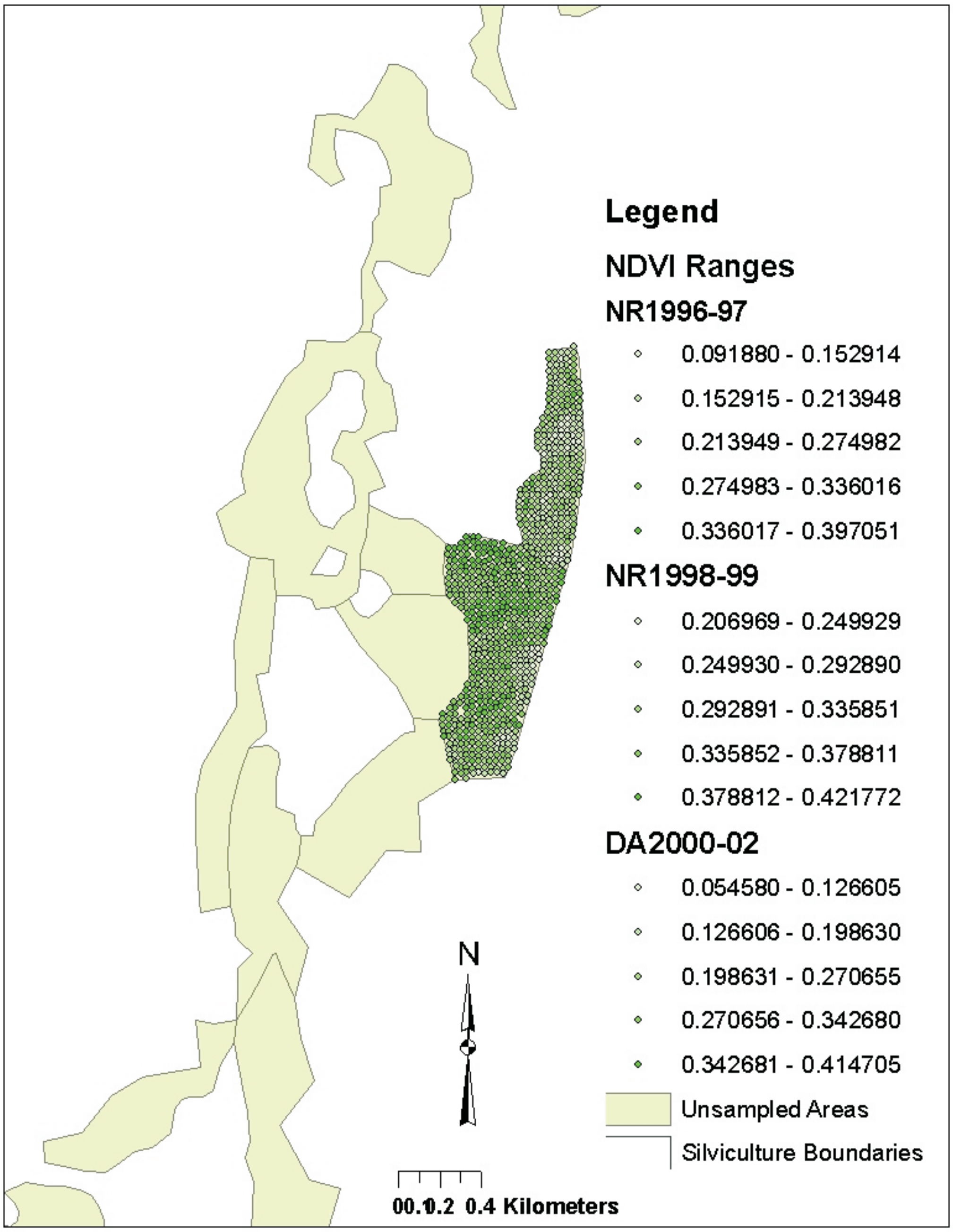

Fig. 3. Equal-interval graduated spectral response of sample sites (December, 2000)

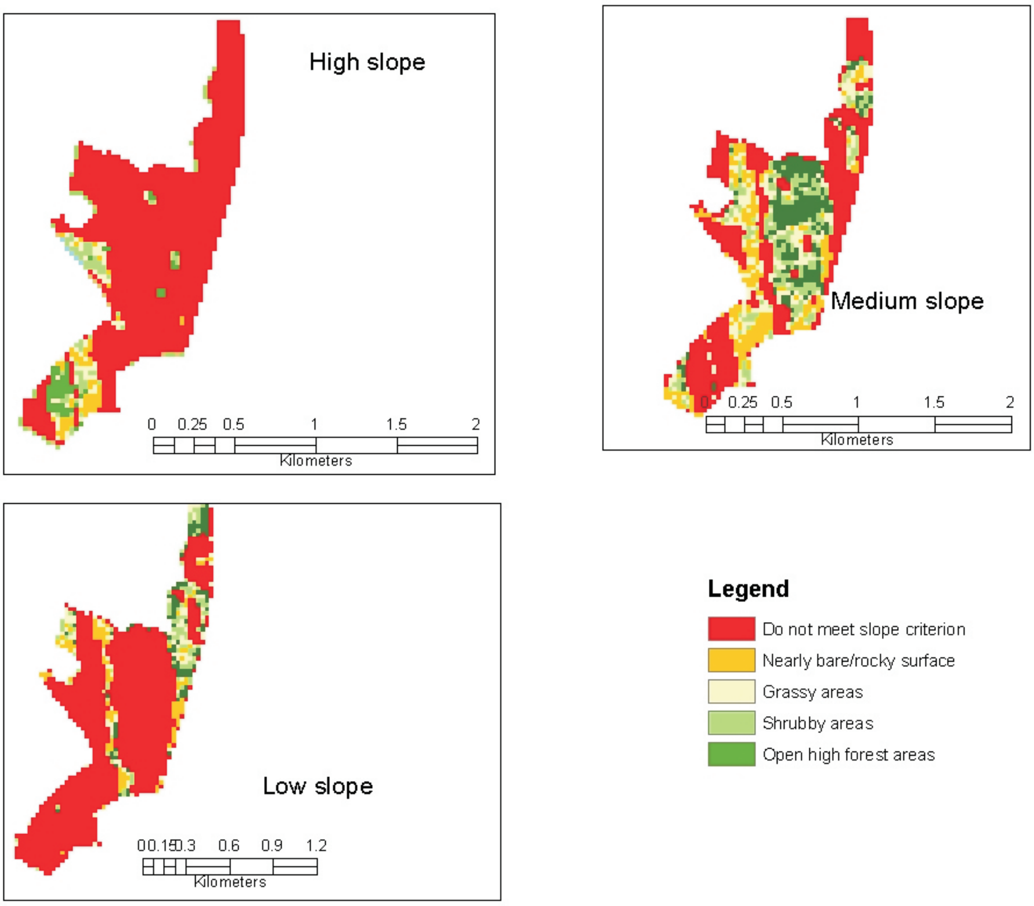

Fig. 4a–c. Vegetation characteristic along different hillslopes (December, 2000)

species were significantly different in their recurrence; $F_{(calc.)} = 24.59576 > F_{(crit.)} = 2.61973$ at d.f. = 3 and 684, $P < 0.05$ (Table 2).

Sørenson's ($S_ø$) similarity in composition of species

The mean similarity in composition of plant species on the forest-farm interphase was 47% and that on each of the low and middle hillslope was 41%. The upper hillslope of NR1996-97 recorded the least similarity of 34%. On the contrary, among the three sampled establishments, only 18% of plant species were strikingly common to NR1996-97 and NR1998-99. Between NR1996-97 and DA2000-02 only 11% of species were common while between NR1998-99 and DA2000-02, only 26% of the species were also common.

Complexity (C_i) of sampled establishments

The crowdedness of plant species expressed as a measure of complexity of

TABLE 1
Species diversity of sampled establishment

Diversity index	*NR1996-97*	*NR1998-99*	*DA2000-02*
Species richness along hillslopes:			
a) High/Upper	83	-	-
b) Middle/Medium	77	-	-
c) Low	96	-	-
d) 'Edge-effect'	95	-	-
Margaleff M_s Base 10	52.233	50.982	43.316
Simpson's D	0.035	0.023	0.023
Simpson's 1/D	28.4	43.5	43.5

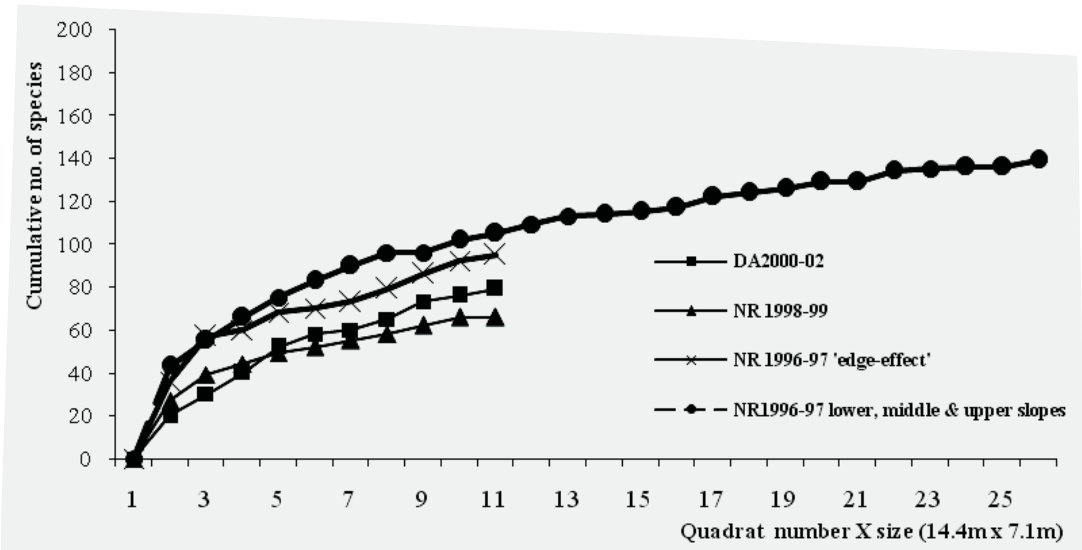

Fig. 5. Cumulative species-area assessment of sampled establishments in the KRFR.

TABLE 2
Recurrence of plant species among sampled establishments

Regeneration Establishments	*Species Richness*	*Sum*	*Average*	*Variance*
NR1996-97	139	680	4.0	25.
NR1998-99	66	208	1.2	5.5
DA2000-02	79	259	1.5	6.4
'Edge-effect'	95	322	1.9	6.3
Total count	172			

vegetation (Table 3) was indicative of a significant difference in the uniqueness of each sampled establishment. A one-way ANOVA of the log transformed complexity of the sampled establishments showed that $F_{(calc.)} = 44.52233 > F_{(crit.)} = 2.65720$, d.f. = 7 and 16, $P < 0.05$. Thus, establishment DA2000-02 is typically the least complex (C_i = 6,221.3) because it was the most lately afforested establishment compared to the NR1996-97 (C_i = 30,268.1) that was much earlier allowed to go through natural regeneration. Nonetheless, the complexity of NR1998-99 is relatively much greater than DA2000-02 and NR1996-97 due to a more regular rehabilitation of that establishment.

aggregation (r = 0.94) of particular species such as *Capsicum frutescens, Cedrela odorata, Chromolaena odorata, Dalbergiela ecastaphyllum, Deinbolia pinnata, Ficus sur, Hoslundia opposita, Mallotus oppositifolius, Margariteria discoidea, Millettia thonningii, Salacia* sp., *Terminalia ivorensis and Theobroma cacao* was noticeable.

Stratification of the sampled silvicultural establishments

On the whole, an exponential distribution of size classes corresponding to decreased counts with considerably large tree size was observed in the sampled KRFR areas (Fig.7a–b). In the DA2000-02, however, a somewhat symmetric size-class distribution was observed. Within each sampled site, the vertical and horizontal strata of woody species showed that not many plant species attained heights of between 20.0–30.0 m (Fig. 7a). The girth size of those tree species were also e”100.0 cm at breast-height (Fig. 7b). No species was e” 20.0 m tall in the DA2000–02, yet in the NR1996–97 and NR1998–99 establishments very few were

TABLE 3
Complexity of the KRFR sampled establishments

Variables	*NR1996-97*	*NR1998-99*	*DA2000-02*
Total quadrat area sampled on ground (m^2)	1,451.5	1,036.8	1,036.8
Habitat area from satellite imagery (ha)	14.4	2.5	35.0
Coverage of species sampled (m^2/0.1ha)	10.1	41.5	3.0
Maximum tree height (m) in sampled field	28	25	15
No. of allometric groups of woody stem thicknesses in sampled field	11	7	7
No. of tree stems per 0.1ha × 10^{-3}	0.07	0.31	0.25
Complexity index (C_i)	30,268.1	148,590.8	6,221.3

Spatial distribution pattern of sampled plant species

Altogether mean distribution in the three sampled establishments showed that, for small values of ^{2}< 8.0 at df = 2, a random dispersion of species in the sampled establishments was obtained at $P > 0.05$ (Fig. 6). However, with large values of ^{2} e” 8.0 a less probable but significant counted (see Fig. 7b). These included such plant species as *Albizia adianthifolia*, *Pterygota macrocarpa*, *Ricinodendron heudelotii*, *Sterculia oblongata*, *Terminalia superba* and *Triplochiton scleroxylon*. The next height layering of tree species was between 10–20 m high. These measured between 50.0–100.0 cm in girth (Fig.7b) and included such species as *Albizia zygia*, *Cedrela* sp., *Cola nitida*, *Elaeis guineensis*, *Ficus exasperata*, *Khaya ivoriensis*, *Morinda lucida*, *Piptadeniastrum africanum* and *Terminalia* spp. in addition to some of the tallest trees earlier mentioned.

Comparatively, the modal heights of trees in the NR1996–97 were higher than in DA2000-02. It is worth mentioning that for the NR1998–99 establishment in particular, the difference in size of histograms (Fig. $7a_{ii}$–b_{ii}), is not an inherent feature of the biological (i.e. tree structure) variable. Rather, it is due to the difference in scale of count numbers and the proportions of counts per bar (i.e. the primary and secondary y-axis).

Relative proportion of eco-morphs in sampled establishments

Proportions of tree and shrub species in the three establishments at the time of investigation showed closely similar percent values (i.e. 36% and 32%, respectively) while woody climbers and vines approximated 19% (Table 4). Herbaceous plant species were approximately 11% while grass species constituted 3%. The only fern recorded was *Adianthum* sp., found in DA2000-02.

Discussion

Vegetation-type maps derived using Remote-sensing data/GIS applications provide a cost-effective tool for operationalizing fire management efforts in fire-prone forests. This is because the extent of accumulated dry

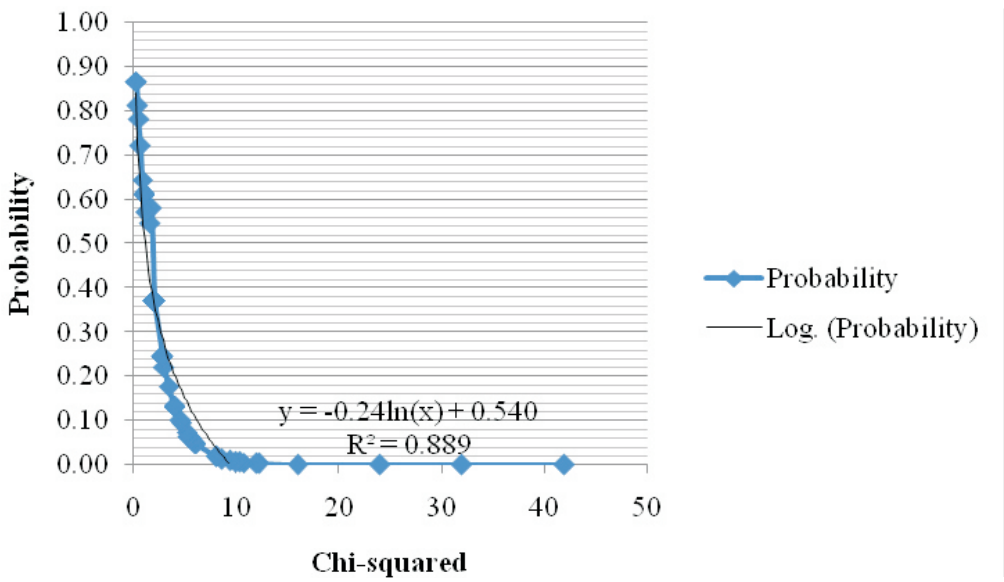

Fig. 6. Critical regions for detecting pattern of species dispersion among sampled establishments

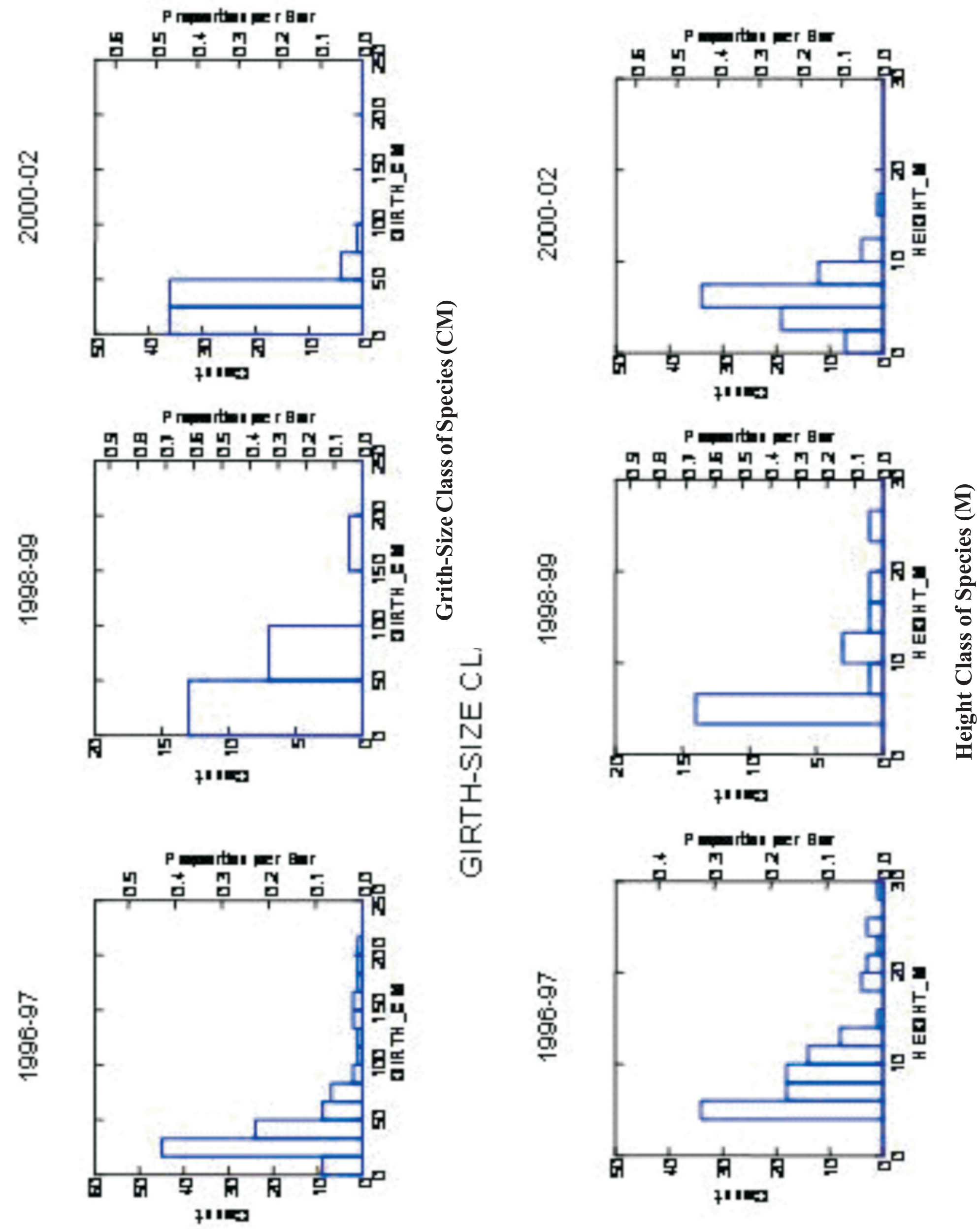

Fig. 7. Girth-and-height distribution of species in sampled KRFR areas.

TABLE 4
Life-form of plant species in sampled establishments (2004/5-2006/7)

No.	*Life-form (categories)*	*No. of species*	*Relative composition* (%)
1	Trees (small, large and pseudo)	60	35.7
2	Shrubs (non-thorny and thorny)	53	31.5
3	Herbs (aerial and underground)	18	10.7
4	Climbers (woody and vine)	31	18.5
5	Graminoids	5	3.0
6	Fern(s)	1	0.6
	Total	168	100.0

biomass that has to be contended with by foresters and fire-fighter squads during fire suppression cannot be taken for granted. In particular, on steep hill slopes (i.e. more than 20°), when the wind effects become extremely strong, and quick to changing directions due to dry biomass, the intensity of fire spread tends to be severely destructive sweeping through tree crowns high above the ground.

Deducing from the tree distribution patterns in Fig. 4a–c, it is obvious that structurally small to medium pole-size trees make up the vegetation in these KRFR establishments. An indication that the bio-quality of these sampled areas could readily be consumed in future intense fires. Important plant species in these tree size-classes most likely to be devastated by fires include many semi-deciduous trees such as *Albizia adianthifolia*, *Albizia zygia*, *Cedrela* sp., *Cola nitida*, *Elaeis guineensis*, *Ficus exasperata*, *Morinda lucida* and *Ricinodendron heudelotii*. Rare wet forest species such as *Khaya ivoriensis*, *Piptadeniastrum africanum, Pterygota macrocarpa*, *Sterculia oblongata*, *Terminalia superba* and *Triplochiton scleroxylon* found are also less likely to withstand cambial kill due to their naturally thin bark thicknesses, light stem densities and levels of their aggregation. Very few plant species were noticed to be aggregated as indicated in Fig. 5.

Essentially, the NR1998–99 was by far greater in aggregation or 'crowdedness' of tree species than the other two establishments. On the contrary, stem densities of trees in the DA2000–02 establishment were typically least aggregated compared to those in the NR1996–97. This makes the vegetation in the NR1998–99 establishment and portions of the middle and upper hill slopes of NR1996–97, as well as many patches of the entire KRFR highly vulnerable to fires because the head fires of the establishments are most likely to propagate burning flames easily, resulting in almost continuous flame contact. However, the woody tree and shrub species such as *Albizia zygia, Baphia pubescens, Blighia welwitschii, Cola millenii*, *Ficus exasperata*, *Harungana madgascariensis*, *Mareya micrantha* and *Olax subscorpioidea,* commonly noticeable as randomly dispersed, are the only likely species to survive intense future fire effects.

Similarly, results of the NDVI derived imagery along the different hill-slopes (Fig.4a–c) modulated by the December climate as suggested by Goldammer & Price

(1998) and Bowman (2007) can trigger forest fires in the KRFR. This is partly so because that is the period of the year in which the vegetation dries-up and becomes susceptible to fires. With technical support from the Forestry Services Department, the participation and involvement of the local communities' fringing the KRFR can be harnessed in fire prevention and suppression as part of community-based fire management (CBFiM). Otherwise, the value of economic loss based on Hobbelstad's (1999) cost evaluation for this IUCN Category VI Protected Area, in terms of species diversity and their distribution, as indicated in Fig. 5 and 6, respectively, could work out to US$2,416.04 loss per annum. This price to be paid annually is perturbing, given that an estimated 50 plus plant families made up of approximately 32 species per 0.10 ha, could be lost in any given wildfire event in these sampled establishments.

Already, about ½ the relative proportions of woody climbers make up the tree and shrub species, as shown in Table 4, in this medium forest stratum (Fig. 7). According to Swaine & Grace (2007), this observed relative proportions of woody climbers in Ghanaian forests is suggestive that i) these KRFR establishments could be experiencing low amounts of rainfall, and ii) that the proportion of these group of life-forms, in all three sampled establishments, NR1996-97, NR1998-99 and DA2000–02, respectively, could act as 'fire-ladders' spreading into the crowns of the 10–20 m high trees in the KRFR. In doing so, the naturally steep hill slopes shown as green false-colour patch open high forests in Fig. 2 could significantly double the spread of fire, pre-heating existing wet vegetation types immediately in front of burning flames as suggested by Luke & MacArthur (1978) and Cheney (1981).

Conclusions and Recommendations

In a nut shell, fire continues to pose the greatest danger to much of the structure and, indeed, the composition of the KRFR (Poku-Marboah, 1998). From previous approaches of simple listing of species through identification of indicator species, remote sensing and geographic information systems application, natural resource evaluation has currently become a very important means of disaster forecasting and management. The challenge ahead, therefore, is to integrate more effective field data with remote sensing techniques and geographic information systems so that the KRFR and other landscape analyses will be able to address future fire disaster management needs. For purposes of community-based fire management in the KRFR sampled areas specifically, the pioneering work of Mistry (1996; 1998b; 1998c; 1998d) that showed how corticolous lichens could potentially be identified and used as fire history bio-indicators must be investigated in future related studies.

Similarly, screening of climber species for their potential volatility, for example, could also be explored in the KRFR and other fire-prone forests as an adaptive strategy towards monitoring and reducing their numbers. Surface fuels (litter) and fuel moisture levels in the KRFR and other fire-prone forests need to be established to determine whether the moisture amounts contained in litter are sufficient to cause smothering of high-intensity fires. The site complexity of different vegetation-types, in particular their characteristics that relate bark thicknesses to stem death, should all be measured and monitored since these variables determine the vulnerability of such sites to fire. In accordance with the Ghana National Wildfire Management Policy objectives on the need to develop Fire Danger Rating Systems (FDRS), it is recommended that FDRs from elsewhere could be adopted to provide advance warning for fire risk management until a national danger rating system is fully established and operationalized. In that regard, the weather station in the Kadjebi District and other synoptic monitoring units of the Ghana Meteorological Services Department, must be well resourced and encouraged to intensify collaboration with other relevant Government Agencies (e.g. Ministry of Agriculture, Forestry Services and Wildlife Departments both of the Forestry Commission, etc.) within the Districts.

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