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Research Article

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Plant Species Diversity in Western Tanzania: Comparison between Frequently Burnt and Fire Suppressed Forests

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ABSTRACT

It has been established that there is a crucial relationship between biological diversity and quality of ecosystem services. Environmental pressures are directly responsible for survival and perpetuation of plant species in ecosystems. In forests and woodlands, wildfire is among the pronounced abiotic factors that influence reproductive success. The present study was confined to two miombo forests, namely, Ilunde which was frequently burnt and Kitwe a fire - suppressed one. The study aimed to compare the diversity of all plant forms (tree, shrubs, saplings, herbs and grasses) in the two forests. Thirty (30) circular concentric plots were established in each forest and used to record total number of individuals of all species. The diversity of plant species was determined using Shannon-Wiener diversity index and compared using ANOVA. MODIS (moderate resolution imaging spectro-radiometry) data at high temporal resolutions were used to determine the fire frequency of Ilunde forest. The diversity of plant species of all forms was significantly high in the frequently burnt forest of Ilunde ($P < 0.005$). Frequent fires increase the diversity of plant species in miombo woodlands. It is likely that disturbances from wildfires eliminate disturbance-sensitive species, ultimately, increasing species diversity by creating niches and resources for use by invading species. There is a need to carry out further studies on the threshold, optimal and critical fire frequencies for high plant species diversity due to environmental concerns.

Key words: *Diversity; Miombo; MODIS; Wildfire; Woodlands*

INTRODUCTION

Almost all fires are ignited by humans, and this has been so since the Iron Age[8]. In many rangelands all over the world, fire has been used as an instrument in the management of rangelands in various ways; to reduce bush cover, enhance seed germination by breaking the hard seed coat, influence changes in species composition and to reduce disease-causing pests[26]. However, how fires affect vegetation particularly miombo species has been and continues to be a matter of discussion[16, 29].

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Miombo woodlands have an estimated worldwide coverage of 2.7 million km^2 (270 million hectares) and are the most extensive tropical woodlands in Africa[12]. Tanzania being among the tropical countries has 374,356 km^2 of miombo woodland in the mainland which is 93.2% of its area[22]. The country has about 33.5 million hectares of forests, however, it is estimated that wildfires destroy about 65,000 ha of forests and other wooded areas annually[1].

Frequent fires change the floristic composition and diversity of vegetation, mainly by killing individuals of the small size classes[6]. Similarly, it was suggested that large size class individuals were mainly affected by wildfires[27]. On the other hand, in a study carried out in Mozambique Shannon-Wiener diversity index of plant species in protected miombo woodlands was 2.3 and was not significantly different from a fallow land of more than 10 years[33].

In Tanzania, the diversity of plant species in miombo woodlands has been variably reported. For example, Shannon-Wiener diversity indices of 3.79 and 3.13 were reported in Kitulanghalo forest respectively[24,35]. Recently, Shannon-Wiener diversity index of 4.27 has been reported in Bereku forest[13]. However, wildfire incidences that are common in Tanzania were not covered in those studies.

In this way, there is a need to study the diversity of tree species in forests and woodlands that are prone to wildfire incidences. The present study aimed at determining the diversity of plant species in frequently burnt miombo woodland of Ilunde and of the fire-suppressed miombo woodland of Kitwe in Kigoma Region of western Tanzania.

MATERIAL AND METHODS

The Study Area

Kigoma Region is among the highly ranked national-wise in terms of high fire frequencies in the period of between 2000 and 2010[23]. The present study was confined to a frequently burnt miombo woodland of Ilunde in Kigoma Region which is located between latitudes 4º 54' and 4º 55' S, and longitudes 29º 36' and 29º 37' E (Figure 1). The fire-suppressed miombo woodland of Kitwe, located between latitudes 4º 54' and 4º 55' S, and longitudes 29º 36' and 29º 37' E was used as a control.

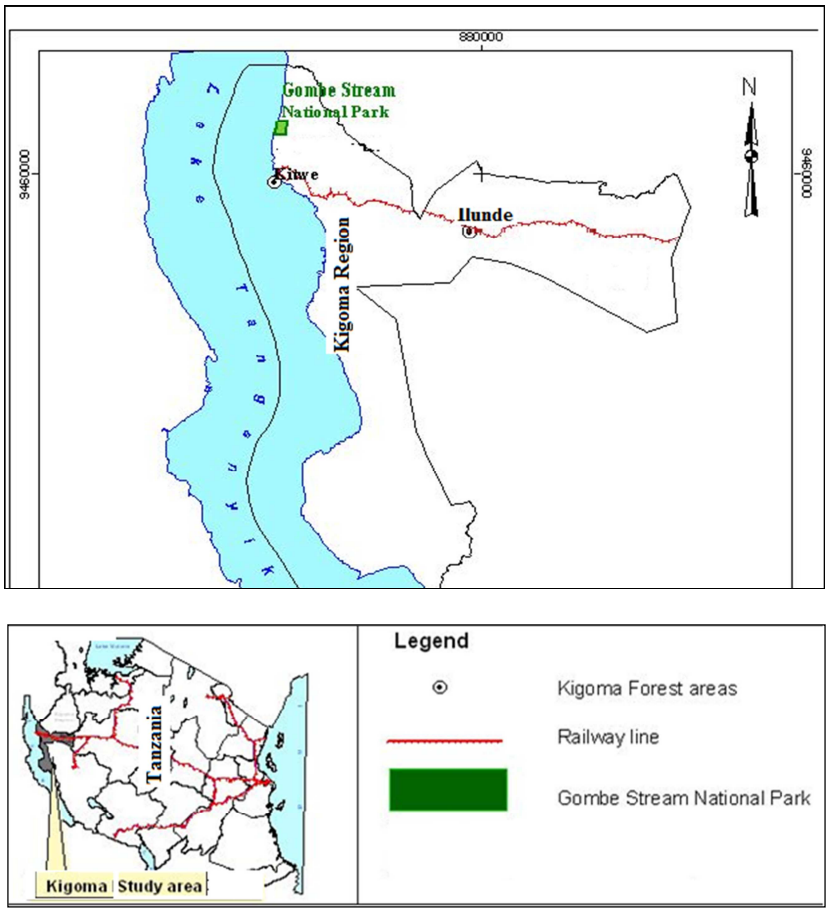

Fig. 1: Location of the study area

The study area is characterized by tropical rainy climate and receives modest amount of rainfall varying from 900-1050 mm and experiences one long wet season lasting from November to May and one long dry season[18]. Vegetation typology of the study sites was once characterized by pristine forests of miombo woodlands[7], though it was severely disturbed later. Currently, Kitwe forest reserve has been protected from anthropogenic disturbances including fire for about fifteen years by the corroboration of the United Republic of Tanzania (URT) and United States Agency for International Development (USAID) under the management of the Jane Goodall Institute (Plate 1). On the other hand, Ilunde forest is frequently burnt due to several anthropogenic activities (Plate 2).

Plate 1. Kitwe forest

Plate 2. Ilunde forest

Sampling of Plant Species

Thirty circular concentric plots were laid in each forest. The inventory design which was used in this study was systematic random sampling. The sampling intensities for Kitwe and Ilunde forests were 2.4% and 0.03%, respectively. Financial status, time limitation and purpose of the forest inventory may necessitate the sampling intensity to be as low as 0.01%[21].

The distance between concentric plots was 150 m and 100 m in Kitwe and Ilunde forests respectively, on the basis of their area coverage. The National Forest Resources Monitoring and Assessment (NAFORMA) which has been adopted as a national framework for assessment, monitoring, reporting and verification of Reducing Emissions from Deforestation and Forest Degradation (REDD) related activities was used in the present study with some modifications[32].

Radius with 15 m was used to sample trees, radius with 10 m was used to sample shrubs and saplings and radius with 2 m was used to sample herbs and grasses. In the present study, a tree is defined as a woody species with diameter at breast height (DBH) of $\geq$ 5 cm as adopted from studies carried out in miombo woodlands of the Eastern Arc Mountains and in Mozambique[36,27].

Scientific names and total number of individuals per plot were recorded in the field. Species which were difficult to identify in the field were collected, pressed and transported to the herbarium of the University of Dar es Salaam for proper identification using respective flora or by matching with dried herbarium specimens of known identity.

Fire Frequency in Ilunde Forest

MODIS (moderate resolution imaging spectro-radiometry) data at high temporal resolutions from the University of Maryland were used in detection of fire frequency in Ilunde forest. Pixel resolution of MODIS data is 250 m at best, limiting fine scale assessments[34].

Data Analysis

Shannon-Wiener diversity index which measures rarity and commonness of species within a sampled community was used in the present

study. Diversity measures are used to clarify different aspects of variability within and between communities. Diversity has two basic components namely richness and equitability[20]. Statistically, the index is monitoring the probability of whether the next sample will contain the same species as the previous sample or whether the next sample will be a new species[20]. Shannon-Wiener diversity index was obtained from the formula:

$$H' = -\sum_{i=1}^{S} Pi \ln Pi$$

Where:

H = Shannon-Wiener diversity index

S = total number of species

Pi = the proportion of abundance of the i th species i.e. (*ni*/N)

ln = natural logarithm

The difference in diversity of plant species between the frequently burnt and fire-suppressed miombo woodlands was assessed by Analysis of Variance (ANOVA) in accordance with[37].

RESULTS AND DISCUSSION

Results

Diversity of Plant Species in the Two Forests

In the studied miombo woodlands, Ilunde was more diverse than Kitwe in all plant forms (trees, shrubs, saplings, herbs and grasses) with Shannon-Wiener diversity index ranging from 1.89 to 3.08 (with a mean ± standard error of 2.67 ± 0.06). In Kitwe, Shannon-Wiener diversity index ranged from1.30 to 2.97, with a mean of 2.15 ± 0.09 (Figure 2). One-Way Analysis of Variance revealed significant difference in the diversity of all forms of plants between the two forests ($P < 0.05$)

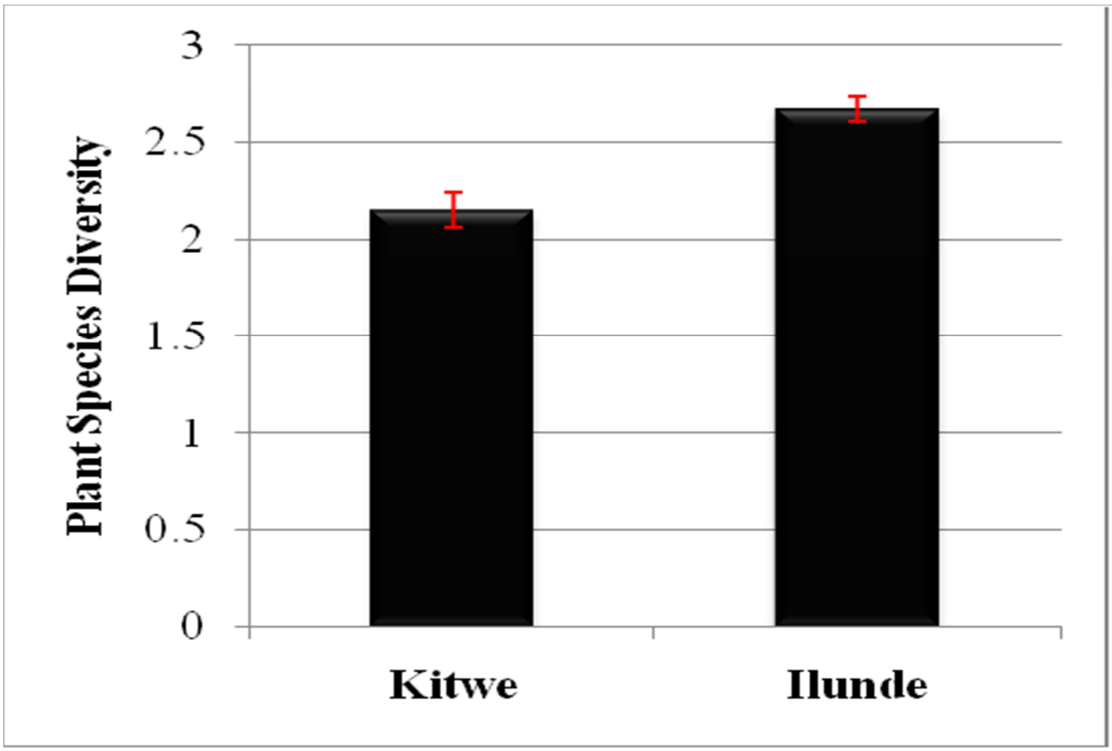

Fig. 2: Diversity of all plant forms in the two forests

Similarly, Ilunde forest was more diverse in herbs and grasses with Shannon-Wiener diversity index mean of 1.77 ± 0.05. Kitwe forest had Shannon-Wiener diversity index mean of 1.3 ± 0.09 for herbs and grasses (Figure 3). One-Way Analysis of Variance showed that the diversity of herbs and grasses between the two forests was significantly different ($P < 0.05$).

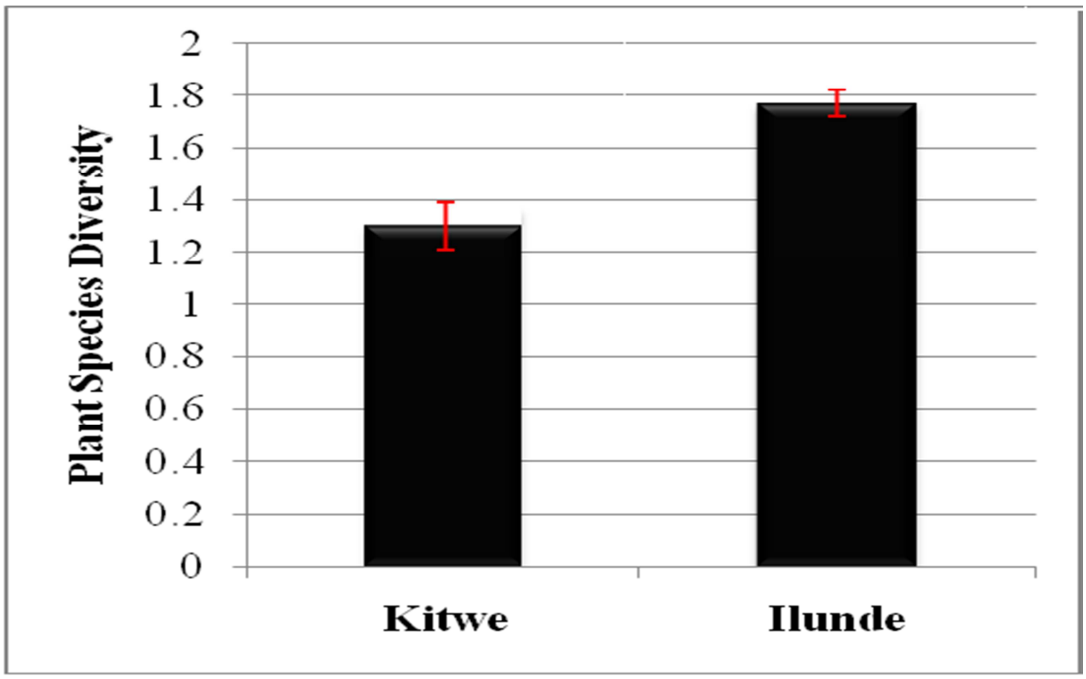

Fig. 3: Diversity of herbs and grasses in the two forests

Furthermore, Ilunde forest was more diverse in shrubs and saplings with Shannon-Wiener diversity mean of 1.57 ± 0.057. In Kitwe forest Shannon-Wiener diversity index mean for shrubs and saplings was 1.25 ± 0.1. (Figure 4). The results of One-Way Analysis of Variance revealed that the diversity of shrubs and saplings between the two forests was significantly different ($P < 0.05$).

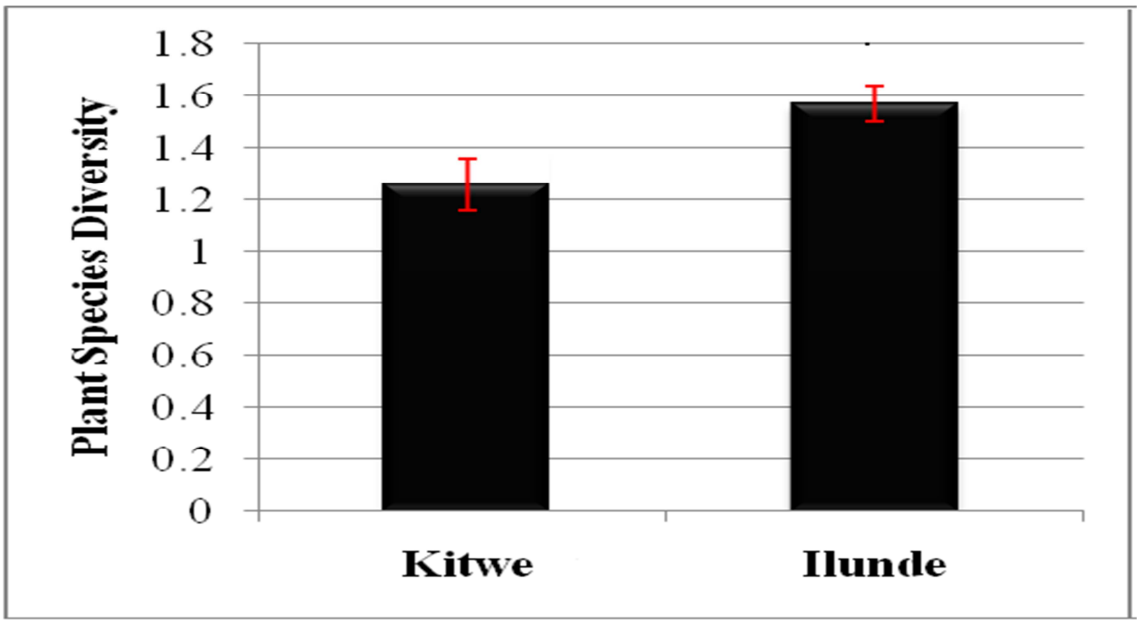

Fig. 4: Diversity of shrubs and saplings in the two forests

Ilunde was more diverse in tree species with Shannon-Wiener diversity index mean of 2.16 ± 0.07. In Kitwe, trees had Shannon-Wiener diversity index mean of 1.83 ± 0.09 (Figure 5). Kruskal-Wallis test revealed significant difference in the diversity of tree species between the two forests ($P < 0.05$).

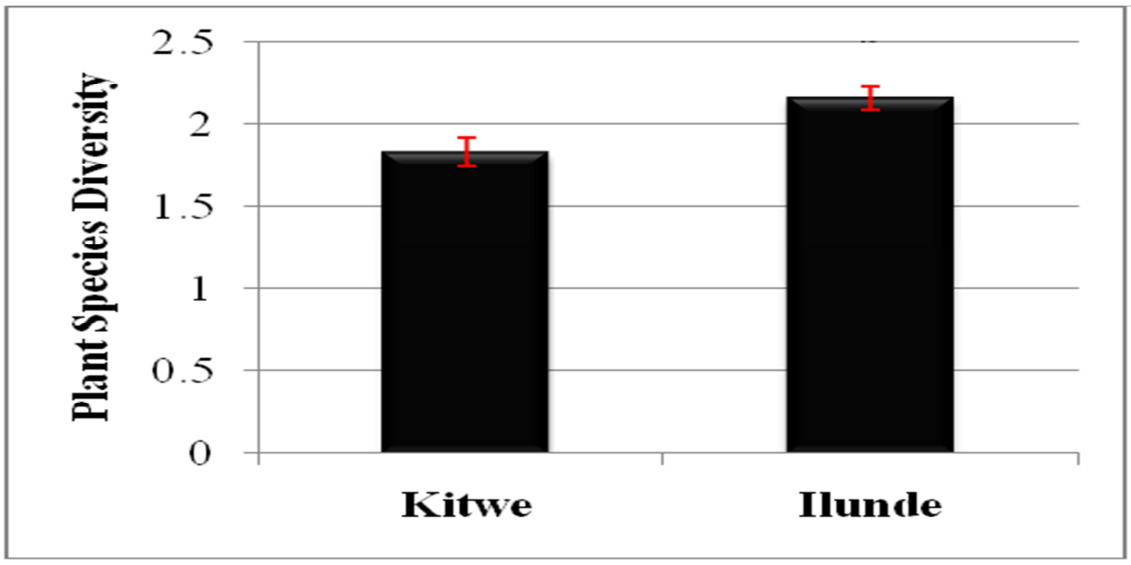

Fig. 5: Diversity of tree species in the two forests

Fire Frequency in Ilunde Forest

Figure 6 illustrates the frequency of fire detected by 16 Days 250 m MODIS Satellite Imagery from the year 2001 to 2012. The average number of wildfires per annum was 35 during this time.

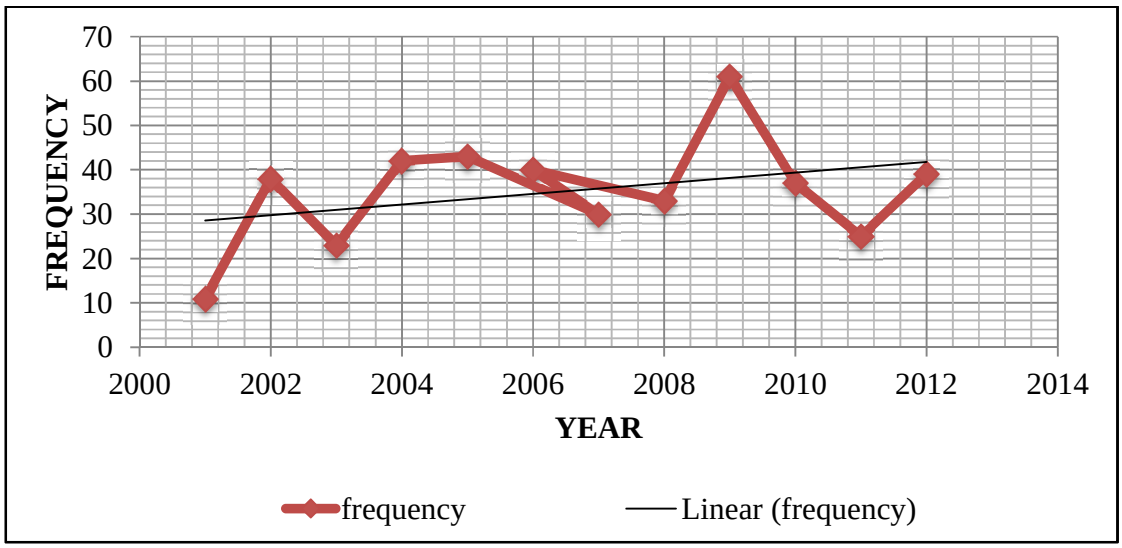

Fig. 6: Fire frequency in Ilunde forest

DISCUSSION

The values of Shannon-Wiener diversity index of 2.67 ± 0.06 and 2.15 ± 0.09 in Ilunde and Kitwe forests respectively, suggest that entirely the study area is reasonably diverse. Shannon-Wiener diversity indices greater than 2 signify medium to high diversity of species[4]. However, Shannon-Wiener diversity indices obtained in the present study are lower than those reported in several Tanzanian miombo woodlands[24, 35, 13]. Conversely, the values of Shannon-Wiener diversity indices that were obtained in the present study are in agreement to those reported in miombo woodlands of Mozambique[33].

In the present study, it has been observed that Ilunde forest which is frequently burnt was more diverse than Kitwe, the fire suppressed forest. Loss of fire-intolerant species due to high frequency wildfires could be responsible for enhancing non-indigenous

species to occupy vacated spaces thereby increasing the diversity of plant species in this forest. The high richness of herbs and grasses could also be responsible for increasing the overall species diversity. Utilization of herbs and grasses as fuels during repeated burning possibly enhanced flourishing of these life forms in Ilunde forest. Grasses and herbs were the most dominant life forms in this forest.

Wildfire suppression in Kitwe probably contributed to low recruitments of non-indigenous species in the forest. This is because increase in canopy and large accumulation of litter possibly rendered selective environment for non-indigeneous species in Kitwe forest. Many plant species, including the shade-intolerant require fire to open gaps in vegetation canopy that will later on let in light, allowing their seedlings to compete with the more shade-adapted seedlings of other species[17]. As a result the shade intolerant species take over[3]. On the other hand, it has been reported that high species diversity in fire-prone areas results from intermediate resource availability that reduces dominance and competitive exclusion of all forms of plants[19].

Also, in Kitwe forest the enormous accumulation of litter observed during the present study is likely to limit the growth/establishment of herbs and grasses by hindering seed germination hence lowering their diversity. Dense canopy cover does not favour regeneration since only shade adapted plants can sustain the associated competition[10, 27]. Few species of shrubs and saplings in Kitwe could be attributed to suppression of wildfires, a factor which might have provided suitable conditions for a reasonable number of saplings to grow into mature trees. This is similar to what was reported that long-return intervals of fires are known to prevent the transformation of forests to shrubland and grassland[28].

The high diversity of shrubs and saplings was recorded in Ilunde forest where wildfires were frequent. This is an indication that repeated burning prevents saplings to develop into mature trees. Repeated fires maintain firetraps which limit plant growth[5], also, savanna trees only recruit into mature populations once they escape the zone of grass fires[15].

Other factors such as climate, genetic and edaphic could also account for the differences in the diversity of plant species between the studied forests. However, these factors were not assessed in the present study though their role is considered important. Nevertheless, soil fertility, moisture or humid conditions explain the differences in species diversity in ecological systems[14, 31].

Findings on high species diversity in frequently burnt areas were reported in several studies[30, 25, 11]. On the other hand, results of the present study contradict to what have been reported in some other areas[2, 33].

CONCLUSION

Globally, there has been a substantial potential for improving fire management for greenhouse gases reduction and biodiversity conservation. However, on the basis of the results of the present study, fire exclusion is likely to cause a decline in the diversity of plant species. This implies a need to carry out further studies on the suitability of early dry season fire for high plant species diversity and management of greenhouse gases.

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Appendix 1. Tree Species in Ilunde Forest

Species	
Albizia gummifera	10
Albizia harveyi	4
Annona senegalensis	70
Hexalobus monopetalus	75
Azanza garckeana	5
Boscia salicifolia	27
Brachystegia boehmii	306
Brachystegia spiciformis	178
Burkea africana	18
Canthium burtii	16
Cassipourea malosana	7
Chrysophyllum bangweolense	25
Combretum adenogonum	6
Combretum collinum	69
Combretum molle	90
Combretum psidioides	63
Commiphora africana	1
Dalbergia nitidula	10
Dichrostachys cinerea	16
Diospyros kirkii	59
Diplorhynchus condylocarpon	1704
Dombeya cincinnata	32
Flueggea virosa	494
Gardenia ternifolia	2
Grewia bicolor	23
Grewia forbesii	4
Holarrhena pubescens	4
Hymenocardia acida	169
Hymenodictyon acida	153
Isoberlinia angolensis	1
Julbernadia globiflora	310
Lannea schimperi	23
Lonchocarpus bussei	18
Maprounea africana	111
Margaritaria discoidea	27
Markhamia obtusifolia	72
Monotes africanus	88
Multidentia crassa	31
Ochna mossambicensis	35
Pavetta schumanniana	4
Pericopsis angolensis	204
Pseudolachnostylis maprouneifolia	100
Pterocarpus angolensis	91
Pterocarpus tinctorius	47
Rhus natalensis	19

Rothmannia englerana	20
Schrebera trichoclada	10
Securidaca longipedunculata	2
Stereospermum kunthianum	6
Strychnos cocculoides	2
Strychnos innocua	9
Strychnos madagascariensis	9
Strychnos potatorum	14
Strychnos pungens	141
Celtis philipensis	17
Strychnos spinosa	3
Swartzia madagascariensis	111
Tamarindus indica	1
Terminalia kaiserana	80
Vitex doniana	2
Vitex mombassae	75
Ximenia caffra	6
Zanha africana	1

Appendix 2. Tree Species in Kitwe Forest

Species	**Abundance**
Afzelia quanzensis	10
Annona senegalensis	69
Hexalobus monopetalus	62
Antidesma venosum	29
Bauhinia petersiana	15
Boscia salicifolia	2
Brachystegia microphylla	380
Brachystegia spiciformis	19
Bridelia cathartica	12
Bridelia micrantha	10
Brysocarpus orientalis	11
Burkea africana	65
Canthium burtii	9
Senna siamea	20
Chrysophyllum bangweolense	74
Combretum molle	88
Commiphora africana	3
Crossopteryx febrifuga	107
Dalbergia melanoxylon	69
Dalbergia nitidula	189
Dichrostachys cinerea	16
Diplorhynchus condylocarpon	2236
Euclea natalensis	3
Ficus ingens	6
Ficus sur	3
Ficus sycomorus	1

Flueggea virosa	587
Gardenia ternalea	1
Gardenia ternifolia	4
Grewia cornocarpa	20
Grewia forbesii	19
Holarrhena pubescens	6
Hymenocardia acida	85
Hymenodictyon acida	86
Julbernadia globiflora	3765
Khaya anthotheca	97
Lannea schimperi	21
Lannea stuhlmanii	3
Mangifera indica	35
Mapronea africana	2
Margaritaria discoidea	15
Markhamia lutea	4
Markhamia obtusifolia	60
Multidentia crassa	19
Mundulea sericea	16
Ochna mossambicensis	56
Ozoroa insignis	11
Parinari curatellifolia	113
Pavetta schumanniana	47
Pericopsis angolensis	118
Phyllanthus reticulatus	44
Podocarpus milanjianus	17
Pseudolachnostylis maprouneifolia	250
Psorospermum febrifuga	27
Pterocarpus angolensis	134
Pterocarpus tinctorius	261
Rhus natalensis	24
Rothmannia englerana	275
Rytignia uhligii	7
Rytignia/Canthium	16
Sterculia africana	5
Stereospermum kunthianum	152
Strychnos innocua	632
Strychnos madagascariensis	12
Celtis philipensis	77
Strychnos spinosa	41
Swartzia madagascariensis	79
Agelanthus kayseri	1
Thylachium africanum	30
Tinnea aethiopica	23
Vitex doniana	56
Vitex mombassae	4
Ximenia caffra	12
Zanha africana	6
Ziziphus mucronata	2

Appendix 3. Shrubs and Saplings in Ilunde Forest

Species	**Abundance**
Annona senegalensis	10
Hexalobus monopetalus	2
Azanza garckeana	2
Brachystegia boehmii	53
Brachystegia spiciformis	27
Canthium burtii	18
Chrysophyllum bangweolense	42
Clerodendrum capitatum	3
Combretum collinum	7
Combretum molle	19
Combretum psidioides	3
Diplorhynchus condylocarpon	117
Flueggea virosa	93
Holarrhena pubescens	3
Hymenocardia acida	71
Hymenodictyon acida	4
Julbernadia globiflora	34
Lannea schimperi	3
Leptactina benguelensis	28
Lonchocarpus bussei	2
Maprounea africana	21
Markhamia obtusifolia	57
Monotes africanus	11
Multidentia crassa	50
Ochna mossambicensis	11
Pavetta schumanniana	11
Pericopsis angolensis	37
Pseudolachnostylis maprouneifolia	4
Psorospermum febrifuga	1
Psychotria kirkii	6
Pterocarpus angolensis	1
Pterocarpus tinctorius	15
Rhus natalensis	3
Rothmannia englerana	12
Schrebera trichoclada	2
Stereospermum kunthianum	5
Strychnos spinosa	18
Swartzia madagascariensis	17
Terminalia kaiserana	38
Tetracera litoralis	103
Vitex doniana	12
Vitex mombassae	86
Ximenia caffra	1

Appendix 4. Shrubs and Saplings in Kitwe Forest

Species	**Abundance**
Afzelia quanzensis	3
Annona senegalensis	13
Hexalobus monopetalus	12
Brachystegia microphylla	6
Bridelia cathartica	11
Brysocarpus orientalis	11
Canthium burtii	4
Canthium zanzibaricum	1
Combretum collinum	5
Combretum molle	1
Crossopteryx febrifuga	8
Dalbergia nitidula	1
Desmodium velutinum	3
Diplorhynchus condylocarpon	97
Euclea natalensis	3
Flueggea virosa	68
Holarrhena pubescens	6
Julbernadia globiflora	213
Lannea schimperi	1
Leptactina benguelensis	30
Markhamia lutea	10
Ochna mossambicensis	8
Pavetta schumanniana	50
Phyllanthus reticulatus	5
Pseudolachnostylis maprouneifolia	9
Psorospermum febrifuga	5
Pterocarpus tinctorius	13
Rhus natalensis	6
Rothmannia englerana	38
Rytignia parvifolia	3
Stereospermum kunthianum	6
Strychnos innocua	86
Celtis philipensis	3
Strychnos spinosa	4
Swartzia madagascariensis	1
Tapiphyllum burnettii	7
Tinnea aethiopica	51
Vitex doniana	9
Zanha africana	7

Appendix 5. Herbs and Grasses in Ilunde Forest

Species	**Abundance**
Andropogon gayanus	101
Bidens pilosa	11
Biophytum abyssinicum	5
Blepharis maderaspatensis	4
Brachiaria brizantha	158
Brachystegia boehmii	153
Brachystegia spiciformis	5
Bulbostylis buchananii	6
Cassytha filiformis	5
Chrysophyllum bangweolense	11
Combretum psidioides	1
Commelina africana	18
Crinum papillosum	2
Dalbergia nitidula	11
Digitaria abyssinica	35
Diplorhynchus condylocarpon	10
Emilia integrifolia	9
Eragrostis pateus	13
Flueggea virosa	86
Gutenbergia polycephala	100
Heteropogon contortus	22
Hymenocardia acida	21
Hymenodictyon acida	2
Hyparrhenia filipendula	278
Hyparrhenia rufa	20
Indigofera volkensii	2
Julbernadia globiflora	13
Lannea schimperi	5
Leptactina benguelensis	19
Leucas deflexa	25
Maprounea africana	4
Markhamia obtusifolia	2
Triclisia sacleuxii	20
Merremia tridentata	32
Microchloa kunthii	80
Monechma debile	22
Multidentia crassa	5
Ochna mossambicensis	28
Pandaka rubrolutea	133
Pennisetum polystachion	18
Polycarpaea corymbosa	30
Rothmannia englerana	4
Senecio abyssinicus	126
Setaria sphacelata	98
Setaria vexillata	5

Spermacoce chaetocephala	18
Spermacoce senensis	27
Sporobolus pyramidalis	5
Stereospermum kunthianum	3
Strychnos pungens	31
Strychnos spinosa	54
Terminalia kaiserana	10
Tetracera litoralis	105
Themeda triandra	93
Triumfetta rhomboidea	1
Vernonia glabra	1
Vernonia perrottetii	20
Vernonia poskeana	9
Vitex doniana	4
Vitex mombassae	12

Appendix 6. Herbs and Grasses in Kitwe Forest

Species	**Abundance**
Abrus precatorius	4
Andropogon gayanus	40
Loudetia simplex	580
Asparagus africanus	2
Aspilia mossambicensis	8
Barleria sacleuxii	11
Bidens pilosa	1
Biophytum abyssinicum	7
Brachystegia microphylla	6
Brysocarpus orientalis	8
Canthium burtii	1
Senna mimosoides	2
Combretum molle	7
Combretum zeylani	5
Commelina africana	15
Crossopteryx febrifuga	8
Cyanotis foecunda	20
Desmodium barbatum	10
Dichrostachys cinerea	2
Diplorhynchus condylocarpon	40
Eragrostis pateus	16
Flueggea virosa	30
Gutenbergia polycephala	27
Holarrhena pubescens	2
Hyparrhenia filipendula	35
Hyptis suaveolens	3
Imperata cylindrica	12
Indigofera rhynchocarpa	1

Ipomoea sinensis	9
Julbernadia globiflora	159
Kohautia longifolia	10
Landolphia kirkii	2
Leptactina benguelensis	393
Loudetia simplex	4
Memecylon sansibaricum	35
Triclisia sacleuxii	28
Ochna mossambicensis	11
Oldenlandia corymbosa	29
Pandaka rubrolutea	189
Panicum coloratum	3
Panicum maximum	3
Parinari curatellifolia	3
Pavetta schumanniana	30
Pennisetum polystachyon	10
Perotis hildebrandtii	10
Polycarpaea corymbosa	20
Polygala erioptera	2
Pyschotria kirkii	3
Rhynchosia hirta	1
Rothmannia englerana	11
Rottboellia exaltata	2
Secamone parvifolia	5
Senecio abyssinicus	8
Spermacoce chaetocephala	60
Spermacoce senensis	41
Strychnos innocua	71
Celtis philipensis	30
Stylosanthes fruticosa	1
Tapiphyllum burnettii	3
Tephrosia villosa	40
Tinnea aethiopica	5
Vernonia perrottetii	2
Vitex doniana	1
Waltheria indica	2
Zanha africana	1