Plant diversity of Betel Leaf Agroforestry of South Meghalaya, Northeast India

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Abstract. Tynsong H, Tiwari BK, Dkhar M. 2018. Plant diversity of Betel Leaf Agroforestry of South Meghalaya, Northeast India. Asian J For 2: 1-11. Large areas of lowland tropical forests of South Meghalaya have been converted into betel leaf agroforestry systems by the tribal people living in the area. The betel leaf agroforestry with diverse and structurally complex shade canopies conserve a significant portion of the original forest biodiversity. The impact of land use change on the biodiversity was studied using standard vegetation analysis and biodiversity estimation methods. A total of 160 plant species were recorded in natural forests out of which 75 were trees, 40 shrubs, and 45 herbs, while in betel leaf agroforestry, a total of 159 plant species, 94 trees, 17 shrubs and 48 herbs were recorded. A total of 34 tree species, 13 shrub species, and 14 herb species were common in both the land uses. All the plant species were native species. The study revealed that the conversion of natural forest to betel leaf agroforestry in South Meghalaya has no significant impact on tree and herb diversity. However, the basal area and density are affected to some extent. The land use change has also affected the density and diversity of shrubs. The study concludes that betel leaf agroforestry in South Meghalaya developed by the indigenous War Khasi tribe through experiential learning over several generations has emerged as a fairly sustainable agroforestry system causing minimal impact on plant diversity.

Keywords: Betel leaf agroforest, cash crop, natural forest, South Meghalaya

INTRODUCTION

Biodiversity cannot be conserved effectively if conservation strategies are restricted to protected natural ecosystems alone (Moguel and Toledo 1999). Ryan (1992) reported that there are only about 7000 protected areas in the world, covering approximately 650 million ha, which represent less than 5% of the earth’s land surface. The rest of the terrestrial environment is affected by human activities, including agriculture and other developmental works. Most ecology and biodiversity-related researches focusing on undisturbed ecosystems, human impacted and managed ecosystems have not received due attention needless to say agroforestry, home gardens, polycultures that are part of the indigenous agricultural practices contributing a great deal in biodiversity conservation (Toledo 1990; Tynsong and Tiwari 2011). Toledo et al. (1994) and Tiwari et al. (2017) reported that there is increasing evidence that the mosaic structure of landscapes under indigenous and local knowledge-based management systems maintain and even improve biodiversity. Forest ecosystems can range from little-disturbed natural forests to agro-industrial, monospecific plantations. Between these two extremes is the traditional agroforestry under indigenous management, which combines relatively high and sustainable economic benefits with a seemingly diversified, productive system. The area under natural and semi-natural forests is decreasing by 13 million ha annually (FAO 2006). Contrary to this, the average annual rate of forest plantation establishment is 5 million ha (FAO 2014). There are indications that the area under agroforestry systems will continue to increase, making it important to assess its potentials to fulfill biological conservation as well as its economic purpose. The question is whether agroforestry systems can harbor biodiversity which is similar to that in natural forests or not.

Northeastern India is a part of the Indo-Burma biodiversity hotspot harboring about 50% plant biodiversity of India (ca. 8000 species), of which 31.58% (ca. 2526 species) is endemic (DE, MEDHI 2014). The region is rich in orchids, ferns, oaks (Quercus spp.), bamboos, rhododendrons (Rhododendron spp.), magnolias (Magnolia spp.) etc. According to Conservation International (2011), Indo-Burma is the most threatened hotspot with 5 % original habitat is remaining. Threats to species, sites, and landscapes are immediate and severe (Baltzer et al. 2001; Nooren and Claridge 2001; IUCN 2011). The combination of economic development and an increasing human population is exerting enormous pressure on the region’s natural resources, and overexploitation has eradicated species from many areas. Meghalaya harbors 3128 species of angiosperms which include 1237 endemic species and 53 threatened plant species (Khan et al. 1997). The biodiversity of natural forests of Meghalaya has been studied by Tiwari et al. (1998), Upadhyaya (2002), Jamir and Pandey (2003) and Tripathi et al. (2006). However, biodiversity of agroforestry has not received due attention.
Betel leaf (Piper betle L.) is an important cash crop in India and Bangladesh with huge demand in the Middle East, Britain, Pakistan and some Africans counties (Haider et al. 2013). This huge market demand has acted as a driver for conversion of a large chunk of natural forests into betel leaf based agroforestry system in India, Bangladesh, Sri Lanka, Malaysia, Philippines and East Africa (Arambewela et al. 2005; Nath and Inoue 2009a). Betel leaf is traditionally consumed with slices of areca nut and a thin coating of lime by people of South and South-east Asia, the Gulf States, and the Pacific islands (Nath and Inoue 2009b). Betel leaf has a trade worth of INR 7000 million in India alone (Balasubrahmanyam et al. 1994), where about 15-20 million people consume betel leaves on a regular basis (Jana 1996). Jeng et al. (2002) reported that worldwide over 2 billion people consume betel leaf. However, in comparison to other land uses that replaces natural forest, traditional betel leaf agroforestry with diverse and structurally complex shade canopies are among the agricultural land uses that are more likely to conserve a significant portion of the original forest biodiversity as in this land use conversion the natural forests are never clear felled (Tynsong 2009). With a sustained increase of world betel leaf consumption and growing human population in many of the betel leaf consuming regions, pressures to intensify betel leaf production are likely to increase, which will result into more conversions of natural forests to betel leaf based agroforestry.

In Meghalaya, the farming of plant betel leaf (Piper betle L.) is done without cutting of naturally growing trees or burning of the field. Betel leaf grows along with trees, shrubs, and herbs on the same piece of land. During the first year after planting the betel leaf, the farmers prune the canopy of all trees except few important timber trees, fruit trees, and non-coppicing tree species. The cutting of tree branches is done, so the newly planted betel leaf grown at the base of the trees may receive enough sunlight and nutrients from the decaying leaves and branches of the lopped trees. After three to four months, most trees start sprouting again and after one year the whole plantation lopped trees. After three to four months, most trees will result into more conversions of natural forests to betel leaf based agroforestry.

The plant diversity survey was conducted in one Natural Forest (hereafter NF) and one Betel Leaf Agroforestry (hereafter BLA) of South Meghalaya, India. The NF was located in Siatabon Village (latitude 25°16’ N, longitude 91°56’ E, altitude 1003 m asl) and the BLA was located in Nongkwai Village (latitude 25°20’ N, longitude 91°39.54’ E, altitude 600 m asl) (Figure 1). Cherrapanjee-Mawsynram Plateau, one of the wettest places in the world is located in this region. The mean annual maximum and minimum temperatures are 23°C and 13°C, respectively. The mean annual rainfall is 11565 mm. The slope of the area is predominantly towards the south and the angle of the slope varies between 10° and 40°. The area has a large number of rivers and rivulets, which drain into the plains of Bangladesh. At the present times, narrow and deep river valleys separate one hill range from the other. The population density is sparse. Horticulture, forestry, and fisheries are the principal occupations of the people. Agriculture is limited to some small valleys where mainly tuber crops are grown. Areca nut, orange, betel leaf, jackfruit, bay leaf, honey and broom grass are the important products of the region. The area is inhabited by War Khasi people, a tribal community having a long tradition of forest conservation. People collect, process and market a large variety of non-timber forest products (NTFPs) and medicinal and aromatic plants (MAPs) such as Cinnamomum tamala, Piper peepuloides, Phrynium capitatum, bamboo, honey, mushrooms, nuts, wild tubers, edible worms, insects and leafy vegetables from the forests (Tynsong et al. 2012).

**Data collection**

For plant diversity studies, an extensive survey was carried out during the months of January 2006 to October 2008. The data were collected once in every season of the year for a period of two years. Composition and structure of NF and BLA were determined within 100 m² plots (10 m × 10 m) for trees (dbh ≥5 cm), 25 m² plots (5 m × 5 m) for shrubs and 1 m² plots (1 m × 1 m) for herbs. The total sample area for each study site was 1 ha for the tree, 0.05 ha for shrub and 0.01 ha for herbs. Tree species with > 10 cm diameter at breast height (dbh) were individually counted, measured and numbered. The density and frequency of occurrence of the species per plot was also estimated.
Data analysis

Plant specimens collected from the two forest types were identified with the help of Flora of Assam (Kanjilal et al. 1934-1940) and Flora of Jowai (Balakhrishnan 1981-1983). The identifications were confirmed by consulting the herbaria at Botanical Survey of India, Northeastern Circle, Shillong, India. The nomenclatures of the species are as per the regional flora. Analysis of variance (ANOVA) and correlation coefficient values (r) was calculated using Statistica Version 6 (Serial no: BX1117619309D60).

**Basal area:** The basal area of each overstory tree was calculated using equation (1). The basal area values were then extrapolated to per hectare basis.

\[
BA = \frac{\pi D^2}{4}
\]  

Where:
- \(BA\) : basal area (m² ha⁻¹);
- \(D\) : diameter at breast height (cm); and
- \(\pi\) : pi (3.142).

**Frequency, density, and abundance:** The frequency, density, and abundance of the species were determined following the methods of Misra (1968) and Muller-Dombois and Ellenberg (1974). The frequencies of occurrence were obtained to ascertain species abundance and species evenness. The following biodiversity indices were computed.

**Simpson index of dominance (D):** Simpson index of dominance (D) (Simpson 1949) was obtained using equation (2):

\[
D = \sum \left(\frac{n_i}{N}\right)^2
\]  

Where:
- \(n_i\) : number of individuals of ith species.
- \(N\) : total number of individuals of all the species.

**Species relative density (RD):** This refers to the number of individuals of a given species divided by the total number of individuals of all species. This was obtained using equation (3):

\[
RD = \frac{n_i \times 100}{N}
\]

Where:
- \(RD\) : relative density;
- \(n_i\) : number of individuals of species;
- \(N\) : total number of individuals in the entire population

**Importance value index (IVI):** For tree species, it was obtained by summing RD and RDo, and then dividing it by 2 as given by Equation (4).

\[
IVI = \frac{RD + RDo}{2}
\]

Where:
- \(IVI\) : importance value index;
- \(RD\) : relative density;
- \(RDo\) : relative dominance.

*Figure 1.* The study site in Natural Forest (hereafter NF) and Betel Leaf Agroforestry (hereafter BLA) of South Meghalaya, India
The Shannon-Wiener diversity index (H). Shannon-Wiener diversity index (Shannon and Wiener 1963) was obtained by using Equation (5):

\[ H = - \sum \left( \frac{n_i}{N} \right) \log_e \left( \frac{n_i}{N} \right) \]  

Where: 
\[ n_i : \text{IVI of each species and} \]
\[ N : \text{total IVI} \]

Species evenness (E): Pielou’s evenness index (Pielou 1975) was obtained by using equation 6.

\[ E = \sum \left( \frac{n_i}{N} \right) \log_e \left( \frac{n_i}{N} \right) / \log_e S \]  

Where: 
\[ n_i : \text{IVI of each species,} \]
\[ N : \text{total IVI and} \]
\[ S : \text{Number of species} \]

RESULTS AND DISCUSSION

Plant diversity
In a natural forest, a total of 160 plant species were recorded out of which 75 were trees, 40 shrubs, and 45 herbs while in betel leaf agroforestry a total of 159 plant species, 94 trees, 17 shrubs and 48 herbs were recorded. A total of 34 tree species, 13 shrub species, and 14 herb species were present in both forest types. All the plant species encountered were native species (Table S1). For shrub component, species richness, number of families and number of genera were significantly higher in NF as compared to BLA. However, for tree and herb components, number of families, number of genera and Shannon Diversity Index, there is a slight increase in BLA as compared to NF (Table 1). The similarity between NF and BLA for trees, shrubs and herbs species was 43.34%, 37.93%, and 38.32 % respectively. The one-way analysis of variance (ANOVA) showed significant variation (P≤0.001) of tree, shrub, and herb between NF and BLA. The correlation coefficient values (r) were analyzed, it showed a positive significant correlation between tree (r = 0.87, P≤0.001), shrub (r = 1.00, P≤0.001) and herb (r = 1.00, P≤0.001).

Three dominant families of tree in NF were Lauraceae (11 species), Fagaceae (8 species) and Euphorbiaceae (8 species) while dominant families of tree in BLA were Euphorbiaceae (12 species) Lauraceae (12 species) and Moraceae (8 species). On shrubs, three dominant families in NF were Rubiaceae (9 species), Moraceae (4 species) and Poaceae (3 species) while in BLA they were Rubiaceae (6 species), Arecales (2 species) and Urticaceae (2 species). On Herb, dominant families in NF included Zingiberaceae (5 species), Rubiaceae (4 species) and Melastomataceae (4 species) while dominant families in BLA included Asteraceae (5 species), Rubiaceae (4 species) and Poaceae (3 species). We encountered 24 families of tree, 9 families of shrub and 9 families of herb present in both forest types.

Tree species with high IVI in each forest type were: Lithocarpus fenestatus, Lithocarpus elegans and Sarcosperma griffithii (NF); Duabanga grandiflora, Sarcosperma griffithii, and Ficus glomerata (BLA). The ten most important tree species in two forest types are given in Table 2. A list of endemic (E) and rare (R) species found in both the forest types is given in Table 3.

Main uses of plants in betel leaf agroforestry
All 94 tree species recorded in BLA were maintained by local people as supporting trees for betel leaf to grow. However, it was observed that most preferred tree species well supporting the growth of betel leaf include Artocarpus heterophyllus, Duabanga grandiflora, Sarcosperma griffithii, and Ficus glomerata (BLA). The ten most important tree species in two forest types are as follows: (i) timber divided into: high value timber (HT) and low value timber (LT), (ii) fuelwood divided into: high value fuelwood (HFW) and low value fuelwood (LFW), (iii) edible stuff (E), (iv) medicinal stuff (M), (v) tool making stuff (T), (vi) ornamental stuff (O), (vii) craft (C), (viii) packing leaf (PC), (ix) latex producing plant (L) and (x) nonspecific use (NSU). Edible plants included: fruit, vegetable, and seed. In BLA as a whole, the usages were 21 as Timber trees (HT = 10 and LT = 11), 51 as fuelwood (HFW = 20 and LFW = 31), 15 as edible stuff, 17 as medicinal stuff, 40 with nonspecific uses and as making tools stuff, ornamental stuff, craft, spice stuff, packing leaf and latex producing plant for the rests with a total of 15 plant species (Table 4).

### Table 1. Diversity and community characteristics of plant species in Natural Forest (NF) and Betel Leaf Agroforestry (BLA) of South Meghalaya, India

| Parameter                  | NF          | BLA         |
|----------------------------|-------------|-------------|
|                            | Tree        | Herb        | Tree        | Shrub       | Herb        |
| Sampling size (ha)          | 1.0         | 0.4         | 0.02        | 1.0         | 0.4         | 0.02        |
| Number of families          | 33          | 21          | 27          | 41          | 13          | 31          |
| Number of genera            | 61          | 33          | 37          | 78          | 21          | 42          |
| Species richness            | 75          | 40          | 45          | 94          | 17          | 48          |
| Density (ha⁻¹)              | 1972        | 19280       | 347563      | 1788        | 7660        | 423688      |
| Basal area (m²ha⁻¹)         | 52.26       | -           | -           | 50.06       | -           | -           |
| Species evenness index (E)  | 0.83        | 0.90        | 0.93        | 0.90        | 0.45        | 0.95        |
| Shannon diversity index (H) | 3.87        | 3.35        | 3.55        | 4.10        | 2.70        | 3.68        |
Table 2. Population characteristics of ten most important tree species in natural forest and betel leaf agroforestry

| Tree species                           | Freq. (%) | DBH (cm) | Basal Area (m² ha⁻¹) | IVI   |
|----------------------------------------|-----------|----------|-----------------------|-------|
| Lithocarpus fenestra (Roxb.) Rehder    | 41        | 1.58     | 4.96                  | 40.66 |
| Lithocarpus elegans (Blume.) Soep.     | 48        | 1.37     | 4.29                  | 30.8  |
| Sarcosperma griffithii Benth.          | 51        | 0.94     | 2.94                  | 16.58 |
| Machilus bombycina King.               | 38        | 0.80     | 2.52                  | 12.35 |
| Schima wallichii Choisy.               | 22        | 0.68     | 2.12                  | 11.66 |
| Quercus lanceofolia Roxb.              | 29        | 0.65     | 2.04                  | 10.51 |
| Castanopsis hystrix A.DC.              | 34        | 0.58     | 1.84                  | 10.48 |
| Helicia erratica Hk.f.                 | 40        | 0.58     | 1.82                  | 8.76  |
| Castanea sativa Miller.                | 19        | 0.51     | 1.61                  | 8.5   |
| Quercus spicata Smith.                 | 16        | 0.49     | 1.55                  | 6.02  |

BLA

Duabanga grandiflora (Roxb. Ex DC.) Walp.
Sarcosperma griffithii Benth.
Ficus glomerata Roxb.
Ficus benjamina L. var. comosa Kurtz.
Phoebe cooperiana U.N.Kanjilal ex A.Das.Nov.sp.
Wrighitia tomentosa Roem & Sch.
Artocarpus lakoocha Roxb.
Toona ciliata Roem.
Caryota urens L.
Adenanthera pavonina L.

Table 3. Endemic and rare plant species present in the natural forest and betel leaf agroforestry

| Plant species                           | Family           | Status | Forest stands |
|-----------------------------------------|------------------|--------|---------------|
| Acer oblongum Wall.                     | Aceraceae        | R      | NF            |
| Citrus latipes (Swingle.)Tanaka.        | Rutaceae         | E, R   | NF            |
| Cyathea gigantea (Wall ex Hook.) Holtm. | Cyatheaceae      | R      | NF            |
| Daphniphyllum himalayanse Muell.       | Euphorbiaceae    | E      | NF            |
| Drimycarpus racemosus Hk.f.             | Anacardiaceae    | E      | BLA           |
| Erythroxylon kuhnianum Wall.            | Malpighiaceae    | E      | NF            |
| Euonymus lawsonii Clarke & Prain.      | Celastraceae     | E      | BLA           |
| Ilex embelioiides Hk.f                 | Aquifoliaceae    | E, R   | BLA           |
| Sarcosperma griffithii Benth.           | Sapotaceae       | R      | NF & BLA      |

Shrub

Ardisia griffithii C.B.Clarke.
Ixora subsissillis Wall.
Mahonia pycnophylla Fedde.
Rubus khasiansus Cordat.

Herb

Eriocaulon cristatum Mast.
Impatien tripetala DC.
Osbekia capitata Benth.
Sonerilla khasiana Dyer.

Note: NF- natural forest, BLA-betel leaf agroforestry, E- Endemic, R- Rare

Discussion

Tree species diversity and richness (H' = 4.10; 94 species) in BLA was higher than that in NF (H' = 3.87; 75 species). Also, herb species diversity and richness in BLA (H' = 3.68; 48 species) were higher than NF (H' = 3.55; 45 species). However, shrub species diversity and richness (H' = 2.70; 17 species) in BLA was slightly lower than that in NF (H' = 3.35; 40 species) (Table 1). A comparison between the tree species richness of BLA of South Meghalaya with other agroforestry systems shows that tree diversity of BLA was significantly higher (94 tree species) than cocoa agroforestry in southern Cameroon (21 tree species), betel leaf agroforestry in Bangladesh (61 tree species) (Nath et al. 2003) and betel nut agroforestry of...
South Meghalaya (83 tree species) (Tynsong and Tiwari 2010) but it was lower than the coffee farms in Veracruz, Mexico (Lopez-Gomez et al. 2008). Species richness for herb, in BLA of South Meghalaya (48 species) was similar to cocoa agroforestry of south Cameroon (48 herb species) (Sonwa et al. 2007) and slightly higher than the betel nut agroforestry of South Meghalaya (41 herb species) (Tynsong and Tiwari 2010). Tree species in BLA are more diverse as compared to traditional agroforestry of Dellomenna District, Southeastern Ethiopia (H’ = 2.53 to 2.73) (Molla and Kewessa 2015), home garden of Thailand (H’ = 0.9 to 2.7) (Gajaseni and Gajaseni 1999) and traditional agroforestry of Kerala in India (H’ = 1.12 to 3) (Kumar et al. 1994).

Tree basal area in BLA (50.05 m²/ha⁻¹) was marginally less than NF (52.26) (Table 1). However, in comparison with other agroforestry systems, the BLA had higher tree basal area. For example, in cocoa agroforestry and mixed food crops agroforestry in Southeastern Ghana, the basal area was recorded at 8.4 m²/ha⁻¹ and 8.2 m²/ha⁻¹ respectively (Asase and Tetteh 2010). It was also higher than in cocoa plantations in Indonesia (11.9 to 20.5 m²/ha) (Merijn et al. 2007) and in cocoa plantations in the South province of Cameroon (29.7 to 42.6 m²/ha) (Van Gemerden 2004).

Our results suggest that a better stock of forest tree species were maintained in BLA that that in the natural forest of the area. We also observed that the tree species such as Trema polytoria, Macaranga denticulata, Macaranga peltata, Adenanthera pavonina, Ficus roxburghii and Wrightia tomentosa were found only in BLA.

Furthermore, the light-demanding second story tree species such as Trema polytoria, Macaranga denticulata, and Macaranga peltata grow luxuriantly in BLA and were absent in NF due to the higher density of trees resulting into the lower sunlight. Higher herb species diversity in BLA may be attributed to the fact that it was dominated by light-demanding plants, specifically those belonging to Asteraceae, Rubiaceae, and Poaceae. Thus in BLA, the species composition of trees and herbs seem to be directly related to the availability of light. A similar finding was reported in traditional cocoa forest gardens by Bisseleua et al. (2008). Decrease in number of shrub species in BLA could be explained by the traditional management practices of BLA by local people, such as by the weeding out of shrubs growing close to betel leaf plants twice a year by farmers, so the betel leaf have sufficient space and nutrients to grow. Even though in BLA, all tree species were maintained as supporting trees, we observed that high percentage of highly economical useful plant species are retained for the purpose. The preference for multipurpose tree species is understandable in the context that the owners of the agroforestry depend on such plants for timber, food, medicine and fuelwood (Tiwari et al. 2004). Motiur et al. (2006) also found that agroforestry in Bangladesh supply important forest products like fruit, fuelwood, timber and bamboo to meet household demands. Besides as supporting trees, tree species were maintained mainly for timber, fuelwood, and edible stuff purposes. Arctocarpus heterophyllus, Cedrela toona, Duabanga grandiflora, and Schima wallichii are preferred timber trees, while Macaranga denticulata, Macaranga hypoleuca, Macaranga peltata, Quercus dealbata, and Quercus lanceolata are most preferred as fuelwood trees. A total of 17 medicinal plant species were recorded in BLAs. BLAs are also the habitat for 14 endemic and 6 rare plants. Thus these manmade ecosystems serve the purpose of biodiversity conservation, at the same time they also provide goods and services to the local inhabitants.

Conclusion

The Betel Leaf Agroforestry harbors plant diversity comparable to the natural forests and provides habitat for endemic and rare plant and animal species. The land use change has a negligible impact on tree and herb diversity. However, it has a significant impact on density and diversity of shrub species. Betel Leaf Agroforestry of South Meghalaya is best-suited land use practice with minimal impact on plant diversity and forest community structure. We conclude that for a more robust study and conclusions regarding the impact of Betel Leaf Agroforestry on plant diversity, further research needs to be carried out across the region.

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### Table 4. Number of plant species and their main uses in BLA in South Meghalaya, India

| Main uses          | No of plant species |
|--------------------|---------------------|
| Timber             | High value          |
|                    | Low value           |
| Fuelwood           | High value          |
|                    | Low value           |
| Edible             |                     |
| Medicinal          |                     |
| Tool               |                     |
| Ornamental         |                     |
| Craft              |                     |
| Packing Leaf       |                     |
| Latex Producing    |                     |
| Plant              | No Specific Use     |
|                    |                     |
|                    | Total               |
|                    |                     |

| Main uses          | No of plant species |
|--------------------|---------------------|
| Timber             | 10                  |
| Fuelwood           | 11                  |
| Edible             | 20                  |
| Medicinal          | 31                  |
| Tool               | 15                  |
| Ornamental         | 17                  |
| Craft              | 6                   |
| Packing Leaf       | 5                   |
| Latex Producing    | 1                   |
| Plant              | 40                  |
| No Specific Use    |                     |
|                    | Total               |
|                    | 159                 |
REFERENCES

Alam MK, Mohiuddin M. 1995. Conservation of tree diversity through betel-leaf (Piper betel) based Agroforestry in Sylhet, Bangladesh. J For Science, 24: 49-53.

Arambewela L, Kumaratunga KGA, Dias K. 2005. Studies on Piper betle of Sri Lanka. J Nat Sci Found Sri Lanka, 33: 133-139.

Asase A, Tetteh DA. 2010. The role of complex agroforestry systems in the conservation of forest tree diversity and structure in southwestern Ghana. Agroforestry System, 79: 355-368.

Balakrishnan NP. 1981-1983. Flora of Jowai, Meghalaya. Vol. I & II. Botanical Survey of India, Howrah, India.

Balasubrahmanyam VR, John JK, Rawat AKS, Tripathi RD, Chaurasia RS. 1994. Betelvine (Piper betle L.). National Botanical Research Institute, Lucknow, India.

Baltzer MC, Nguyen TD, Shore RG (eds.). 2001. Towards a vision for biodiversity conservation in the Forests of the Lower Mekong Ecoregion Complex. Hanoi: WWF Indochina Program.

Bissellou D, Herbst V, Vital S. 2008. Plant biodiversity and vegetation structure in traditional coca forest gardens in southern Cameroon under different management. Biodiv Conserv 17: 1821-1835.

Conservation International. 2011. The world’s 10 most threatened Forests Hotspots. Conservation International, New York.

De LC, Medhi RP. 2014. Diversity and Conservation of Rare and Endemic Orchids of North East India - A Review. Indian J Hill Farming 27 (1): 138-153.

FAO. 2014. Planted forests. Rome: Food and Agricultural Organization. Food and Agriculture Organization of the United Nations, Rome.

FAO. 2006. Global Forest Resources Assessment 2005-Progress towards sustainable forest management. FAO Forestry Paper 146. Food and Agriculture Organization of the United Nations, Rome.

Gajaseni N, Gajaseni J. 1999. Ecological rationalities of the traditional homestead garden in the Chao Phraya Basin, Thailand. Agrofor Syst 46: 63-32.

Haider MR, Khaire A, Rahman MM, Alam MK. 2013. Indigenous management practices of betel-leaf (Piper betel L.) cultivation by the Khasia community in Bangladesh. Indian J Trad Knowl 12: 231-239.

IUCN [International Union for Conservation of Nature]. 2011. IUCN red list of threatened species. Version 2011.1. http://www.iucnredlist.org [20 November 2017].

Jamil SA, Pandey HN. 2003. Vascular plant diversity in the sacred groves of Jaintia Hills in northeast India. Biodiv Conserv 12: 1497-1510.

Jana BL. 1996. Improved technology for betel leaf cultivation. “Seminar-cum-Workshop on Betel leaf Marketing”, Directorate of Agricultural Marketing, Digha, Midnapur, West Bengal, India, June 5-6, 1996.

Jeng JH, Chen SY, Liar CH, Tung YY, Lin BR, Hahn LJ, Chang MC. 2002. Modulation of platelet aggregation by areca nut and betel leaf ingredients: Roles of relative oxygen species and cyclooxygenase. Free Radic Biol Med 32: 860-871.

Kanjilal UN, Kanti Pal PC, Das A, De RN, Bor NL. 1934-1940. Flora of northeastern Assam. Vols 5. Government Press, Shillong, India.

Khan ML, Shaily M, Kamaljit SB. 1997. Effectiveness of the protected area network in biodiversity conservation, a case study of Meghalaya state. Biodiv Conserv 6: 853-865.

Kumar BM, George SJ, Chinnamani S. 1994. Diversity, structure and standing stock of wood in the home gardens of Kerala in Peninsular India. Agrofor Syst 21: 131-213.

Lopez-Gomez AM, Williams-Linera G, Manson RH. 2008. Tree species diversity and vegetation structure in shade coffee farms in Veracruz, Mexico. Agri Ecosys Environ 124: 159-167.

Merijn MB, Steffan-Dewenter I, Tscharntke T. 2007. The contribution of cacao agroforests to the conservation of lower canopy ant and beetle diversity in Indonesia. Biodiv Conserv 16: 2429-2444.

Misra R. 1968. Ecology Work Book. Oxford and IBH, New Delhi.

Moguel P, Toledo VM. 1990. Biodiversity Conservation in Traditional Coffee Systems of Mexico. Conservacion Mexicana, 13: 11-21.

Molla A, Kewessa G. 2015. Woody Species Diversity in Traditional Agroforestry Practices of Delmomenna District, Southeastern Ethiopia: Implication for Maintaining Native Woody Species. Intl J Biodiv. DOI: 10.1155/2015/643031.

Mouter RM, Furuakava Y, Kawata I, Rahman M, Alam M. 2006. Role of homestead forest in household economy and factors affecting forest production: a case study in southwest Bangladesh. J For Res 11: 89-97.

Mueller-Dombois D, Ellenberg H. 1974. Aims and Methods of Vegetation Ecology. John Wiley, New York.

Myers N, Mittermiler R A, Mittermiler CG, Gustava AB, Du F, Kent J. 2000. Biodiversity hotspots for conservation priorities. Nature 403: 853-858.

Nath TK, Inoue M. 2009h. Forest-based settlement project and its impacts on community livelihood in the Chittagong Hill Tracts, Bangladesh. Intl For Res 11: 394-407.

Nath TK, Inoue M. 2009a. Sustainability Attributes of a Small Scale Betel Leaf Agroforestry System: A Case Study in North-Eastern Hills Forests of Bangladesh. Small Scale For 8: 289-304.

Nath TK, Makato I, Islam MJ, Kabir MA. 2003. The Khasia tribe of northeastern Bangladesh, their socio-economic status, hill farming practices and impacts on forest conservation. For Trees Livelihood 13: 297-311.

Nooren H, Claridge G. 2001. Wildlife trade in Lao PDR: the end of the game. Netherlands Committee for IUCN, Amsterdam.

Perfecto I, Rice R, Greenberg R, Van Der VM. 1996. Shade coffee: a disappearing refuge for biodiversity. Biodiv Sci 46: 598-608.

Piclou EC. 1975. Population and community ecology. Principles and Methods. Gordon and Breach Science Publishers Inc., New York.

Ryan JC. 1992. Life Support: Conserving Biological Diversity. Worldwatch Paper 108. Worldwatch Institute, Washington, D.C.

Saha N, Azam MA. 2004. The indigenous hill-farming system of Khasia tribes in moulibazaar district of Bangladesh: Status and impacts. Small-Scale For Econ Manag Pol 3: 273-281.

Schoth G, Harvey CA. 2007. Biodiversity conservation in cocoa production landscapes: an overview. Biodiv Conser 16: 2237-2244.

Schenk, W. 1963. The mathematical theory of communication. University Illinois Press, Urbana, IL.

Simpson EH. 1949. Measurement of diversity. Nature 163: 688.

Sonwa DJ, Nkongmeneck BA, Weise SF, Thcatat M, Adesina AA, Janssens MJJ. 2007. Diversity of plants in cocoa agroforestry in the humid forest zone of Southern Cameroon. Biodiv Conserv 16: 2385-2400.

Takhataian A. 1988. Floristic Region of the World. Bishen Singh Mahendra Pal Singh, Dehradun, India.

Tiwari BK, Barik SK, Tripathi RS. 1998. Biodiversity value, status and strategies for conservation of sacred groves of Meghalaya, India. Ecosyst Health 4: 20-32.

Tiwari BK, Tynsong H, Dikhr M. 2017. Traditional knowledge-based conservation and utilization of bioresources by War Khasi tribe of Meghalaya, India. In: Madhav K, Rosemary H, Dayuan X, William A, Kaoru I, Peter B (eds.) Knowing our Lands and Resources: Indigenous and Local Knowledge and Practices related to Biodiversity and Ecosystem Services in Asia. Knowing our Lands and Resources 10. UNESCO, Paris.

Tiwari BK, Tynsong H, Rani S. 2004. Medicinal and aromatic plants: Medicinal plants and human health. In: Burlay J, Evans J, Youngquist JA (eds.). Encyclopedia of Forest Sciences. Elsevier, Oxford, UK.

Toloedo, VM, Ortiz B, Medellin S. 1994. Biodiversity islands in a sea of pastureland: indigenous resource management in the humid tropics of Mexico. Etnoecológica 3: 37-50.

Toloedo, VM. 1990. The ecological rationality of peasant production. In: Alhier M, Hecht S (ed.). Agroecology and Small-farm Development. CRC Press, Boca Raton, Florida.

Tripathi OP, Pandey HN, Tripathi RS. 2006. Tree diversity and community characteristics of the sub-tropical evergreen forest in the buffer and core zones of Nokrek biosphere reserve, Northeast India. In: Pandey HN, Barik SK (eds.). Ecology, Diversity and Conservation of Plants and Ecosystems in India. Regency Publication, New Delhi.

Tynsong H, Tiwari BK. 2011. Diversity and population characteristics of woody species in natural forests and arecanut agroforestry of South Meghalaya, Northeast India. Trop Ecol 52: 243-252.

Tynsong H, Tiwari BK Dikhr M. 2012. Contribution of NTFPs to cash income of the War Khasi community of southern Meghalaya, Northeast India. For Stud China 14: 47-54.

Tynsong H, Tiwari BK. 2010. Diversity of plant species in Arecanut agroforestry in the tropical evergreen forest of South Meghalaya, Northeast India. J For Res 21: 281-286.

Tynsong H. 2009. Plant diversity and NTFP management in community forests of War area Meghalaya. [Dissertation]. North-Eastern Hill University, Shillong, India.

Upadhyay K. 2002. Studies on plant biodiversity and ecosystem function of sacred groves of Meghalaya. [Dissertation]. North-Eastern Hill University, Shillong, India.

Van Gemerden BS. 2004. Disturbance, diversity and distributions in Central African rain forest. [Dissertation], Wageningen University, The Netherlands.

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Table S1: Plant species, their families, density (individual ha⁻¹) recorded in Natural Forest (NF) and Betel Leaf Agroforest (BLA) of South Meghalaya, Indonesia

| Tree species                     | Family              | Frequency | Density | IVI |
|----------------------------------|---------------------|-----------|---------|-----|
| Acer oblongum Wall.              | Aceraceae           | 3.00      | 4       | 0.48 |
| Actinodaphne abovata (Nees.) Blume. | Moraceae            | 4.00      | 10.00   | 7   | 0.77 |
| Actinodaphne angustifolia Nees.  | Moraceae            | 3.00      | 4       | 0.61 |
| Adenanthera pavonina L.          | Fabaceae            | 40.00     | 44      | 6.39 |
| Aesculus assamica Griff.         | Euphorbiaceae       | 7.50      | 6       | 1.02 |
| Aglaia perviridis Hiern.         | Meliaceae           | 37.50     | 36      | 5.29 |
| Alstonia sclaris Brown.          | Apocynaceae         | 10.00     | 8       | 1.32 |
| Amoora rokituka W&A.             | Meliaceae           | 12.50     | 10      | 1.71 |
| Antidesma khasianum Hk.f.        | Euphorbiaceae       | 15.00     | 12      | 2.10 |
| Aporosa dioica (Roxb.) Muell. Arg. | Euphorbiaceae       | 11.00     | 7.50    | 18   | 6   | 2.24 |
| Ardisia floribunda Wall.         | Myrsinaceae         | 16.00     | 42      | 4.48 |
| Artocarpus heterophyllos Ham.     | Moraceae            | 12.50     | 20      | 2.45 |
| Artocarpus lakoocha Roxb.        | Moraceae            | 40.00     | 36      | 7.01 |
| Baccuarea sapida (Roxb.) Muell.  | Euphorbiaceae       | 24.00     | 20.00   | 46   | 18 | 5.52 |
| Bombusa tulda Roxb.               | Poaceae             | 12.00     | 58      | 5.82 |
| Bambusa vulgaris Schrad.         | Poaceae             | -         | 2.50    | 80   | -   | 5.06 |
| Beilschmiedia brandisii Hk.f.    | Moraceae            | -         | 7.50    | 6    | -   | 1.78 |
| Bischofia javanica Blume.        | Euphorbiaceae       | 15.00     | 12      | 6    | 2.60 |
| Bombax malabaricum DC.           | Malvaceae           | 2.50      | 4       | 0.82 |
| Brassaiopsis glomerulata (Blume.) | Araliaceae          | 7.50      | 14      | -   | 1.90 |
| Bridelia monta Willd.            | Euphorbiaceae       | 20.00     | 16      | -   | 2.67 |
| Callicarpa vestica Wall. ex Cl.   | Verbenaceae         | -         | 12.50   | 10   | -   | 1.66 |
| Canthium glabrum Blume.          | Rubiaceae           | 6.00      | 11      | -   | 1.17 |
| Caryota urens L.                 | Arecales            | -         | 27.50   | 26   | -   | 6.85 |
| Casearia kurzii C.B.Clarke.      | Pittosporaceae      | 10.00     | 8       | -   | 3.50 |
| Castanopsis hystrich A.D.C.      | FAGACEAE           | 34.00     | 59      | 10.48 |
| Castenea sativa Miller.          | FAGACEAE           | 19.00     | 48      | 8.50 |
| Cedrela toona Roxb.               | Meliaceae           | -         | 7.50    | 6    | -   | 1.28 |
| Chrysophyllum rozbarghii G.Don.   | Sapotaceae          | 5.00      | 7       | -   | 0.96 |
| Cinnamomum bejoygota Buch.-Ham.  | Lauraceae           | -         | 20.00   | 20   | -   | 3.27 |
| Cinnamomum camphora F.Nees.      | Lauraceae           | 9.00      | 14      | -   | 1.71 |
| Cinnamomum tamala Fr. Nees.      | Lauraceae           | 21.00     | 10.00   | 36   | 12 | 4.86 |
| Citrus latipes (Swingle)Tanka.    | Rutaceae            | 6.00      | 6       | -   | 1.05 |
| Citrus macroptera Lour.          | Rutaceae            | -         | 2.50    | 2   | -   | 0.36 |
| Cryptocarya amygdalina Nees.      | Lauraceae           | 12.00     | 15.00   | 20   | 12 | 2.76 |
| Cryptocarya andersoni King.      | Lauraceae           | -         | 25.00   | 20   | -   | 3.46 |
| Cryptocarya floribunda Nees.     | Lauraceae           | -         | 5.00    | 6    | -   | 1.30 |
| Cyathaea gigantea (Wall ex Hook.) | Cytaceae            | 2.00      | 5       | -   | 0.37 |
| Daphniphyllum himlayanay Muell.  | Euphorbiaceae       | 5.00      | 18      | -   | 1.72 |
| Derris robusta Benth.             | Fabaceae            | -         | 7.50    | -   | 1.39 |
| Diospyros kaki L.                | Sapotaceae          | 8.00      | 35.00   | 11   | 28 | 1.49 |
| Diospyros pilosula Wall.         | Ebenaceae           | -         | 10.00   | 8    | -   | 1.26 |
| Diospyros sp.                    | Ebenaceae           | -         | 10.00   | 8    | -   | 1.43 |
| Drimycarpus racemosus (Roxb.) Hk.f. | Anacardaceae       | -         | 10.00   | 10   | -   | 1.71 |
| Duabanga grandiflora (Roxb. Ex DC.) | Walp.              | 6.00      | 32.50   | 15   | 58 | 2.32 |
| Dysosylyum hamiltoni Hiern.      | Meliaceae           | -         | 20.00   | -   | 30   | 4.14 |
| Ebreia acuminata Br.             | Boraginaceae        | 7.00      | 10.00   | 10   | 8   | 1.32 |
| Elaeocarpus lanceolus Roxb.       | Elaeocarpaceae      | -         | 7.50    | -   | 6   | 1.13 |
| Elaeocarpus sikkimensisMast.     | Elaeocarpaceae      | -         | 17.50   | 32   | -   | 4.59 |
| Elaeocarpus lanceolus Roxb.       | Elaeocarpaceae      | 11.00     | 22      | -   | 2.58 |
| Engelhardtia spicata Blume.      | Lagiaceae           | 5.00      | 7.50    | 7    | 14 | 0.94 |
| Erythroxylon kunthianum Wall.     | Malpighiaceae       | 7.00      | 10      | -   | 1.34 |
| Erythroxylon kunthianum Wall.     | Malpighiaceae       | 7.00      | 25      | -   | 2.39 |
| Euonymus lawsonii Clarke & Prain. | Celastraceae        | -         | 10.00   | 8    | -   | 1.37 |
| Eurya acuminata DC.              | Theaceae            | 8.00      | 5.00    | 14   | 26 | 1.64 |
| Ficus benjamina L. var.comosa Kurtz. | Moraceae           | -         | 7.50    | -   | 12   | 10.51 |
| Ficus faveolata Wall.             | Moraceae            | 4.00      | 10.00   | 13   | 12 | 1.21 |
| Ficus gibba Blume.                | Moraceae            | -         | 12.50   | 10   | -   | 1.60 |
| Ficus glomerata Roxb.             | Moraceae            | -         | 27.50   | 92   | -   | 10.99 |
| Ficus hirta Vahl.                 | Moraceae            | 5.00      | 5       | -   | 0.82 |
| Ficus roxburghii Wall.            | Moraceae            | -         | 20.00   | 46   | -   | 5.72 |
| Ficus sp.                        | Moraceae            | 13.00     | 27      | -   | 3.15 |
| Garcinia grummi-gotta (L.) Roxb.  | Clusiaceae          | -         | 5.00    | 4    | -   | 0.72 |
| Garcinea spicata Hk.f.            | Gutiferaceae        | 5.00      | 13      | -   | 1.38 |
| Garcinia lanceolarium Datz.       | Gutiferaceae        | 7.00      | 12      | -   | 1.73 |
| Garcinia paniculata (G.Don) Roxb. | Gutiferaceae        | 13.00     | 17      | -   | 2.42 |
| Genus Name | Family Name | Code | Domain | Kingdom | Phylum  |
|-----------|-------------|------|--------|---------|---------|
| Garuga pinnata | Roxb. | Burseraceae | 4.00 | - | 4 | - | 0.65 |
| Glocidion khassicum | Hk.f. | Euphorbiaceae | 6.00 | 12.50 | 13 | 10 | 1.37 |
| Glocidion thomsonii | Hk.f. | Euphorbiaceae | - | 10.00 | - | 10 | - | 1.39 |
| Gynocardia odorata | R.Br. | Flacourtaceae | - | 22.50 | - | 22 | - | 3.43 |
| Helicia erratica | Hk.f. | Proteaceae | 40.00 | 2.50 | 52 | 2 | 8.76 |
| Hydrangus persicolor | Kurzii Warb. | Flacourtaceae | - | 7.50 | - | 6 | - | 1.16 |
| Ilex embeloides | Hk.f. | Aquifoliaceae | - | 7.50 | - | 6 | - | 1.33 |
| Itea macrophylla | Wall. | Saxifragaceae | 7.00 | - | 21 | - | 2.42 |
| Knema andamanica | Hk.f. | Myristicaceae | 2.00 | - | - | 0.33 |
| Knema linifolia | (Roxb.) Warb. | Myristicaceae | 8.00 | 27.50 | 9 | 32 | 1.40 |
| Liguostrobus robustum | (Roxb.) Blume. | Oleaceae | 8.00 | 7.50 | 8 | 6 | 1.30 |
| Lithocarpus elegans | (Blume.) Soep. | Fagaceae | 48.00 | 10.00 | 133 | 8 | 30.80 |
| Lithocarpus fenestralis | (Roxb.) Tehder | Fagaceae | 41.00 | - | 169 | - | 40.66 |
| Litsea citrina | Blume. | Lauraceae | 8.00 | - | 11 | - | 1.53 |
| Litsea elongata | Wall. | Lauraceae | - | 7.50 | - | 10 | - | 1.40 |
| Pinus kesiya | Hk.f. | Pinaceae | 1.00 | 7.50 | 4 | - | 0.16 |
| Litsea leiathana | (Kurz.) Hk.f. | Lauraceae | 3.00 | - | 5 | - | 0.60 |
| Litsea semecarpifolia | (Wall. ex Nees) Hook. | Lauraceae | 4.00 | 7.50 | 4 | 6 | 0.70 |
| Macaranga denticulata | Muell. Arg. | Euphorbiaceae | - | 2.50 | - | 2 | - | 0.34 |
| Macaranga peltata | (Roxb.) Muell. Arg. | Euphorbiaceae | - | 10.00 | - | 20 | - | 2.07 |
| Machilus bombayina | King. | Lauraceae | 38.00 | 22.50 | 79 | 46 | 12.35 |
| Macropanax candicans | (Wall.ex D.Don) Seem. | Araliaceae | 22.50 | - | 34 | - | 4.82 |
| Magnoglossa indicus | Wight. | Euphorbiaceae | 9.00 | - | 13 | - | 1.74 |
| Magnolia pterocarpa | Roxb. | Magnoliaceae | 2.00 | - | 4 | - | 0.49 |
| Magnolia sp. | - | Magnoliaceae | 14.00 | 5.00 | 42 | 4 | 4.61 |
| Mallotus ferrugineus | Roxb. | Euphorbiaceae | - | 20.00 | - | 20 | - | 2.90 |
| Mesua ferrea | L. | Clusiaceae | - | 2.50 | - | 2 | - | 0.50 |
| Michelia cathcartii | Hk.f.&Th. | Magnoliaceae | - | 25.00 | - | 20 | - | 3.58 |
| Morus laevigata | Wall. | Moraceae | - | 25.00 | - | 22 | - | 3.87 |
| Musa paradisiaca | L. | Musaceae | 12.50 | - | 14 | - | 2.30 |
| Myrica esculenta | Buch-Ham.ex D.Don. | Myricaceae | 9.00 | - | 11 | - | 1.61 |
| Myrica nagi | Thunb. | Myricaceae | 4.00 | - | 7 | - | 0.81 |
| Oroxylum indicum | Vent. | Bignoniaceae | 14.00 | 10.00 | 25 | 8 | 3.82 |
| Ostodes paniculata | Blume. | Euphorbiaceae | 2.00 | 12.50 | 4 | 12 | 0.33 |
| Pandanus odoratissimus | L. | Pandanaceae | 5.00 | - | 14 | - | 1.59 |
| Phoebe cooperiana | U.N.Kanjilal ex A.Das,Nov.sp. | Lauraceae | 17.00 | 30.00 | 24 | 70 | 3.61 |
| Phoebe lanceolata | Nees. | Lauraceae | 9.00 | 10.00 | 17 | 12 | 2.52 |
| Pinus roylei | Hk.f. | Pinaceae | 1.00 | - | 4 | - | 0.16 |
| Pittosporum glabratum | Lindl. | Pittosporaceae | - | 12.50 | - | 12 | - | 1.74 |
| Pterospermum acerifolium | Willd. | Sterculiaceae | - | 2.50 | - | 2 | - | 0.85 |
| Quercus dealbata | Hk.f.&Th. | Fagaceae | 8.00 | - | 24 | - | 3.06 |
| Quercus dilatata | Lindl. | Fagaceae | 12.00 | - | 46 | - | 5.50 |
| Quercus lanceaefolia | Roxb. | Fagaceae | - | 12.50 | - | 10 | - | 1.54 |
| Quercus coccifera | Fagaceae | 29.00 | - | 67 | - | 10.51 |
| Quercus coccifera | Hk.f. | Fagaceae | 16.00 | 5.00 | 53 | 6 | 6.02 |
| Rhododendron arboreum | Sm. | Ericaceae | 1.00 | - | 5 | - | 0.21 |
| Sapindus miosaus | Roxb. | Euphorbiaceae | 6.00 | 7.50 | 12 | 6 | 2.27 |
| Sapindus jussieuana | Benth. | Euphorbiaceae | 7.00 | 25.00 | 9 | 30 | 1.61 |
| Sarcola indica | L. | Caesalpinaceae | - | 12.50 | - | 14 | - | 1.98 |
| Sarcochraea griffithii | Benth. | Sapotaceae | 51.00 | 57.50 | 106 | 132 | 16.58 |
| Schima wallichiana | Choisy. | Theaceae | 22.00 | 10.00 | 64 | 8 | 11.66 |
| Sterculia roxburghii | Wall. | Sterculiaceae | 3.00 | 12.50 | 6 | 10 | 0.54 |
| Streospermum chenomoides | (L.) DC. | Bignoniaceae | 4.00 | 22.50 | 6 | 38 | 0.65 |
| Styrax serrulatum | Roxb. | Styraceae | 14.00 | 10.00 | 25 | 10 | 3.06 |
| Symlocos ramosissima | Wall. | Symlocaceae | 7.00 | - | 12 | - | 1.54 |
| Tetrameles nudiflora | R.Br. | Tetrameraceae | - | 2.50 | - | 2 | - | 1.44 |
| Toona ciliata | Roem. | Ochnaceae | 12.00 | 32.50 | 19 | 26 | 2.46 |
| Travesia palmata | (Roxb.) Vis. | Araliaceae | 27.00 | - | 37 | - | 6.02 |
| Trema polystroa | Planch. | Ulmaceae | 17.50 | - | 18 | - | 2.74 |
| Unidentified1 | - | Unidentified | - | 15.00 | - | 16 | - | 3.01 |
| Unidentified2 | - | Unidentified | 16.00 | - | 32 | - | 4.20 |
| Unidentified3 | - | Unidentified | 16.00 | - | 15.00 | - | 1.20 |
| Unidentified4 | - | Unidentified | 6.00 | - | 46 | - | 1.20 |
| Unidentified5 | - | Unidentified | 9.00 | - | 17 | - | 2.24 |
| Unidentified6 | - | Unidentified | 2.00 | - | 6 | - | 0.52 |
| Villetrella integrifolia | Gaud. | Ulmaceae | 10.00 | - | 16 | - | 1.93 |
| Wenderhardia tinctoria | DC. | Rubiaceae | 18.00 | 15.00 | 37 | 16 | 4.84 |
| Wendlandia panicula DC. | - | Rubiaceae | - | 7.50 | - | 16 | - | 1.62 |
| Wrightia tomentosa | Roem & Sch. | Apocynaceae | - | 32.50 | - | 76 | - | 8.19 |
| Syzygium tetragonum | (L.) Skeels. | Myrtaceae | 42.00 | 2.50 | 86 | 2 | 12.50 |

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| Total | - | - | 1972 | 1788 | 300 | 300 |
|-------|---|---|------|------|-----|-----|

**Shrub component**

| Genus | Family |
|-------|--------|
| Adenosaeae sp. | Rubiaceae |
| Ardisia griffithii C.B.Clarke. | Myrsinaceae |
| Ardisia sp. | Myrsinaceae |
| Boelheria malabarica Wedd. | Urticaceae |
| Calamus arborensce Griff. | Arecaceae |
| Camellia caduca C.B. Clarke. | Theaceae |
| Cephallotachyum sp. | Poaceae |
| Cephallotachyum pallidum Munro. | Poaceae |
| Chloranthus glaber Thunb. | Chloranthaceae |
| Clerodendron serratum Spreng. | Verbenaceae |
| Coffea benghalensis Roxb. | Rubiaceae |
| Coffea sp. | Rubiaceae |
| Cyathea alboseata Copel. | Cyatheaceae |
| Daphne involucrata Wall. | Thymelaeaceae |
| Daphne involucrata Wall. | Thymelaeaceae |
| Draeaca fragrans (L.) Ker-Gawl. | Agavaceae |
| Eupatorium odoratum Spreng. | Asteraceae |
| Eurya japonica Thunb. | Theaceae |
| Ficus clavata Wall. | Moraceae |
| Ficus hirta Vahl. | Moraceae |
| Ficus pyriformis Hook. & Arn. | Moraceae |
| Ficus sarmentosa Wall. | Moraceae |
| Flemingia macrophylla (Wild.) Prain. | Fabaceae |
| Goniothalamus sesquipedalis Hk.f.&Th. | Annonaceae |
| Hedychium coccineum Buch.-Ham.ex Sm. | Zingiberaceae |
| Hedychium thysiforme Buch.-Ham.ex Sm. | Zingiberaceae |
| Isora subsissillis Wall. | Rubiaceae |
| Justicia sp. | Acanthaceae |
| Laportea crenulata (Roxb) Gaud. | Urticaceae |
| Luculia pinceana Hook. | Rubiaceae |
| Mahonia pycnothylla Fedde. | Berberidaceae |
| Medinilla rubicunda Blume. | Melastomaceae |
| Morinda angustifolia Roxb. | Rubiaceae |
| Mussaendra roxburghii Hk.f. | Rubiaceae |
| Myrioneuron nutans Kurz. | Rubiaceae |
| Ophiorhiza hispida Hook.f. | Rubiaceae |
| Phrynum capitatum Willd. | Marantaceae |
| Phrynium sp. | Marantaceae |
| Phyllanthus debilis Ham. | Euphorbiaceae |
| Pinanga cracil (Roxb.) Blume. | Arecales |
| Psychotria erecta Hk.f. | Rubiaceae |
| Rubus khasianus Cordat. | Rosaceae |
| Sylvianthus bracteotus Hk.f. | Rubiaceae |
| Thyssanolaena maxima (Rozb.)O.Ktze. | Poaceae |
| Unidentified | Unidentified |
| Wallichia densiflora Mart. | Arecales |
| Zanthoxylum armatum DC. | Rutaceae |
| **Total** | - | - | 19280 | 7660 | 200 | 200 |

**Herb component**

| Genus | Family |
|-------|--------|
| Achyranthes japonica (Miq.) Nakai. | Amaryllidaceae |
| Ageratum conyzoides L. | Asteraceae |
| Ananas brasseus (Lindl.) Schult. & Schult. f. | Bromeliaceae |
| Ananas comosus (L.) Merr. | Bromeliaceae |
| Andropogon glomeratus Wahl. | Poaceae |
| Anotis vightiana Hk.f. | Rubiaceae |
| Anthurium drepopterum (Kuntze.) A.Brown. | Araceae |
| Begonia josephii A.DC. | Begoniaceae |
| Begonia palmata D.Don. | Begoniaceae |
| Begonia picta Sm. | Begoniaceae |
| Bidens pilosa (Blume.) Sherff. | Asteraceae |
| Bolbitis appendiculata J.Sm. | Lomarioidaceae |
| Borleria articulalis (L.C.) F.N. Will. | Rubiaceae |
| Borleria pilosa K.Schum | Rubiaceae |
| Calanthe masuca (D.Don) Lindl. | Orchidaceae |
| Carex vesiculosa Booth. | Cyperaceae |
| Centella asiatica (L.) Urban. | Apiaceae |
| Commelina beghalensis L. | Commelinaceae |

| Total | - | - | 1972 | 1788 | 300 | 300 |
|-------|---|---|------|------|-----|-----|

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| Species Name                  | Family               | Counts    |
|------------------------------|----------------------|-----------|
| Zingiber speciosus (koaegis) Smith. | Zingiberaceae       | 8.13      |
| Zingiber Viola sikkimensis     | Violaceae            | 6.25      |
| Urena labata                   | Balsaminaceae        | 5.63      |
| Trillium erectus               | Melastromaceae       | 8.13      |
| Tacca laevis                   | Acanthaceae          | 4.54      |
| Sonerilla                    | Acanthaceae          | 3.45      |
| Sonerila khasiana             | Acanthaceae          | 3.45      |
| Sida cordifolia               | Polygonaceae         | 9.38      |
| Cytisus pilanthus paniculata  | Fabaceae             | 3.45      |
| Goodyera repens (Ker-Gawl.) Hook. | Orchidaceae       | 6.17      |
| Hemiphragma heterophyllum Wall. | Zingiberaceae       | 3.45      |
| Hydrocotyle javanica Thunb.  | Zingiberaceae       | 3.45      |
| Impatiens balsamina L.        | Balsaminaceae        | 5.63      |
| Impatiens benthhamii V. Steenis. | Balsaminaceae       | 5.63      |
| Impatiens tripetala DC.       | Balsaminaceae        | 5.63      |
| Imperata cylindrica (L.) P. Beauv. | Poaceae            | 5.63      |
| Ipomea purpurea (L.) Roth.     | Convolvulaceae       | 5.63      |
| Justicia sp.                  | Acanthaceae          | 5.63      |
| Kaulina pteropus (Blume) Nayar. | Moraceae             | 5.63      |
| Knobuia corystosus Wild.       | Moraceae             | 5.63      |
| Miconia prasina (SW.) DC.     | Melastromaceae       | 5.63      |
| Onoclea sensibilis L.         | Melastromaceae       | 5.63      |
| Ophiophriza hispida Hf.k.      | Rubiaceae            | 5.63      |
| Ophiophriza hispida Hf.k.      | Rubiaceae            | 5.63      |
| Oplismencom pospositus P. Beauv. | Rubiaceae         | 5.63      |
| Ostbeckia capitata Benth.     | Melastromaceae       | 5.63      |
| Oenanthe L.                   | Melastromaceae       | 5.63      |
| Oxalis compressa              | Oxalidaceae          | 5.63      |
| Papypodium dilatatum Pier.    | Oxalidaceae          | 5.63      |
| Peperomia heyneana Miq.       | Piperaceae           | 5.63      |
| Peperomia reflexa A.Dietr.    | Piperaceae           | 5.63      |
| Phryma leptostachya L.        | Verbenaceae          | 5.63      |
| Polygonum hydropiper L.       | Polygonaceae         | 5.63      |
| Polygonum thunbergii Sieb. & Zucc. | Polygonaceae    | 5.63      |
| Polystichum aculeatum (L.) Roth. | Polystichum  | 5.63      |
| Pronephrium nudatum (Roxb)Holttum. | Thelypteridaceae   | 5.63      |
| Pteris quadriaurita Retz.     | Pteridaceae          | 5.63      |
| Richardia brasilensis Gomes.  | Rubiaceae            | 5.63      |
| Selaginella chrysoconals Hk. et. Grev.) Spring. | Selaginellaceae | 5.63      |
| Sida cordifolia L.             | Moraceae             | 5.63      |
| Smithia ciliata Royle.        | Fabaceae             | 5.63      |
| Sonerila khasiana Clarke.     | Melastromaceae       | 5.63      |
| Spilanthes paniculata DC.     | Asteraceae           | 5.63      |
| Sroblanthus sp.               | Acanthaceae          | 5.63      |
| Taccia laevis Roxb.            | Taccaceae            | 5.63      |
| Torenia diffusa D.Don.        | Scrophulariaceae     | 5.63      |
| Trillium erectus L.            | Liliaceae            | 5.63      |
| Urena labata L.                | Malvaceae            | 5.63      |
| Viola palmaria Ging.          | Violaceae            | 5.63      |
| Viola sikkimensis W. Becker.  | Violaceae            | 5.63      |
| Zingiber rubens Roxb.          | Zingiberaceae       | 5.63      |
| Zingiber sp.                  | Zingiberaceae       | 5.63      |
| **Total**                     |                      | 347563    |

Note: '-' indicates absent values.
Nutrient distribution on soil and aboveground biomass of *Macaranga gigantea* five years after planting

**Abstract.** Susanto D, Kusuma R, Amirta R. 2018. Nutrient distribution on soil and aboveground biomass of *Macaranga gigantea* five years after planting. Asian J For 2: 12-19. The aims of this study were to evaluate growth of *M. gigantea* and to calculate nutrient distribution in the soil and 5-year-old *M. gigantea*. Soil sampling was conducted in all research plots with drill ground at a depth of 0-30 cm and 30-60 cm. The tree biomass was sampled within one stand to calculate the biomass of all the trees within a particular plot. The research findings revealed that plot 5 produces the best growth performance and the plant accumulates 2 times of N, P, K, Ca, Mg nutrients on wood, bark, branches, and leaves, compared to the plants in plots 1. The most distributed nutrients in the soil were magnesium, nitrogen, calcium, and phosphorus. Whereas the most accumulated nutrient in plant was potassium. The relative portion of K nutrients accumulates in the soil is quite small that is 44.18% but in stand was higher that is between 55.82%. It concluded that if the *M. gigantea* harvested at 5 years, it needs to give attention to potassium nutrient for the next of planting cycles.

**Keywords:** Biomass, *Macaranga gigantea*, distribution nutrient, soil

**INTRODUCTION**

*Macaranga gigantea* is tree species that grows naturally in the lowland of tropical rainforest gaps after shifting cultivation (Susanto et al. 2016b), forest fires (Silk 2008) and timber harvestings (Susanto et al. 2017a). This species also potentially as a bioethanol feedstock (Amirta et al. 2016). The plant reproduces by forming flower buds initiated in the dry season and the fruits ripened in the rainy season. The seeds that fell under the tree germinated in approximately 24 days (Susanto et al. 2016a). Bentos et al. (2008) also reported that the flowering of pioneer trees happening at the end of the dry season and fruiting happening at the beginning of the wet season.

*M. gigantea* seeds have low water content, classified into orthodox seeds and produce low seed germination of 2-10% when using dry seed extraction treatment (Suita and Nurhashiby 2009). Mindawati et al. (2010) also reported that soaking the seeds into 0.2% potassium nitrate solution for 20 minutes before germinate on sand medium able increasing seed germination rates up to 20%. On the other hand, Susanto et al. 2016a reported that wet extraction without fruit drying treatment, able increased seeds germination (65%), with germination time first seeds (GTFS) 7.67 ± 1.15 days, germination time last seeds (GLTS) 17.33 ± 4.04, and mean germination times (MGT) 11.97 ± 1.93 days. In the germination process of *M. gigantea* seedlings showed that the highest relative growth rate obtained by seedlings planted on mushroom spawn waste media, followed by compost media, top soil media, and sand media.

Lawrence 2001, reported that seedlings of *M. gigantea* grow rapidly over the first of 18 weeks when planted in polybags if enough supplied with a combination of nitrogen and phosphorus fertilizers. While, *M. gigantea* 6 months after planting in degraded land from unused log piles in Malaysia, indicates that nutritional deficiency is an important factor that inhibits early growth of this plant (Nussbaum in al. 1995).

Susanto et al. (2016b) reported that in secondary forests after shifting cultivation, *M. gigantea* plants accumulate phosphorus and potassium nutrient mostly in the leaves part. On the other hand, in secondary forest after selective logging, *M. gigantea* most accumulated nutrients potassium, calcium, and magnesium. It suggested that bases nutrients, potassium, calcium, and magnesium, large quantities absorbed by *M. gigantea* and extremely important to its growth (Susanto et al. 2017a). In monoculture system, *M. gigantea* was fertilized with NPK fertilizer treatment (age of 1 year), and the most nutrient element accumulated were potassium, followed by phosphorus and then nitrogen (Susanto et al. 2017b).

There is lack information about nutrients content distribution in the soil and aboveground biomass of *M. gigantea*. Therefore, our research focuses on the growth evaluation and soil nutrients and aboveground biomass distribution on 5 years *M. gigantea* planted using monoculture system. This information is very important in the sustainable of *M. gigantea* plantation.
MATERIALS AND METHODS

Study area
This research was conducted in the plot of 5-year-old M. gigantea. Plot was 0.7 ha, at the research forest of Faculty of Forestry, Mulawarman University, Samarinda, East Kalimantan, Indonesia (000.44.71,11 “South and 1170.21; 67,50” East). The trial was set up with five randomized treatments plots with 3 blocks (each containing 20 plants, making 20 x 5 x 3 = 300 plants in the entire trial area). The initial treatment of M. gigantea with NPK fertilizer is P0: 0 g, P1: 40 g, P2: 80 g, P3: 120 g and P4: 160 g. Fertilization is conducted for two times, i.e., after planting and 6 months after planting. Weed cleaning was done once for 4 months until the plant age was 2 years old (Susanto et al. 2017b).

Procedures
Plant measurement and soil analysis
The 5 years after planting of M. gigantea observed through direct measurement. The stem heights, diameter, height increment and diameter increment was parameter in this research. For soil analysis, soil samples were taken at a depth of 0-30 cm and 30-60 cm in each plot. The measurement was conducted after the samples were oven dried with the temperature of 150°C until the weight was constant. Composite sample was wind-dried and its total Nitrogen (Kjendal), available phosphor (Bray), available potassium, calcium, and magnesium were analyzed (Susanto et al. 2017b).

The sampling of Macaranga gigantea Biomass
Biomass measurements are limited only to above ground biomass with mean tree after stratification method. The Determination of the strata boundary for selection of sample trees representing the relevant strata in the plots is performed by the calculation of stratum boundaries by the cumulative method. The trees sampled from one plot were selected after all the available trees were grouped into three stages based on their estimated size according to the formula D²H (diameter squared multiplied by height). The entire stand biomass was calculated by multiplying the dry weight of the components of the sampled tree by the number of trees in each stage, and then it was converted into a biomass per hectare. The wet weight of every component including wood, barks, branch, and leaves was measured according to Ruhiyat 1996 methods. Samples of the wood, barks, branch, and leaves were weighing on wet and dry condition. The plant samples were taken to the laboratory and their nutrient contents (N, P, K, Ca, Mg) were analyzed.

Figure 1. Map of research area in the research forest of Faculty of Forestry, Mulawarman University, Samarinda, East Kalimantan, Indonesia
Nutrient concentrate of plant components analysis

The total N concentrate was measured using Kjeldahl method (extraction, distillation, titration). To measure element of P and K, the plant components were extracted using High-Pressure Digestion method at the temperature of 180°C for 10 hours with HNO3 as a reductant. Phosphor was measured by using calorimetric technique and using nitrate-molybdate-vanadate acid as a coloring agent and was measured by using spectrophotometer at the wavelength of 470 nm. Potassium, calcium, and magnesium were measured by using Atomic Absorption Spectrophotometer at the wavelength of 766.5 nm, 489.5 nm, and 245.2 nm. To calculate macronutrient elements (N, P, K, Ca, Mg) which were accumulated in the three components in the stand, the dry weight of the tree component was multiplied by its nutrient concentrate (Susanto et al. 2017b).

Data analysis

Nutrient distribution in soil and 5 years old M. gigantea was observed. The macronutrient content (N, P, K, Ca, Mg) in the tree component is calculated by multiplying the dry weight of tree component with nutrient concentration of the tree component. Based on nutrient content stored in the soil and which accumulates in the M. gigantea stands, it can be arranged information about the amount of nutrients stored in the soil system (kg,ha-1) and its relative portion (%) for each plot research.

RESULTS AND DISCUSSION

Plant growth

At the age of 5 years, the best growth of M. gigantea on plot 5 with mean stem diameter of 12.88 ± 4.2 cm, stem height of 10.25 ± 2.9 m, increment diameter 2.58 cm.y⁻¹ and hight increment 2.05 m.y⁻¹ (Figure 1).

Figure 2. Growth of Macaranga gigantea 5 years after planting

Figure 3. Macaranga gigantea plants at planting plots ( 5 years)
Plant biomass

The result on aboveground biomass estimation of *M. gigantea* showed that the highest biomass content produced on P4 plot those were 64.51 ton.ha⁻¹, consisting of 27.58 ton of wood, 5.078 ton bark, 22.938 ton of branch (wood and bark), and 8.914 tons of leaves. Wood is the largest component of 50.52 ton.ha⁻¹ and consisting of 27.58 tons of wood and 22.938 tons of branches. The lowest biomass showed on P0 plot those were 25.039 ton.ha⁻¹ and it can be concluded that fertilization of 160 g per plant (P4) increases the biomass production by 250 percent.

Nutrient content of plant components

Potassium is the most accumulated nutrient in five-year-old stands, followed by nitrogen, calcium, phosphorus, and magnesium. The amount of nutrients consumed by *M. gigantea* stands are: potassium ranged from 239.88 - 676.20 kg.ha⁻¹ with an average of 413.50 kg.ha⁻¹; calcium ranged from 66.51-114.56 kg.ha⁻¹ with an average of 232.62 kg.ha⁻¹; nitrogen ranged from 155.91 - 344.00 kg.ha⁻¹ with an average of 232.62 kg.ha⁻¹; magnesium ranged from 36.09 to 77.64 kg.ha⁻¹ with an average of 51.93 kg.ha⁻¹. The highest concentration of nitrogen, phosphorus, potassium, calcium and magnesium stands of *M. gigantea* is at fertilization NPK 160 g per tree (Table 1).

Soil nutrient content

Soil nutrient concentration of each research plot varied in value. There is an increasing tendency of dosage of NPK fertilizer to decrease soil nutrient concentration in each plot. The mean concentration of nutrients N at the highest depth of 0-60 cm in the P2 plot is 13405.4 kg.ha⁻¹ followed by the P1 plot of 12744.5 kg.ha⁻¹, P3 plot 12210.7 kg.ha⁻¹, plot P0 12136.5 kg.ha⁻¹ and the lowest on plot P4 is 10888.7 kg.ha⁻¹. The mean concentration of nutrient P at the highest 0-60 cm of soil depth on plot P0 was 441.3 kg.ha⁻¹, followed by plot P1 435.4 kg.ha⁻¹, on plot P2 386.5 kg. ha⁻¹, plot P4 377.4 kg.ha⁻¹ and the lowest is on plot P3 that is 291.8 kg.ha⁻¹. The mean concentration of K nutrient at the highest depth of ground 0-60 cm in plot P0 is 1034.2 kg.ha⁻¹, followed by plot P2 603.7 kg.ha⁻¹, on plot P1 573.9 kg.ha⁻¹, plot P4 535.2 kg.ha⁻¹ and lowest is on plot P3 that is 448.8 kg.ha⁻¹. The average concentration of Ca nutrient at the highest 0-60 cm soil depth in plot P0 is 26953 kg.ha⁻¹, followed by plot P1 26232 kg.ha⁻¹, on plot P3 25085 kg.ha⁻¹, plot P2 23630 kg. ha⁻¹ and the lowest is on plot P4 that is 21963 kg.ha⁻¹. While the concentration of Mg nutrient at a depth of ground 0-60 cm highest in plot P0 is 51292 kg.ha⁻¹, followed by plot P1 that is 48111 kg.ha⁻¹, plot P2 45603 kg.ha⁻¹, plot P3 39800 kg.ha⁻¹ and the lowest plot of P4 is 38520 kg.ha⁻¹.

The nutrient content of *M. gigantea* biomass is positively correlated with biomass production at 5 years of age. The higher the nutrient content of biomass the higher the biomass production (Figure 5).

On the other hand, the relationship between soil nutrient content and biomass production shows negative correlation, i.e. the higher the biomass production, the lower nutrient content in the soil (Figure 6) The same is also shown in the relationship between soil nutrient content and nutrient content plant biomass (Figure 7).

Distribution of soil nutrients and aboveground biomass *M. gigantea*

From the nutrient content accumulated in the soil and nutrients accumulated in the plant stand, *M. gigantea* can be arranged graph of nutrient distribution in soil and plant *M. gigantea* (Figure 8).

![Figure 4. Biomass Production in Macaranga gigantea plantation (5 years)](image1)

Table 1. Nutrient component of *Macaranga gigantea* plant component in research plot age 5 years

| Nutrients | Fertilizer application | Nutrient content of plant components (kg.ha⁻¹) |
|-----------|------------------------|-----------------------------------------------|
|           | Stem wood | Stem bark | Branch | Leaf | Total |
| N         | T0        | 39.48     | 13.16 | 33.81 | 69.48 | 155.92 |
|           | T1        | 63.59     | 24.18 | 44.05 | 91.74 | 223.56 |
|           | T2        | 48.75     | 21.40 | 35.50 | 70.69 | 176.34 |
|           | T3        | 65.28     | 23.92 | 53.96 | 120.13 | 263.29 |
|           | T4        | 79.16     | 24.74 | 89.54 | 150.57 | 344.01 |
| Mean      | P         | 59.25     | 21.48 | 51.37 | 100.52 | 232.63 |
| K         | T0        | 6.08      | 1.30  | 7.07  | 6.46  | 20.91  |
|           | T1        | 4.94      | 1.34  | 3.35  | 8.17  | 17.79  |
|           | T2        | 2.16      | 1.35  | 5.79  | 6.95  | 16.23  |
|           | T3        | 3.47      | 1.99  | 8.52  | 8.53  | 22.52  |
|           | T4        | 11.72     | 3.14  | 14.79 | 13.39 | 43.04  |
| Mean      |           | 5.67      | 1.82  | 7.90  | 8.70  | 24.10  |
| Ca        | T0        | 27.08     | 13.12 | 14.20 | 12.11 | 66.51  |
|           | T1        | 11.78     | 28.02 | 20.97 | 15.06 | 75.83  |
|           | T2        | 22.36     | 16.85 | 11.27 | 13.07 | 63.55  |
|           | T3        | 14.91     | 24.21 | 20.94 | 16.59 | 76.65  |
|           | T4        | 30.47     | 17.87 | 40.16 | 26.07 | 114.57 |
| Mean      |           | 21.32     | 20.01 | 21.51 | 16.58 | 79.42  |
| Mg        | T0        | 14.46     | 4.50  | 8.318 | 8.82  | 36.10  |
|           | T1        | 18.99     | 11.47 | 12.66 | 12.57 | 55.69  |
|           | T2        | 16.44     | 6.81  | 10.79 | 10.52 | 44.55  |
|           | T3        | 13.97     | 6.82  | 11.18 | 13.72 | 45.69  |
|           | T4        | 25.17     | 8.49  | 25.80 | 18.19 | 77.64  |
| Mean      |           | 17.81     | 7.62  | 13.75 | 12.76 | 51.93  |
Figure 5. Correlation between aboveground biomass nutrient content with aboveground biomass of *Macaranga gigantea* 5 years old

Figure 6. Correlation between soil nutrient content with aboveground biomass nutrient content of *Macaranga gigantea* 5 years old

Figure 7. Correlation between soil nutrient content with aboveground biomass of *Macaranga gigantea* 5 years old
The relative portion of N, P, Ca and Mg nutrients accumulated in the soil is still very large at 89.76-99.93%, whereas those accumulating in *M. gigantea* stands are very small at 0.20% - 10.24%. It means that absorbed nutrients N, P, Ca and Mg by *M. gigantea* are relatively small. On the other hand, the relative portion of accumulated K nutrients in the soil is quite small that is 44.18-81.17% and in *M. gigantea* stands large enough that is between 18.83-55.82%. It means that nutrients K is highly absorbed from soil and accumulates in *M. gigantea* plant tissue, followed by phosphorus, nitrogen, calcium, and magnesium (Figure 8).

### Table 2. Soil nutrient contents in *Macaranga gigantea* plant age 5 years

| Fertilizer application | Soil depth | Soil nutrient content (kg.ha⁻¹) |
|------------------------|-----------|--------------------------------|
|                        | N         | P     | K    | Ca  | Mg  |
| 30-60                  | 5385.7    | 290.7 | 705.9 | 10159 | 24100|
| 0-60                   | 12136.5   | 441.3 | 1034.2 | 26953 | 51292|
| P1                     | 30-60     | 6561.9 | 191.8 | 280.8 | 8710  | 24068|
|                        | 0-30      | 6182.6 | 243.7 | 293.1 | 17522 | 24043|
| P2                     | 30-60     | 7667.8 | 140.9 | 373.1 | 15770 | 22234|
|                        | 0-60      | 5737.6 | 245.6 | 230.6 | 7860  | 23369|
| P3                     | 30-60     | 6867.9 | 96.9  | 239.4 | 11872 | 18774|
|                        | 0-60      | 5342.8 | 195.0 | 209.5 | 13213 | 21026|
| P4                     | 30-60     | 12210.7 | 291.8 | 448.8 | 25085 | 39800|
|                        | 0-60      | 6045.9 | 153.8 | 281.5 | 12169 | 21444|

Note: P0 = control without fertilizer, P1 = NPK fertilizer 40 g, P2 = NPK 80 g fertilizer, P3 = NPK fertilizer 120 g and P4 = NPK 160 g fertilizer.

### Discussion

At the age of 5 years, the best growth of *M. gigantea* found in P4 plot. The plant in P4 plot fertilized by NPK 160 g fertilizer (Figure 1). The same result also found in biomass estimation (Figure 3). In contrast to Susanto et al. (2017b), which states that at the age of 1 year the best growth and production of above-ground biomass were found in the application of NPK fertilizer with the dosage of 120 g. In other hands, Nusbaum et al. (2005) reported that application of soil fertilizer in degraded soil is able to increase dry weight, basal diameter, and height for all plant species at the age of 6 months. The relative height and basal diameter increasing in of fertilized *M. gigantea* seedlings are four times higher than unfertilized plants which have the same treatment.

The result on accumulated nutrient content analysis of N, P, K, Ca and Mg in *M. gigantea* plant compartment showed that the highest nutrient content found in P4 plot, which is treated using NPK 160 g fertilizer. The most N nutrient accumulation was found in the leaves, followed by branches of wood and bark. The most P nutrient element accumulates on the branch followed by leaves, wood, and bark. In other hands, K, Ca and Mg nutrients were more accumulate in branches, wood, leaves, and bark. The absorbed nutrient of M. gigantea from the soil were K reaches 676.20 kg.ha⁻¹, followed by N: 344.01 kg.ha⁻¹, Ca: 114.57, Mg: 77.64 kg.ha⁻¹ and P: 43.04 kg.ha⁻¹.

The nutrient N, P, K, Ca and Mg content in soil (0-60 cm) showed that plot P4 had the lowest nutrient content compared to Plots P0, P1, P2, and P3. Elements of K and P have a lower content than N, Ca and Mg nutrients. It means that *M. gigantea* plant will easily absorb nutrients in the soil for its growth. This plant is a pioneer fast growing species which requires high levels of light in the extensive forest gaps and secondary forest habitats (Davies et al. 1998; Romell et al. 2008). Fast-growing tree species are generally considered to accumulate soil nutrients faster than slow-
growing ones when multiple rotations are implemented (Cossalter and Pye-Smith 2003). Inagaki and Tange (2014) also reported that fast-growing Eucalyptus trees can accumulate more aboveground biomass than N₂-fixing and other non-N₂-fixing broadleaved trees while incorporating less aboveground N. Furthermore, some Acacia and Eucalyptus trees can produce more aboveground biomass than other non-N₂-fixing broadleaved trees while using less P. Montagnini (1998) reported that four years after planting, decrease in soil nutrients were apparent in pure plots of some of the fastest growing species. On the other hand, some fast-growing tree species have strategies that allow them to grow on degraded soils. Montagnini (2000) reported that decreases in soil P, K and Ca were apparent in pure plots of the fastest growing species with the largest accumulation of nutrients in above-ground biomass, such as J. copaia and V. guatemalensis, five years after planting.

The highest is also found in P4 plot. Nitrogen accumulates 344.01 kg.ha⁻¹, 121% higher than non-fertilized control plants accumulating only 155.9 kg.ha⁻¹. The accumulation of phosphorus biomass of M. gigantea on P4 plot is 43.04 kg.ha⁻¹, twice higher than the phosphorus content in control plot is 20.9 kg.ha⁻¹. Potassium accumulates was 676.20 kg.ha⁻¹, three times higher than control plot (239.89 kg.ha⁻¹). While, for the calcium and magnesium nutrients, each accumulates 114.57 kg.ha⁻¹ and 77.64 kg.ha⁻¹ in biomass in plot 4, twice higher compared to the biomass of the P0 control plot those were 66.51 kg.ha⁻¹ and 36.1 kg.ha⁻¹. NPK fertilizer addition higher than 160 g significantly increased N, P, K, Ca and Mg content of M. gigantea plant biomass. This nutrient has important role in photosynthesis because used for the synthesis of organic biomass plant material. This is in accordance with Cossalter and Pye-Smith (2003), which states that fast-growing tree species are generally considered to accumulate soil nutrients faster than slow-growing.

Potassium is the most accumulates nutrient in M. gigantea biomass of 676.20 kg.ha⁻¹ consists of 64% in stem and branch, and 36% in leaf and bark. On the other hand, the relative portion of K nutrients that accumulates in M. gigantea stands is quite large, ranging between 18.83-55.82% (Figure 7) compared to other nutrients. This result shows that nutrient K is the most absorbed nutrient by M. gigantea. Hertemink (2001) reported that fast-growing species Piper aduncum also accumulated large amounts of biomass and nutrients, particular K.

When M. gigantea plant is harvested at 5 years old with stems and branches took out of the system, the greatest nutrient that will be reduced from t soil is potassium, followed by phosphorus, nitrogen, calcium, and magnesium. In the first cycle of harvesting M. gigantea, the soil will lose nutrients by 438 kg.ha⁻¹ (64%), with leaf and bark notes left on the land system. Meckensen, (1999) and Meckensen et al. (2001) reported that nutrient content of fast-growing Eucalyptus deglupta in industrial plant forests in East Kalimantan (100 m³ log and barks) was N: 44.4 kg.ha⁻¹, P: 2.3 kg.ha⁻¹ and K: 125 kg.ha⁻¹. Uri et al. (2003) found that the amount of nutrients accumulated by 1-year-old grey alder in producing one tonne of biomass at an N:P:K ratio of 100:9:43. The uptake of nutrients K by M. gigantea is more abundant than Eucalyptus deglupta. Montagnini (2000) reported that in monoculture plantation, Vochysia guatemalensis had the greatest accumulation of K and Ca. V. guatemalensis, stem harvest would remove less than 30% of N for 50% of total above-ground tree Ca, K, Mg and P. Branches and foliage summed together were 25 to 35% of total above-ground tree biomass, but they generally represent about 50% of above-ground tree nutrients. Mackensen and Foster (2000) reported that calculated major differences in the fertilizer expenses between species. Fertilization costs for Eucalyptus deglupta are generally higher than Acacia mangium. Alriksson and Eriksson (1998) suggested that the choice of tree species harvest and stem-wood harvest, also at similar rates of stem-wood biomass production. On the other hand, Montagnini (2000) reported that continued sampling will be needed to assess the long term effects of plantation treatments on soil chemistry, especially near the end of the rotation.

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REFERENCES

Amrita R, Mukhdlor A, Mujiasih D, Septia E, Supriadi, Susanto D. 2016. Suitability and availability analysis of tropical forest wood species for ethanol production: a case study in East Kalimantan. Biodiversitas 17 (2): 544-552.

Alriksson A, HM Eriksson. 1998. Variations in mineral nutrient and C distribution in the soil and vegetation compartments of five temperate tree species in NE Sweden. Forest Ecology and Management 108 (3): 261-273.

Bentos TV, Mesquita RCG, Williamson GB. 2008. Reproductive phenology of Central Amazon pioneer trees. J Trop Conserv Sci I (3): 186-203.

Cossalter and Pye-Smith. 2003. Fast-Wood Forestry Myths and Realities. Center for International Forestry Research, Jakarta. [Indonesian]

Davies SJ, Ashton PS. 1999. Phenology and fecundity in 11 sympatric pioneer species of Macaranga (Euphorbiaceae) in Borneo. Amer J Bot 86 (12): 1786-1795.

Davies SJ. 1998. Photosynthesis of nine pioneers Macaranga species from Borneo in relation to life history. Ecology 79:2292–2308.

Hertemink AF. 2001. Biomass and nutrient accumulation of Piper aduncum and Imperata cylindrica fallows in the humid lowlands of Papua New Guinea. Forest Ecology and Management 144 (1-3):19-32.

Inagaki M, Tange T. 2014. Nutrient accumulation in aboveground biomass of planted tropical trees: a meta-analysis. J Soil Sci Plant Nut 60 (4): 596-608.

Lawrence D. 2001. Nitrogen and phosphorus enhances growth and luxury consumption of four secondary forest tree species in Borneo. Journal of Tropical Ecology 17:859-869.

Meckensen J.1999. Nutrient management for industrial tree plantation. A practical guidance towards integrated nutrient management. Deutsche
Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH Postfach 5180. D-65726 Eschborn.
Mackensen J, H. Foster. 2000. Cost-analysis for sustainable nutrient management of fast growing tree plantations in East-Kalimantan, Indonesia. For Ecol Manag 131 (1-3): 239-253
Meckensen J, Ruhiyat D, Folster H. 2001. Volume-based nutrient content of Acacia mangium, Eucalyptus deglupta and Paraserianthes falcataeria in industrial tree plantations in East Kalimantan, Indonesia. J Trop For Sci 13:512-526.
Mindawati N, Bogidarmanti R, Nuroniah HS, Kosassih AS, Suhartati, Rahmayanti S, Junaidi A, Rachmad E, Rochmuyanto Y. 2010. Synthesis silviculture research of species alternatives for wood pulp production. Research and Development Center for Increasing Forest Productivity, Bogor, Indonesia.
Montagnini F. 1998. Evaluating the Role of Plantations as Carbon Sinks: An Example of an Integrative Approach from the Humid Tropics. Environ Manag 22 (3): 459-470.
Montagnini F. 2000. Accumulation in above-ground biomass and soil storage of mineral nutrients in pure and mixed plantations in a humid tropical lowland. For Ecol Manag 134 (1-3): 257-270.
Nussbaum R, Anderson J, Spenser T. 1995. Factors limiting growth of indigenous tree seedlings planted on degraded rain forest soil in Sabah, Malaysia. For Ecol Manag 74: 149-159
Romell EG, Hallsgy G, Karlsson A, Garcia C. 2008. Artificial canopy gaps in a Macaranga spp. dominated secondary tropical rain forest—effects on survival and above ground increment of four under-planted dipterocarp species. Forest Ecology and Management 255: 1452–1460
Ruhiyat D. 1996. Estimasi Biomassa Tegakan Hutan Hujan Tropis di Kalimantan Timur. Rimba Kalimantan 1 (1): 42-57. [Indonesian]
Slik FJW, Bernard CS, Van Beek M, Breman FC, Eichhorn KAO. 2008. Tree diversity, composition, forest structure and aboveground biomass dynamics after single and repeated fire in a Bornean rain forest. Oecologia. DOI 10.1007/s00442-008-1163-2.
Susanto D, Ruhiyat D, Sutisna M, Amirta R. 2016a. Flowering, fruiting, seed germination and seedling growth of Macaranga gigantea. Biodiversitas 17 (1): 192-199.
Susanto D, Ruhiyat D, Sutisna M, Amirta R. 2016b. Soil and leaf nutrient status on growth of Macaranga gigantea in secondary forest after shifting cultivation in East Kalimantan, Indonesia. Biodiversitas 17 (2): 409-416.
Susanto, Hayatudin, Setiawan A, Purnomo H, Ruhiyat D, Amirta R. 2017a. Characterizing nutrient status and growth of Macaranga gigantea in tropical rainforest gaps after selective logging in East Kalimantan, Indonesia. Biodiversitas. DOI: 10.13057/biodivi/d180318
Susanto D, Mulyati S, Purnomo H, Ruhiyat D, Amirta R. 2017b. Growth, biomass production and nutrient accumulation of Macaranga gigantea in response to NPK fertilizer application. Nusantara Biosci 9 (3): 330-337.
Suita E, Nurhasyibi. 2009. Seed and plant propagation collection pioneers type Macaranga sp. for forest and land rehabilitation. Info Benih 13 (1): 170-175. [Indonesian]
Uri V, Tullus H, Lohmus K. 2003. Nutrient allocation, accumulation and above-ground biomass in Grey Alder and Hybrid Alder plantations. Silva Fennica 37 (3): 301-311.
Woody biomass and elements uptake in phytoremediation of compost leachate

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Abstract. Abedi T, Avani N. 2018. Woody biomass and elements uptake in phytoremediation of compost leachate. Asian J For 2: 20-24. This study examined the performance of absorption and growth of Alnus glutinosa and Taxodium distichum which underwent leachate irrigation of Rasht Compost Plant. In mid-March 2013, one year old seedlings of Alnus glutinosa and Taxodium distichum were planted in a greenhouse at Safrahaste Poplar Research Station and since then, this study began. The compost leachate was taken from the collection reservoir of leachate coming from open composting of organic municipal wastes and various gardening and plant wastes. Three treatments were applied to the plants, namely the irrigation using: tap water (control / C), pure leachate (P) and the mixture of one volume unit of leachate with one volume unit of running water (1: 1). It was concluded that leachate had a positive influence on the growth of A. glutinosa and T. distichum namely an increase in diameter and height of seedlings in the measurement period which occurred to be caused by fertilization properties of leachate. Statistically, there was no difference in the development of aboveground biomass in the treatment of P, 1:1 and C. This indicated that both irrigation by pure leachate and mixture liquid stimulate growth in the same way as irrigation by water. The dry mass of root showed the same result as aboveground mass. The total dry mass of the leachate treatment for A. glutinose and T. distichum were, respectively, 83.89 g and 78.68 g. The total root dry mass of leachate treatment for A. glutinosa and T. distichum was, respectively, 11.98 g and 9.09 g. The results of elements absorption showed no statistical difference between the aboveground species. The absorption of Ca concentration in root was higher than the absorption of other elements and showed significant difference in 1:1 treatment.

Keywords: Treatment, growth, compost leachate, seedling

INTRODUCTION

The production of renewable energy sources, also in the form of biomass has been increasingly proposed in Iran. Providing sufficient plant nutrients (artificial fertilizers) for their optimal growth are essential importance. At the same time, fertilizers represent an important production cost. Their substitution with waste sources could be a promising option with regard to the reduction of production costs and the simultaneous reduction of spending on the treatment of waste sources like landfill leachate, wastewater from compost production, sludgeand etc. (Justin et al. 2010; Holm and Heinsoo 2013). This paper describes a pot experiment with the aim of obtaining data on the response with respect to biomass accumulation Alnus glutinosa and Taxodium distichum to different concentrations of compost leachate. Several studies report positive effects of leachate irrigation on tree growth, showing its fertilizing potential. Zalesny and Bauer (2007b) found that Salix clones S287 and S566 exhibited responses favoring leachate irrigation over water. Justin et al. (2010) detected that the use of landfill leachate treatments resulted a considerably increased aboveground biomass compared to the control tap water treatment and the growth and biomass accumulation in compost wastewaters treatments were reduced compared to tap water and landfill leachate treatments. Abedi et al. (2014, 2015) investigated Populus deltoides, P. euramericana and Salix alba in phytoremediation.

In both biomass and other forms, the procurement of renewable sources of nutrients is increasingly being proposed in Iran. For optimal plant growth, adequate supply of nutrients for plants is essential. Artificial fertilizers as a main supply of nutrients for plant become the largest absorber factor in production costs in agriculture or plantations. Replacement of artificial fertilizer with alternative fertilizer becomes the most favorable option for farmers in reducing the cost of artificial fertilizer procurement and the cost of the treatment of waste sources like landfill leachate, wastewater from compost production, sludgeand etc. (Justin et al. 2010; Holm and Heinsoo 2013). This study attempts to illustrate experiments with pots aimed at obtaining data on the response of biomass accumulation of A. glutinosa and T. distichum with compost leachate with different concentrations.

Due to its economic and ecological usefulness, T. distichum becomes one of the most well-known conifer trees and it is thought to have high tolerant to flooding and water logging. Although, it and its associated species is more famous for its usefulness in flooding and salinity (El-Dayem 2003).

Alnus glutinosa has a toleration to prolonged submergence of its roots in water for up to 30cm deep. This plant can also grow in much drier sites, though, in such
condition, it will usually not live for a long period and will die soon. *Alnus* can grow well in heavy clay soils, and is in toleration to lime and very infertile sites. It tolerates a wide range of soils but prefers an above 6 pH. It is very tolerant to maritime exposure and can grow very rapidly on early stage. (http://www.pfaf.org/user/plant.aspx).

**MATERIALS AND METHODS**

Safrabaste Poplar Research Station was used as a place of experimentation. It is located in eastern part of Gilan province in north of Iran (37° 19’ N, 49° 57’ E) and the experiment was done in growing season in 2013.

One year old seedlings of *Alnus* and *Taxodium* were used as plants of experimentation and they were collected from the nursery of the Safrabaste Poplar Research Station. Their high biomass production capacity and their function as endemic species of hyrcanian forests of Iran made them chosen as the objects of experimentation. At the beginning of the planting season, i.e. in the middle of March 2013, the seedlings were planted in experiment pots filled with loamy-sandy soil from around the area with a depth of 40 cm. The initial substrate used in the experiment were analyzed in the soil laboratory. In accordance with the standard procedure described by the Soil Science Society of America, the main physical and chemical characteristics of the soil were determined (Page et al. 1982). Table 1 shows a list of substrate analysis, physical characteristics and analytical methods applied in this study.

Compost leachate was gathered from a leachate reservoir belonging to Compost Plant of Municipal Waste Management of Rasht, North of Iran (37° 10’ N, 49°34’ E). The analysis for its chemical content was performed in the Laboratory of Guilan Department of Environment (Rasht, North of Iran) using approved Standard Methods for the Examination of Water and Wastewater (Eaton et al. 2005).

Table 2 shows the composition of leachate for the experiment. It was dark brown with smelly odour. A 20 l plastic tank was used to store the leachate while it was mixed with tap water create a mixture with specified degree of dilution. Before the filling of the tank, chemical analysis of leachate was performed.

For as long as eight weeks, at the beginning, tap water was used to water the plants. When the experiment started in mid-May 2013, three treatments were applied to the plant, namely the watering treatment with: (C) tap water (control), (P) pure leachate and (1: 1) the mixture of one unit of leachate with one unit of tap water (by volume). The experiment layout is a complete random design consisting of five treatments with ten replicates for each treatment. The experiment lasts until early December. The pots with the plants inside were placed randomly on an experiment field under a transparent roof to avoid rainfall but still exposed to sunlight. The plants were irrigated with a mixture of water for as much as the absorption capacity of substrate against water (0.5 l per pot) in the first week of the experiment. Pure leachate is leach without dilution. Tap water for C treatment and for the preparation of the water mixture is from the public drinking water supply.

The growth on diameter and height of the trees was monitored bi-monthly. At breast high, the diameter was measured, and from the soil surface to the apical bud at the terminal shoot, the height was recorded (Zalesnyet al. 2007a). For eight months of the growth phase, the average growth rate of diameter and height of the trees for each treatment was calculated bi-monthly (Figure 1 and 2).

After eight months, all trees were cut down and were separated into 2 parts, namely: aboveground (stems, branches and leaves) and root system. The parts of the root system were separated carefully and washed thoroughly with distilled water. Next, the roots and the stems were dried in an oven at 60°C for 48 hours. The biomass (Figure 5 and 6) and absorbed-elements (Figure 7 and 8) of aboveground and of root were calculated carefully. Data were calculated using SPSS 16.0 statistical package. The statistical dissimilarity among treatments is ascertained by the analysis of variance. The outcomes were regarded remarkable at p <0.05. The tree growth rate was displayed on graphs of the diameter and of height against time.

### Table 1. Soil analyses and physical characteristics of the substrate used in the experiment

| Component | Unit | Amount |
|-----------|------|--------|
| pH | - | 8.31 |
| EC | mS cm⁻¹ | 1.26 |
| N\_{org} | % | 0.08 |
| N\_{tot} | % | 0.01 |
| P | mg kg⁻¹ | 0.69 |
| K | mg kg⁻¹ | 57.60 |
| Ca | mg kg⁻¹ | 400 |
| Mg | mg kg⁻¹ | 24 |
| Soil texture | - | Loamy sand |
| sand | % | 86 |
| silt | % | 5 |
| clay | % | 9 |

### Table 2. Composition of pure compost leachate

| Parameter | Unit | Amount |
|-----------|------|--------|
| pH | - | 5.22 |
| EC | mS cm⁻¹ | 1.26 |
| N\_{org} | mg L⁻¹ | 21.384 |
| NO₂ | mg L⁻¹ | 0.08 |
| NO₃ | mg L⁻¹ | 21.3 |
| SO₄ | mg L⁻¹ | 7101 |
| Na | mg L⁻¹ | 211 |
| K | mg L⁻¹ | 250 |
| Ca | mg L⁻¹ | 152 |
| Mg | mg L⁻¹ | 1103 |
| Pb | mg L⁻¹ | 0.27 |
| Ni | mg L⁻¹ | 0.342 |
| Cd | mg L⁻¹ | 0.0047 |
| Cr | mg L⁻¹ | Trace |
| COD | mg L⁻¹ | 260500 |
| BOD | mg L⁻¹ | 130000 |
| TSS | mg L⁻¹ | 3060.6 |
| Turbidity | mg L⁻¹ | 12500 |

The growth on diameter and height of the trees was monitored bi-monthly. At breast high, the diameter was measured, and from the soil surface to the apical bud at the terminal shoot, the height was recorded (Zalesnyet al. 2007a). For eight months of the growth phase, the average growth rate of diameter and height of the trees for each treatment was calculated bi-monthly (Figure 1 and 2).

After eight months, all trees were cut down and were separated into 2 parts, namely: aboveground (stems, branches and leaves) and root system. The parts of the root system were separated carefully and washed thoroughly with distilled water. Next, the roots and the stems were dried in an oven at 60°C for 48 hours. The biomass (Figure 5 and 6) and absorbed-elements (Figure 7 and 8) of aboveground and of root were calculated carefully. Data were calculated using SPSS 16.0 statistical package. The statistical dissimilarity among treatments is ascertained by the analysis of variance. The outcomes were regarded remarkable at p <0.05. The tree growth rate was displayed on graphs of the diameter and of height against time.
RESULTS AND DISCUSSION

High quantity of contents of components were given to plants in the pots. The contents of N, P and K were much greater in number in leachate treatments than in soil, but Ca content was lower compared to that in soil filled in the pots. The higher ion concentration in leachate also reflected higher electrical conductivity (1.26 mS cm\(^{-1}\)) compared to that in soil (0.128 mS cm\(^{-1}\)). Metal contents were low in collected-leachate. For eight months, by P treatment, \textit{A. glutinosa} and \textit{T. distichum} showed the highest diameter growth with the average of 1.356 and 1.128 cm respectively (Figure 1). Over a period of eight months, the higher rate of height growth was found in the treatment of P and 1:1 (Figure 2).

For aboveground biomass, the greater mean was in the treatment of 1:1, but it was not significant difference from other treatments (p<0.05) (Figure 5). For root biomass, the greater mean was in the treatment of 1:1, which was not significant difference from the treatment of C, but gave a significant difference from P treatment (p<0.05) (Figure 6).

Discussion

The positive effects of leachate irrigation on tree growth and its fertilizing potential for plants have been reported by many studies. Justin et al. (2010) found that utilization of landfill leachate treatment increased the amount of surface biomass significantly compared with the control tap water treatment, but tree growth and biomass accumulation in wastewater compost treatment decreased compared to the treatment of tap water and compost leachate. The results of Abedi et al. (2014, 2015) showed a positive effect of compost leachate on tree species. Depend on the constituents of the leachate and soil, as well as the nutrient demands of the genotypes tested, the concentrations and amounts of leachate will be determined (Zalesny and Bauer 2007b).

In all treatments, no statistically significant differences between the aboveground biomass could be found (Figure 5). High concentration in the P treatment turned out to be toxic, meaning that the water mixture in P treatment already had too high concentration of salts and other elements (Table 2).

The compost leachate was a by-product of composting of organic matter, having a low pH (5.22) which is a sign of unfinished degradation processes of raw organic matter, where due to the inadequate oxygen levels. The comparison of the plants growth in the several treatments showed apparently normal and healthy-looking trees. The compost leachate was a by-product of the decomposition process of organic matter and it has a low pH (5.22) which shows a sign of incomplete decomposition processes of raw organic matter due to the insufficient oxygen levels. The differentiation of the plants growth in the some treatments indicated apparently normal and healthy-looking trees.

The practice level of nitrogen were also elevated in compost leachate. There is an acknowledged patency in common agricultural practice that supplementary nitrogen is utilized to manage distinctive toxicity issues and boost vegetation growth (Ayers and Westcot 1994). Kadlec and Wallace (2009) notified that more elevated concentrations of sulphate (402 mg SO\(_4\)/L) in compost leachate could bring negative effect on plant accretion in water-saturated root part and should also be highlighted. In this study, the sulphate concentration was 7101 mg SO\(_4\)/L. Still, the plant continued to accrue.

Figure 1. Mean growth in diameter (cm) of \textit{Alnus glutinosa} and \textit{Taxodium distichum} with three concentrations of compost leachate

Figure 2. Mean growth in height (cm) of \textit{Alnus glutinosa} and \textit{Taxodium distichum} with three concentrations of compost leachate
Fung et al. (1998) Abedi et al. (2014) stated that elevated rates of salt (1.0% NaCl) quickly lessened the accretion of Populus and owned an instantaneous result on predawn leaf water potency, photosynthesis and stomata resistance. It has been notified that the Populus was sensitive to salt, but *A. glutinosa* which was hardwood tree species and *T. distichum* which was softwood tree species have no negative reactions to elevated concentration of salts. It is obvious that pure compost leachate can be used without treated for study species. However, transferring the experiment to the field would enable leaching of the excess water from the root zone, and the washing-out of salts by precipitation to the lower soil layers, thus better survival with the same amounts of pure compost leachate as used in the pot experiment. The development of aboveground biomass is important from the leachate consumption and phytoremediation point of view (Justin et al. 2010). It is crystal clear that the unspoiled compost leachate can be exerted without being carried out for study species. Nevertheless, redeploying the trial to the field would enable leaching of the excess water from the root zone, and the washing-out of salts by precipitation to the lower soil layers, thus better survival with the same amounts of pure compost leachate as used in the pot experiment. The
establishment of aboveground biomass is necessary from the leachate usage and phytoremediation viewpoint (Justin et al. 2010).

The outcome of elements absorption shows no statistically variation between above ground species. Lower K absorption was found on C treatment while the most elevated absorption of Ca happened above ground (Figure 7). The absorption of Ca concentration on root was higher than the absorption of other elements and show significant variance in 1:1 treatment (Figure 8). There was a conclusion that compost leachate positively affected the development of A. glutinosa and T. distichum in their diameter and height in measuring time due to the leachate's property of fertilization (Figure 1 and 2). The diameter and height of trees have no significant differentiation (p< 0.05) in all treatments (Figure 3 and 4).

In the treatment of 1:1, the highest aboveground biomass was yielded by both species. There was statistically no differentiation between the treatment of P, 1:1 and C in establishing aboveground biomass. This shows that leachate watering with P or 1:1 mixtures boosted the growth in the same way as the watering with pure water. The root dry mass indicated the same results as that of aboveground mass. Total aboveground dry mass of leachate treatments for A. glutinosa and T. distichum was 83.89 and 78.68 g, respectively. The amounts for water treatments was 47.12 and 35.90 g, respectively. Total root dry mass of leachate treatments for A. glutinosa and T. distichum was 11.98 and 9.09 g, respectively. The amounts for water treatments was 5.57 and 2.75 g, respectively. Zalesny and Bauer (2007b) chose fast-accretion Populus and Salix clones and their genomic groups after doing phytoremediation concept: Biomass production and growth of Populus deltoides under compost leachate irrigation, J For Sci 61 (6): 250-254.

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REFERENCES

Abedi T, Moghaddami Sh, Laskar Bolouki E. 2014. Growth of Populus and Salix species under compost leachate irrigation. Ecologia Balcanica 6 (2): 57-65.

Abedi T, Moghaddami Sh. 2015. Phytoremediation concept: Biomass production and growth of Populus deltoides under compost leachate irrigation, J For Sci 61 (6): 250-254.

Adler A, Dimitriou I, Aronsson P, VerwijstT, Weih M. 2008. Wood fuel quality of two Salix viminalis stands fertilised with sludge, ash and sludge-ash mixtures. Biomass Bioenerg 32 (10): 914-925.

Ayers RS, Westcot DW. 1994. Water Quality for Agriculture. FAO, Rome.

Dimitriou I, Aronsson P, Weih M. 2006. Stress tolerance of five willows clones after irrigation with different amounts of landfill leachate. Bioresource Technol 97: 150-157.

Eaton AD, American Public Health Association, American Water Works Association, Water Environment Federation. 2005. Standard Methods for the Examination of Water and Wastewater. American Public Health Association: 1325, Washington, D. C.;

EL-Dayem A. 2003. Effect of Fertilizer Treatments on Taxodium distichum Seedlings Grown in Alkali Soil. XII World Forestry Congress. 21-28 September 2003, Quebec City, Canada.

Fung LE, Wang SS, Altman A, Hu’terman A. 1998. Effect of NaCl on growth, photosynthesis, ion and water relations of four poplar genotypes. For Ecol Manag 107: 135-146.

Greger M, Landberg T. 1999. Use of willow in phytorextraction. Intl J Phytoremed 1: 115-123.

Holm B, K. Heinsoo. 2013. Influence of composted sewage sludge on the yield of willow short rotation coppice. Environ Protect Eng 39 (1): 17-32.

Justin MZ, PajkN, Zupanc V, Zupancic M. 2010. Phytoremediation of landfill leachate and compost wastewater by irrigation of Salix viminalis and Populus clones after irrigation with different amounts of landfill leachate. For Ecol Manag 30: 1032-1042.

Kadlec RH, Wallace SD. 2009. Treatment Wetlands, 2nd ed. CRC Press, Boca Raton, FL.

Klang-Westin E, J. Eriksson. 2003. Potential of Salix as phytorextractor for Cd on moderately contaminated soils. Plant Soil 249: 127-137.

Navarro JM, Tornero OP, Morte A. 2014. Alleviation of salt stress in citrus seedlings inoculated with arbuscularmycorrhizal fungi depends on the rootstock salt tolerance. J Plant Physiol 171: 76-85.

Page AL, Miller RH, Keeney DR. 1982. Methods of Soil Analysis. Part 2, Chemical and Microbiological Properties. American Society of Agronomy, Inc. Soil Science of America, Inc. Madison, Wisconsin, USA.

Pulford ID, Dickinson NM. 2005. Phytoremediation technologies using trees. In: Prasad MNV, Naidu R (eds.). Trace Elements in the Environment. CRC Press, New York, USA.

Zalesny JA, Zalesny RSJr, Coyle DR, Hall RB. 2007. Growth and biomass of Populus irrigated with landfill leachate. For Ecol Manag 248: 143-152.

Zalesny RSJr, Bauer OE. 2007. Selecting and utilizing Populus and Salix for landfill covers: Implications for leachate irrigation. Intl J Phytoremed 9: 497-511.
The effects of fires on plants and wildlife species diversity and soil physical and chemical properties at Aberdare Ranges, Kenya

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Abstract. Njeri WF, Githaiga JM, Mwala AK. 2018. The effects of fires on plant and wildlife species diversity and soil physical and chemical properties at Aberdare Ranges, Kenya. Asian J For 2: 25-38. This study was aimed to determine the effects of fires on species diversity (plants, animals, birds), and soil physical and chemical properties at the Aberdare Ranges forest, Kenya. Data were collected on five sites that experienced fires in 2002, 2009, 2012, 2013, and 2014 from both burnt and unburnt areas. Point Centered Quarter and quadrant methods were used for woody vegetation sampling and herbaceous vegetation sampling, respectively. Foot count was done for animal census and point count for birds. The data showed that the herbaceous vegetation in burnt sites had significantly higher species diversity than the unburnt sites in the areas that experienced fire before 2014. The fire had triggered the regeneration of the herbaceous plants. The burnt sites had a significantly higher percentage cover. The fire has an immediate adverse effect on the population of animals as demonstrated on the site consumed in 2014. No animal species was found on the site seven days after the fire when data was collected. The animal diversity was proportional to the vegetation density caused by the vegetation regeneration due to fires. All the burnt sites had fewer birds than the unburnt sites. Effects of fires were prominent in the upper layer of the soil for all the soil properties under study. Burning caused an increase in pH, potassium, organic carbon and cation exchange capacity. The study demonstrated that fires lead to an immediate adverse effect on vegetation, wildlife and soil chemical properties. Postfire management is necessary on sites that have recently experienced fires to rehabilitate them. Authorities responsible for the management of forests must ensure that people are kept out of those sites to allow vegetation to recover without interference. Reforestation can also be done on the burnt sites to increase plant and habitat for the wildlife.

Keywords: Animal diversity, birds, fire, plant diversity, soil properties

INTRODUCTION

Forests are indispensable sources of harvested products and a variety of services which include: provision of food, timber, fuel, genetic materials among others, regulating services such as protection of watershed and carbon storage, cultural facilities and supporting services (Kozioowski 2002). Forest ecosystem services have been shown to be of high economic value since they provide raw materials for food, fuel, and shelter (Constanza et al. 1997). In forest valuation studies, service components such as carbon storage or hydrological protection frequently fetch higher values than forest products. However, forests throughout the world, and especially in the tropics, are threatened by natural-induced disturbances such as windthrow, droughts, floods, disease outbreaks among others and human-induced disturbances such as fires, logging, charcoal burning, forest clearance for farming among others (Kozioowski 2002).

One phenomenon that threatens forest worldwide is forest fires. The forest fire can be defined as the free propagation of uncontrolled fire in forest ecosystems, caused by accidental, natural or intentional causes (Chuvieco 2009). Forest fires are a severe hazard and can cause considerable damage to ecological, economic, cultural and human resources (Long et al. 2001).

More than 220,000 forest fires occur in a year around the world resulting in burning in more than 6 million ha of forests (Gonzalez et al. 2005). Many studies have been conducted on the assessment and management of forest fires. Some countries like Russia, the United States of America and Canada have led the way in forest fire research (Sturtevant et al. 2009) by developing forest fire management systems and forest fire risk forecast systems in time and space. Kenya is also adopting a fire management system through Kenya Forest Service by recording all the fire incidences and stocking every station with fire equipment although the progress has been slow.

Knowledge of the impact of the fire has attained increased importance to land managers because fire as a disturbance process is a part of ecosystem management. Fire can initiate changes that affect the composition, structure, and pattern of vegetation on the landscape. A disturbance is necessary to maintain a diversity of living things and processes (Botkin 1990; Morgan et al. 1994).

Old growth forests are a valuable component of biodiversity, and one way to assess the effectiveness of forest management is by evaluating the proportion of old growth forest currently present concerning that was historically present (Lesica 1996). Anthropogenic activities create fire-prone ecosystems in the tropics through the alteration of vegetation cover by logging, burning, and development. The new ecosystems differ substantially in
carbon budget, nutrient cycling, fuel and habitat characteristics (Swetnam et al. 1999).

As one of Kenya's five main water towers, the forests of the Aberdares play a critical role in supporting the country's economy. They are the primary source of water for Nairobi. Furthermore, 55% of Kenya's electricity is generated by water flowing from the Aberdares and Mt. Kenya. The Aberdares are the main catchments for Sasumua and Ndakaini dams, which mainly act as the water source for Nairobi—a city of more than three million people that accounts for 60% of Kenya GDP. The energy, water and some raw materials used to drive some economic activities in the city and its environ are derived from the Aberdare ecosystem. Proper management of this ecosystem is crucial for the national economy (Ark 2011). Nevertheless, fires may interfere with the ability of Aberdares to continue providing its services hence affecting the national economy.

This study was carried out in the western Aberdares at Geta forest zone. Five sites that had been burnt at different periods were identified, and data were collected in both burnt sites and unburnt sites. The data were collected during the wet season and dry season. Point Centered Quarter method was used for the woody vegetation, whereas the quadrant method was employed for the herbaceous plant. Herbivores were counted using foot count, and the birds were counted using point count. Soil samples were collected from all the sites and taken to a soil laboratory for physical and chemical analysis. The soil properties analyzed include pH, nitrogen, organic matter, potassium, phosphorous, and Cation Exchange Capacity.

The specific objectives were (i) to determine the effect of fire on plant species diversity at different time periods. (ii) to assess the impact of fire on a population of herbivores and birds at different time periods. (iii) to determine the effects of fire on soil physical and chemical properties at a different period.

MATERIALS AND METHODS

Study area

Geographic location

The study was carried out at the Aberdare Range, Kenya close to the equator (Figures 1 and 2). It is the third highest mountain in Kenya, with two central peaks: Oldonyo Lesatima (also known as Sattima) and Kinangop, which are at altitudes of 4,001 and 3,906 meters respectively. The Range presents a deeply dissected topography sloping gradually to the east. In contrast, the western side drops along impressive fault escarpments towards the Rift Valley (www.britannica.com retrieved 2014-06-17). The Aberdare mountain range lies between Latitude 0° 00”-01°00” South and Longitude 36° 30”-36°55” East running in an NNW-SSE direction. Altitude varies from 1850 min the lower parts to about 4000 m at the highest point. Individually, the study was done at Geta forest zone which is at the western side of the Aberdares and the most significant part of the Aberdares hills. Data was also collected from Kipipiri hill which lies next to the Aberdare ranges.

Climate of Aberdare Ranges

Altitude largely determines the environment of the Aberdare Ranges. The rainfall distribution is greatly influenced by the movement of inter-tropical convergence zones of air masses of the southern and northern hemisphere. It is characterized by two rainy seasons: long rains from April to May, and short rains from October to November. Rainfall reaches a maximum of around 2,600 mm annually on the south-eastern slopes but varies with altitude and exposure to the dominant wind from the Indian Ocean (Butynski 1999). On the western part, rainfall reduces sharply from about 1,400 mm at the forest border to less than 700 mm in the valley of the Malewa River.

The northern end of the range has 3-4 dry months per year with the seasonal distribution showing three rainfall peaks: march-may (long rains), July-August, and November. Elsewhere, the rainfall distribution is bimodal with peaks in April-May and October-November and only 1-2 dry months each year. Temperature decreases with increase in altitude and rainfall also decline with height.

Vegetation in Aberdare Ranges

Vegetation zones at the Aberdare Ranges including the bamboo zone, the closed-canopy forest belt, and the sub-alpine and alpine vegetation. The forest belt covers a significant part of the range. Most of the forest is gazetted as forest reserves. The first trees and shrubs species at the Aberdares are shown in Table 1.

Figure 1. The location of Aberdares in Kenya
Figure 2. Study sites locations in Western Aberdares, Kenya

Table 1. The key vegetation species at the Aberdare ranges, Kenya (Ng’ang’a 1990)

| Vegetation zone            | Altitude in m asl and location | Key trees and shrub species                                                                 |
|----------------------------|---------------------------------|---------------------------------------------------------------------------------------------|
| Montane forest zone        | 1900-2500 / East                | Cassipourea malosana, Ekebergia capensis, Teclea nobilis, Calodendrum capense, Podocarpus  |
|                            | 2100-2500 / South-East          | latifolius, Nuxia congesta, Ocotea usambarensis, Macaranga kilimandscharica, Neoboutonia   |
|                            |                                 | macrocalyx, Tabernaemontana staphiana, Prunus Africana                                        |
| Moist forest               | 2100-2500 / South-East          | Cassipourea malosana, Ekebergia capensis, Teclea nobilis, Calodendrum capense, Podocarpus   |
|                            |                                 | latifolius, Nuxia congesta, Ocotea usambarensis, Macaranga kilimandscharica, Neoboutonia     |
|                            | 2300-3200 / North, North-East   | macrocalyx, Tabernaemontana staphiana, Prunus Africana                                        |
|                            |                                 |                                                                                               |
| Dry forest                 | 1800-2400 / South-West          | Juniperus procera, Calodendrum capense, Teclea simplicifolia Juniperus                         |
|                            | 2400-3300 / West                | procera, Olea europaea (africana), Podocarpus                                                 |
|                            | 2300-3200 / North, North-East   | falcatus, Nuxia congesta                                                                       |
|                            | 2400-3000 / East, South-East    |                                                                                               |
|                            | 2700-3300 / West                |                                                                                               |
| Bamboo zone                |                                 |                                                                                               |
|                            | 2950-3500 (discontinuous)       | Hagenia abyssinica, Hypericum revolutum, Rrapanoe melanophloeos                                |
|                            | 2900-3560 (discontinuous)       | Hagenia excelsa, Erica trimera, Erica arborea, Cliftonia nitudula, Helichrysum nandense,     |
| Hagenia-Hypericum zone     |                                 | Strobe kilimandscharica                                                                         |
| Ericaceous zone            |                                 |                                                                                               |

Some parts of the upper forest zone fall within the Aberdare National Park. A high diversity of forest types characterizes the forest belt of the Aberdare Range due to the wide altitudinal range and the climatic differences between the slopes. The Aberdare Range is heavily-forested, much of them have been protected within the Aberdare National Park since its creation in 1950 (Ng’ang’a and Kamande 1990).

Vegetation zones and species distribution are characterized according to the different climatic zones and altitudes, mostly through variation in vegetation structure, cover, and composition. A total of 778 species, sub-species and varieties of vascular plants belonging to 421 genera and 128 families, have been documented in the Aberdare.
**Animals in Aberdare Ranges**

The Aberdare Range forests host some threatened fauna species. The Jackson mongoose (*Bdeugale jacksoni*), endemic to Kenya’s montane forests and the rarely seen golden cat (*Felis aurata*) are two threatened mammals. Other large threatened mammals of international conservation interest that occur in Aberdare forests are bongo (*Ttragelaphus eurycerus*), giant forest hog (*Hylochoerus meinertzhageni*), black rhino (*Diceros bicornis*), elephant (*Loxodonta africana*), leopard (*Panthera pardus*) and African hunting dog (*Lycaon pictus*). Also, the forest harbors bushbuck (*Tragelaphus scriptus*), mountain reedbuck (*Redunca fulvorufa*), waterbuck (*Kobus ellipsi pyrnmus*), suni (*Neotragus moschatus*), cape buffalo (*Syncerus caffer*), side-striped jackel (*Canis adustus*), eland (*Taurotragus oryx*), and varieties of duikers and bushbabies. The forests are rich in primates, and the common ones include the black-and-white colobus monkey (*Colobus guereza*), vervet monkey (*Cercopithecus aethiops*), sykes monkey (*Cercopithecus mitis*), and baboons (*Papio anubis neumanni*) (Waithaka 1994).

The Aberdare Range is internationally recognized as an Important Bird Area (IBA). The Range is a home for 52 of Kenya’s 67 Afrotropical highland species and six of the eight restricted range species in the Kenyan montane endemic bird areas. Over 270 species of birds have been documented in the Aberdares including the following globally threatened and restricted-range species: Sharpe’s Longelaw, Aberdare Cisticola, Abbott’s Starling, Jackson’s Francolin, Hartlaub’s Turaco and Bar-tailed Trogon are characteristic and spectacular birds of the Aberdare Range.

**Soils in Aberdare Ranges**

The grounds are polygenetic and occur in profoundly undulating topography, subjected to intense leaching and have a low base saturation. The grounds are derived from massive lava flows, thick beds of volcanic tuffs and ash showers of geological formation. Soils are deeply weathered, highly porous, stone free, free draining and support deep rooting associations of forest vegetation.

Soils on the upper eastern slopes of the Aberdare Ranges is highly fertile, being of basaltic origin. They are well drained, usually very deep, dark reddish brown, friable clays with a humid topsoil layer. On the western boundary of the Ranges, soils are also of medium to high inherent fertility, but are more variable and interspersed with poorer draining soils and lower productivity. The grounds of the moorlands are umbric andosols which derived from volcanic glass. The area is characterized by a high content of organic matter and is very porous.

The soils of the Northern Aberdare are rich in clay content (82.7%) and consist almost exclusively of kaolinite. Red kaolinite soils are found on slopes, and dark grey, swelling montmorillonitic (black cotton) grounds are located in areas of impeded drainage.

The soils of the southern area are characterized by dark surface horizons and are rich in organic matter. Their bulk density is low and includes Leptosols which are distinguished by a continuous coherent hard rock at very shallow depth, strong brown loams, eutrophic brown soils on volcanic ash and Gleysols which show hydromorphic properties within 50 cm of the surface and are found in valley bottoms.

**Methods**

The data were collected between September 2013 and March 2014. Both the wet season (September 2013 to December 2013) and dry season (January 2014 to March 2014) were covered. Five locations in the forest that had been burnt in 2002, 2009, 2012, 2013 and 2014 were selected. These sites were chosen since they were close to each other and had similar topography and vegetation. In every location, data were collected from both the burnt area and unburnt area that acted as a control. The unburnt regions were separated from burnt areas by buffers of at least 100M to avoid fire effects.

**Woody vegetation sampling**

Point Centered Quarter (PCQ) sampling technique was utilized for the woody vegetation sampling. Three line transects (500 m long) were randomly set in each site, and sampling points along the transect lines were randomly set. Each sampling point was divided into four quarters by the use of a perpendicular line placed at right angles to the line transect. Individual woody plants species closest to the point in each quarter was identified, and the points to individual plant distances were measured using a tape measure (Kevin 2007). The data that was recorded included: The nearest tree species to the sampling point point to individual plant distance measured, the height of tree estimated measured using clinometer, diameter at breast height (DBH) measured by Vernier calipers or a tape measure and canopy cover measured by tape measure.

**Herbaceous plants sampling**

Quadrat sampling method was used (Cox 1990). Sampling was done on areas affected by fire in 2002, 2009, 2012, 2013 and 2014. Three line transects of 500 m long were randomly set in both burn and unburnt areas at each site. Sampling points along the transect lines were randomly placed. Herbaceous layer species were sampled at each location using a quadrat measuring 0.25m². The percentage cover of the species was determined through estimation in all the quadrats, while the heights of the plants were measured using a tape measure.

**Wildlife census**

Direct foot count was done on all study sites to estimate the number of wildlife. The calculation was done once every week where the species name and the number of individuals were recorded. An indirect animal count was also be done by use of animal dung as described by Barnes, (1996). The indirect technique gave an index of abundance rather than a measure of animal density (Sutherland 1996). The length of fine dung may vary between habitat and
between time periods, weather, dung decomposition rate, fiber content and the number of dung beetles and termites. Very fresh dung was marked, and during the second visit, the fresh dung scored in the previous visit was compared to the dung in the site and ignored any dung that looked more decayed. The indirect animal count gave a good indication of the study site use. The following equation was used to convert the number of dungs into the number of animals.

\[
\text{Number of animals} = \frac{\text{Number of dung}}{\text{Number of days between visits} \times \text{defecation rate}}
\]

The species diversity was calculated using Shannon Weiner diversity index.

**Bird count**

Bird count was done once every week in the morning hours between 9.00 AM to 12.00 Noon. Point count was done along two transects in each study site. In every place, the bird count was done on the same day in both burnt and unburnt areas. The sampling points were chosen systematically on the transect after every 100m. In every sampling point, the birds were observed for 10 minutes by use of naked eyes and 8x40 binoculars. The bird species found and the heard calling was recorded. The distance between the observer and the birds and the activity of the bird were also recorded. Species diversity was calculated using Shannon Weiner diversity index.

**Soil sampling and pH**

In every site, the burnt and unburnt sites (three sampling points at random) were selected such that their terrain was as similar as possible. Area for sampling was cleared of vegetation. The soil was dug up to 45cm depth. Samples were taken from 0-15cm, 15-30cm and 30-45cm in every sampling point for further analysis at the University of Nairobi soil laboratories. The grounds were air dried, sieved through 2mm screen and analyzed for physical and chemical properties. For each sample, pH was determined using distilled water in the soil to water ratio of 1: 2.5 (Peech 1965).

**Total nitrogen**

Total Nitrogen content was determined by Kjeldahl digestion method (Fleige et al. 1971). For 1 g of each soil sample, 3.5 mL of phenolic-sulphuric acid (36N) was added and left to stay for 15 minutes. Then, 0.5 g of Sodium thiosulphate was added and the samples left to rest for another 15 minutes. 0.5g of potassium sulfate, 0.5g of selenium reaction mixture and 3.5 mL of concentrated sulphuric acid were thereafter added. The samples were then digested using an electric Kjeltic digestion block. The digested samples were distilled after addition of 40 mL of 10N NaOH solution. A 1% boric acid solution captured the released nitrogen in the form of NH₃ aqueous. The trapped NH₃ was titrated with the 0.01N solution of standard sulphuric acid. The results were expressed as total percentage nitrogen. The amount of nitrogen was calculated from the stoichiometric relationship that 1 mL of 0.01N sulphuric acid used in the titration are equivalent to 0.14 mg of nitrogen.

**Organic carbon**

The organic carbon was measured by the Walkley Black wet oxidation method (Black 1965). The soil samples were crushed and passed through a 0.6 mm sieve. Ten mL of dichromate solution was added into 1g of the soil sample. Twenty mL sulphuric acid was added into the solution and mixed gently and the mixture allowed to stand for 30 minutes. It was then diluted to 200 mL with deionized water. Ten mL of Phosphoric acid, 0.2g ammonium fluoride, and ten drops diphenylamine indicator were added.

The solution was titrated using a standard solution of ferrous sulfate. This procedure was repeated for all the soil samples, and the organic carbon content was calculated using the equation below:

\[
\% C = \frac{\text{Me of } K_2Cr_2O_7 - \text{Me of } Fe_2S04S0_4 \times 0.39}{\text{weight of soil}} \times 100
\]

Where:

- Me : Milliequivalents (normality * mLs of solution)
- 0.39 : Correction factor

**Potassium**

Potassium was extracted from air-dried soil samples by shaking the sample with 0.5M ammonium acetate acid solution for 30 minutes to effectively displaces the potentially available potassium ions. The potassium content of the filtered extract was then determined using a Jenway PFP7 Flame Photometer.

**Phosphorous**

Phosphorus content was determined at an acidity of 0.20M H₂SO₄ by reacting with ammonium molybdate using ascorbic acid which acts as a reductant in the presence of antimony using spectrophotometer (Mehlich 1984). Air-dried soil measuring 2g was passed through < 2.0 mm into a 50 mL glass Erlenmeyer flask. 20.0 mL of Mehlich 3 extracting solution was added. The extraction flask was placed on a mechanical shaker for five minutes. The suspension was filtered immediately and the extract collected in 40 mL plastic vials.

**Cation exchange capacity**

Following the ammonium extraction method, the soil samples were equilibrated with 1N ammonium acetate of an adjusted pH of 7.0, then washed using four 50 mL portions of ethanol, or until no NH₄⁺ ions were seen in the supernatant liquid after centrifuging as tested by Nessler's reagent.

The soil samples were then distilled using the Kjeldahl distilling unit after addition of magnesium oxide. Distillate (200 mL) was collected over 2% boric acid-indicator solution. The distillate was then titrated to the endpoint with 0.1N standard HCl solution. One mL of 0.1N HCl used in titration is equal to 1 milliequivalent per 100g of soil for an original soil sample site of 10g. The amount was expressed in milliequivalents per 100g of soil (Black 1965).
Data analysis

Species diversity of the vegetation and wildlife was estimated using Shannon Weiner diversity index:

\[ H' = -\sum Pi \cdot \log Pi \]

\[ Pi = \frac{n_i}{N} \]

Where:
- \( n_i \) is number of individuals of species \( i \)
- \( N \) is total number of species

The data were analyzed using SPSS version 20 and Microsoft Excel spreadsheet statistical packages. For the woody species diversity, T-test was used to examine whether there was a difference between the burnt sites and unburnt sites. Univariate Analysis of Variance (ANOVA) was used to determine whether there were differences in the DBHs, heights, and canopies between the burnt and unburnt sites. ANOVA was also used to determine whether there were differences in DBHs, heights, and canopies among the five burnt sites.

For the herbaceous vegetation, T-test was applied to determine whether there was a difference in species diversity between the burnt and unburnt sites. Percentage cover of the herbaceous vegetation was first transformed utilizing arcsin transformation before it was analyzed. ANOVA was used to determine the differences in cover, number of individual plants and heights between the burnt sites and unburnt sites and among the five burnt sites. The possible sources of variances where there were more than two groups were determined using the Post Hoc method. The average of individuals was separated by the LSD method.

A t-test was also used to determine whether there was a difference in wildlife species diversity. For the soil properties, ANOVA was used to determine if there was any difference between the burnt and unburnt sites. ANOVA was also used to assess differences among the three depth levels. It was also used to determine differences in the soil properties among the five burnt sites.

RESULTS AND DISCUSSION

Woody species diversity

The data demonstrate that fires did not affect the species diversity of the woody plants as the calculated species diversity index did not show any significant difference between the species diversity in the burnt sites and the unburnt sites (Table 2). The mean species diversity of all burnt places was 2.045 ± 0.102, and that of all unburnt sites was 2.040 ± 0.102.

Woody species community structure analysis

A total of 7 different species belonging to 7 different families were counted. The woody species found in all the sites are shown in Table 3.

DBH

The mean DBH of all the woody species at the burnt sites were less than those at the unburnt sites. The mean DBH of the burnt sites increased with the years after burning with the one of 2014 being the smallest at 0.34±0.1m and that of 2009 is the highest at 0.60±0.2m. Although time had caused recovery of the woody species in burnt sites, there was no burnt site whose DBH had recovered to be equal or more than that of the unburnt site. The DBH of all species is shown in Figure 3.

There was a significant difference in the DBH of all species between all burnt sites and all unburnt sites with the species in the unburnt locations having a higher mean DBH of 0.63 ± 0.026m and those in the burnt locations having a mean DBH of 0.49 ± 0.026m. There was also a significant difference in the DBH between all the five burnt sites with the maximum mean difference being between 2002 and 2014 and the minimum mean difference being between 2002 and 2009.

Height

The heights of the woody species were smaller in the burnt sites than those in the unburnt sites. The average height of the burnt sites increased with the years after burning with the one of 2014 being the shortest at 21±5.2m and that of 2002 is the tallest at 24±5.1m. There is no burnt site whose the height had recovered to be equal or more than that of the unburnt site. Figure 4 listed all the heights of all woody species. There was no significant difference in the heights among all burnt sites and all unburnt sites and between all the burnt sites at different years.

Canopy

The mean canopies of all the burnt sites were smaller than the unburnt sites. The mean canopies of the burnt sites increased with the years after burning with the one of 2014 being the lowest at 1.5±0.4m and that of 2002 is the highest at 4.7±1.0m. There is no burnt site whose the canopy had recovered to be equal or more than that of the unburnt site. The values of the canopy of all species are shown in Figure 5.

Table 2. The species diversity (H') of the woody vegetation in burnt and unburnt sites

| Year | Burnt (h’) | Unburnt (h’) |
|------|------------|--------------|
| 2002 | 1.786 | 1.778 |
| 2009 | 2.341 | 2.362 |
| 2012 | 1.894 | 1.848 |
| 2013 | 2.018 | 2.114 |
| 2014 | 2.185 | 2.098 |

Table 3. The woody species found in all the sites and the families they belong

| Family       | Species                  | Burnt sites | Unburnt sites |
|--------------|--------------------------|-------------|---------------|
| Bignoniaceae | Markhamia lutea          | 101         | 94            |
| Canellaceae  | Warbugia ugandensis      | 113         | 95            |
| Cupressaceae | Juniperus procera        | 62          | 85            |
| Lauraceae    | Ocotea usambarensis      | 95          | 86            |
| Oleaceae     | Olea africana            | 105         | 97            |
| Podocarpaceae| Podocarpus falcatus      | 91          | 100           |
| Stilbaceae   | Nuxia congesta           | 36          | 39            |
There was a significant difference in the canopy between all burnt sites and unburnt sites ($F_1, 64 = 12.467; P<0.05$). There was also a substantial difference in the canopy between all the five burnt sites ($F_4, 28 = 17.418; P<0.05$) with the maximum mean difference being between 2002 and 2014 of $3.157 \pm 0.44m$ and the minimum mean difference being at 2002 and 2009 of $0.371 \pm 0.44m$.

**Herbaceous species diversity**

Fire markedly reduced species diversity of the herbaceous plants immediately after it occurred. However, the species diversity quickly recovered within one year and got higher than the unburnt sites as plants regenerated after the fires. The place that had been burnt less than a year ago, i.e., in 2014, is the only one that had lesser species diversity than the unburnt site. Within a year, the herbaceous vegetation had already recovered and was more in the places that had been burnt. The species diversity of the herbaceous plant of all sites is shown in Table 4.

**Herbaceous species structural analysis**

In all the burnt sites, a total of 39 species were counted while in all unburnt places, a total of 22 species were counted. Only seventeen species were found in the burnt sites. All the species found in the unburnt places were also found in the burnt locations. Table 5 is a list of the herbaceous plant species that were found in the burnt sites and not found in the unburnt locations.

| Year | Burnt ($H'$) | Unburnt ($H'$) |
|------|--------------|----------------|
| 2002 | 2.441        | 1.682          |
| 2009 | 2.469        | 1.716          |
| 2012 | 2.369        | 1.837          |
| 2013 | 2.298        | 1.603          |
| 2014 | 0.950        | 1.737          |

**Table 5.** The herbaceous species found in the burnt locations and not found in the unburnt locations and the families they belong.
Cover

The site burnt on 2104 was the only one that had a lower mean percentage cover compared to its unburnt places. All the other burnt places had more percentage cover than their unburnt sites as the herbaceous vegetation in those burnt sites had already regenerated and exceeded the unburnt sites. It took only one year for the herbaceous vegetation to restore its cover increase. The percentage cover of all the species found in every place is shown in Figure 6.

After Arcsin transformation of the percentage cover, there was a significant difference between the percentage cover of the burnt sites and the unburnt sites with the burnt sites having a higher mean cover 8.39±0.94% than the unburnt sites which had a mean cover of 5.47±0.84%.

There was also a significant difference in the cover between all the burnt sites in the different years (F₄, 7₃=8.309; P<0.05). The most considerable mean difference was between the year 2014 and 2002 which was 20.23 ± 4.09%, and the smallest mean difference was between the year 2009 and 2002 which was 1.42 ± 2.13%.

Number of individual plants

The location burnt in 2014 was the only one showing a lower number of herbaceous plants compared to the unburnt places (Figure 7). All the other burnt places had a higher number of herbaceous plants than the unburnt sites as fire led to regeneration in a year's time leading to a higher number of individuals in the burnt places.

There was a significant difference between the number of individuals in the burnt sites and the unburnt sites with the burnt sites having a higher mean number of 58.42±8.37 plants than the unburnt places which had a mean number of 35.83±7.53 plants.

There was also a significant difference in the number of individuals between all the burnt sites in the different years (F₄, 7₃=3.101; P<0.05). The maximum mean difference was between the year 2014 and 2002 which was 58.23 ± 20.97 plants and the minimum mean difference was between the year 2009 and 2002 which was 16.48 ± 18.34 plants.

Height

The site burnt in 2014 was solely the one that had a smaller mean height of herbaceous plants compared to the unburnt sites. All the other burnt sites had a bigger mean height of herbaceous plants than the unburnt sites. The height of every species is displayed in Figure 8.

There was a significant difference between the height of the herbaceous plants with the burnt sites having a higher mean height of 81.56±5.05cm than the unburnt sites which had an average height of 61.85±4.47cm.

There was also a significant difference in the height of the plants between all the burnt sites in the different years. The maximum mean difference was between the year 2014 and 2002 which was 41.34 ± 14.9cm, and the minimum mean difference was between the year 2009 and 2002 which was 10.74 ± 13.04 cm.

Animals

Nine different species from 5 families were counted in all the sites (Figure 9). There were no animals that were scored in the place that was burnt in 2014. Only the sites that had been burnt in 2014 and 2013 had fewer animals than their corresponding unburnt locations. All the other burnt places had more animals compared to their similar unburnt sites. The site that was burnt in 2012 had the highest number of animals which was 132. Amongst the unburnt sites, 2014 had the highest number 86. There were no animals that were counted in the site that was burnt in 2014. Only the sites that had been burnt in 2014 and 2013 had fewer animals than their corresponding unburnt sites. All the other burnt sites had more animals compared to their corresponding unburnt sites. The site that was burnt in 2012 had the highest number of animals which was 132. Amongst the unburnt sites, 2014 had the highest number 86.
Animals species diversity

Table 6 shows no animal was observed on the site that had recently been burnt (less than two weeks after the fire-2014). In the place that had been burnt one year ago, the species diversity of the animals was less than the unburnt site. In all the other areas that had been burnt more than one year ago, the species diversity of the animals was more than in their corresponding unburnt sites.

Birds

Thirty four species belonging to 13 different families were counted in all sites. All the unburnt sites had a higher number of birds than the unburnt sites (Figure 10).

The species diversity of the birds is shown in Table 7. In all sites, the diversity was higher which had been burnt more than a year ago than in the unburnt sites. Only the sites that had been burnt less than a year ago had less species diversity than the unburnt sites because there was more vegetation in the burnt sites that provided habitat and food for the birds.

Soil properties

pH

The mean pH values of soils from both the burnt sites and unburnt sites at the three levels of depth are displayed in Figure 11. The soils were acidic as their pH ranged from 3.4 in 2014 unburnt site to 6.5 in the site which was burnt. At 0-15 cm depth, the mean pH of the burnt sites was higher in the sites burnt in 2014, 2013, 2012 and 2009. The locations that were burnt in 2002 was the only that had a lower pH compared to the unburnt site. The mean pH at 0-15 cm of the burnt and unburnt sites was 5.28±0.68 and 4.26±0.57 respectively. There was a significant difference in pH of the soil at the 0-15 cm depth between burnt sites and unburnt sites (t 0.05 (1), 14=3.619; P˂0.05).

At 15-30cm, the mean pH of all the burnt sites was higher than the unburnt sites. The mean pH of the burnt sites at this depth was 4.99±0.28, and that of the unburnt sites was 4.68±0.27. The pH at a depth of 15-30cm had a significant difference between the burnt sites and unburnt sites (t 0.05 (1), 14=3.961; P˂0.05).

At 30-45cm, the mean pH of the burnt sites was higher than unburnt sites apart from the sites burnt in 2002 and 2009. The mean pH of the burnt sites was 4.85±0.27 while that of the unburnt sites was 4.82±0.32. The pH at a depth of 30-45cm did not have a significant difference between the burnt and the unburnt sites (t 0.05 (1), 14=0.349; P>0.05).

Table 6. The species diversity (H') of animals in burnt and unburnt sites

| Year  | Burnt (H') | Unburnt (H') |
|-------|------------|--------------|
| 2002  | 1.6771     | 1.5924       |
| 2009  | 1.6315     | 1.5997       |
| 2012  | 1.9407     | 1.7144       |
| 2013  | 1.2613     | 1.7926       |
| 2014  | 0          | 1.8623       |

Table 7. The species diversity (H') of birds observed burnt and unburnt sites

| Site  | Burnt (H') | Unburnt (H') |
|-------|------------|--------------|
| 2002  | 2.7352     | 2.6989       |
| 2009  | 2.8815     | 2.8291       |
| 2012  | 2.7871     | 2.6314       |
| 2013  | 2.1923     | 2.2248       |
| 2014  | 2.2036     | 2.6927       |

Figure 9. The total number of animals found in all the burnt and unburnt sites

Figure 10. The total count of birds in all burnt and unburnt sites.
Nitrogen

Data for percent nitrogen is shown in Figure 12. The data indicate that at 0-15 cm deep, the amount of nitrogen in the soils from the burnt sites was lower than in soils from unburnt sites in the sites burnt in 2014, 2013 and 2012. However, on the sites that were burnt in 2009 and 2002, the soils had slightly higher nitrogen content compared to the unburnt site. The mean nitrogen at 0-15 cm of the burnt sites was 0.68±0.19%, and that of the unburnt sites was 1.10±0.66%. There was a significant difference in soil nitrogen at the 0-15cm depth between burnt sites and unburnt sites (F1, 34=5.353; P˂0.05).

At 15-30cm, the mean nitrogen of all the burnt sites was lower than the unburnt sites apart from the site burnt in 2014 where the mean nitrogen was higher in the burnt site than in the unburnt site. The mean nitrogen of the burnt sites at this depth was 0.58±0.21%, and that of the unburnt sites was 0.70±0.17%. At this depth, nitrogen amount was comparable between burnt and unburnt sites.

At 30-45cm, the mean nitrogen of the burnt sites was lower than unburnt sites apart from the sites burnt in 2014. The mean nitrogen of the burnt sites was 0.45±0.26% while that of the unburnt sites was 0.67±0.26%. The nitrogen at a depth of 30-45cm had a significant difference between the burnt and the unburnt sites (F1, 34=29.55; P˂0.05).

Univariate tests of nitrogen between depths showed that there was a significant difference between the three levels of depths (F2, 51=7.819; P˂0.05). After post hoc tests, the main difference was between 0-15cm and 30-45cm as well as between 0-15cm and 15-30cm. On the other hand, there was no significant difference between 15-30cm and 30-45cm depth.

There was a significant difference in the nitrogen level between the sites burnt at different years, with the maximum mean difference observed between 2002 and 2014, and the minimum mean difference was between 2002 and 2012.

Organic carbon

The mean organic carbon values in the soils from all the sites are shown in Figure 13. The data indicate that at 0-15 cm deep, the mean organic carbon of the burnt sites was higher in the sites burnt in 2014, 2013 and 2012 than in their unburnt sites. The sites that were burnt in both 2009 and 2002 had a lower mean organic carbon compared to the unburnt site. The mean organic carbon at 0-15 cm of the burnt sites was 7.05±0.93, and that of the unburnt sites was 6.07±1.26. At a depth of 0-15cm, there was a significant difference between the amount of organic carbon in the burnt sites and unburnt sites (F1, 34=29.55; P˂0.05).

At 15-30cm, the mean organic carbon of the sites burnt in 2014, 2013 and 2012 was higher than the unburnt sites. The sites burnt in 2009 and 2002 had a lower mean organic carbon than in the unburnt sites. The mean organic carbon of the burnt sites at this depth was 6.07±1.26, and that of the unburnt sites was 5.60±1.52. At this depth, the amount of organic carbon between the burnt sites and the unburnt sites was relatively the same.

At 30-45cm, the mean organic carbon of the sites burnt in 2014 and 2012 was higher than the unburnt sites. The sites burnt in 2009, 2002 and 2013 had a lower mean organic carbon than in the unburnt sites. The mean organic carbon of the burnt sites was 5.19±1.94% while that of the unburnt sites was 5.27±1.31%. The organic carbon at a depth of 30-45cm had no significant difference in the amount of organic carbon between the burnt sites and the unburnt sites (F1, 34=0.141; P=0.05).

Univariate tests of organic carbon between depths showed that there was a significant difference between the three levels of depths (F2, 51=6.374; P˂0.05). After post hoc tests, the main difference was between 0-15cm and 30-45cm as well as between 0-15cm and 15-30cm. On the other hand, there was no significant difference between 15-30cm and 30-45cm depth.

There was a significant difference in the organic carbon between the sites burnt at different years. The maximum mean difference was between 2002 and 2014 which was 1.76±0.69%, and the least mean difference was between 2002 and 2013 which was 0.54±0.69%.
Potassium

The average values of the potassium in the soils from all the sites are shown in Figure 14. The data demonstrate that at 0-15 cm deep, the mean potassium was higher in all the burnt sites than in their unburnt sites apart from the site burnt in 2009. The mean potassium at 0-15 cm of the burnt sites was 2.68±1.78 and that of the unburnt sites was 1.14±0.61.

At 15-30 cm, the mean potassium of all the burnt sites was higher than the unburnt sites. The mean potassium of the burnt sites at this depth was 1.58±0.98 Cmol/kg, and that of the unburnt sites was 1.21±0.81 Cmol/kg. At 15-30 cm, there was no significant difference in the amount of potassium between the burnt sites and the unburnt sites (F, $1, 34=0.766; P>0.05$).

At 30-45 cm, the mean potassium of the sites burnt in 2014, 2012 and 2002 was higher than the unburnt sites. The sites burnt in 2013 and 2009 had lower mean potassium than that of unburnt sites. The mean potassium of the burnt sites was 1.31±0.97 Cmol/kg while that of the unburnt sites was 1.03±0.61 Cmol/kg. At 30-45 cm depth, there was also no significant difference in the amount of potassium between the burnt sites and the unburnt sites (F, $1, 34=1.659; P>0.05$).

Univariate tests of potassium between depths showed that there was a significant difference between the three levels of depths (F, $2, 51=5.951; P<0.05$). After post hoc tests, the main difference was between 0-15 cm and 30-45 cm where the mean difference was 1.32 Cmol/kg and P<0.05. Between 0-15 cm and 15-30 cm, there was also a significant difference. However, between 15-30 cm and 30-45 cm, there was no significant difference.

There was a significant difference in the potassium between the sites burnt at different years. The maximum mean difference was between 2002 and 2014 which was 2.71±0.43 Cmol/kg, and the minimum mean difference was between 2002 and 2009 which was 0.46±0.43 Cmol/kg.

Phosphorous

The mean phosphorous values in the soils from all the sites are shown in Figure 15. The data shows that at 0-15 cm depth, the mean phosphorous was lower in all the burnt sites than in their unburnt sites apart from the site burnt in 2009. The mean phosphorous at 0-15 cm of the burnt sites was 8.26±2.49 ppm and that of the unburnt sites was 13.32±3.83 ppm. The amount of phosphorous was significantly different between the burnt sites and unburnt sites at this depth.

At 15-30 cm, the mean phosphorous was lower in all the burnt sites than in their unburnt sites apart from the site burnt in 2009. The mean phosphorous at 15-30 cm of the burnt sites was 7.59±3.86 and that of the unburnt sites was 10.11±2.89 ppm. There was no significant difference in the amount of phosphorous between the burnt sites and the unburnt sites (F, $1, 34=3.55; P>0.05$).

At 30-45 cm, the mean phosphorous of the sites burnt in 2014, 2012 and 2002 was lower than the unburnt sites. The areas burnt in 2013 and 2009 had higher mean phosphorous than in the unburnt sites. The mean phosphorous of the burnt sites was 8.49±3.46 ppm while that of the unburnt sites was 9.01±1.72 ppm.

Univariate tests of phosphorous between depths showed that there was no significant difference between the three levels of depths. There was a significant difference in the phosphorous between the sites burnt at different years. The maximum mean difference was between 2002 and 2014 which was 5.93±0.73 ppm, and the minimum mean difference was between 2002 and 2009 which was 0.14±0.73 ppm.

Cation Exchange Capacity (CEC)

The mean CEC values in the soils from all the sites are shown in Figure 16. The data shows that at 0-15 cm deep, the mean CEC was higher in all the burnt sites than in their unburnt sites apart from the site burnt in 2002.

At 15-30 cm, the mean CEC was higher in all the burnt sites than in their unburnt sites apart from the site burnt in 2002. The mean CEC at 15-30 cm of the burnt sites was 20.16±2.78 mol/kg, and that of the unburnt sites was 18.34±3.41 mol/kg. The CEC at a depth of 15-30 cm did not have a significant difference between the burnt sites and unburnt sites (F, $1, 34=1.523; P>0.05$).

Figure 14. The potassium of soils from all the burnt and unburnt sites at different depths

Figure 15. The phosphorous of soils observed in all the burnt and unburnt sites at different depths
The effect of fire on plant species diversity

Woody vegetation

The results indicated that fires did not contribute to the major adverse effect on the species diversity of the woody species. The reason may be because most fires experienced at Aberdare Ranges are usually ground fires that do not burn down the woody trees but the barks and sometimes small canopies of the woody trees are burnt. As a consequence, there was no difference in the species diversity of the woody species between the burnt sites and the unburnt sites. Tiny woody plants and seedlings are the only ones usually burnt down by the fires occurring at the Aberdares. The large trees found in Aberdares are resilient to ground fires and are not much affected by the fires. The results agreed with the studies that show that the effects of fire on woody vegetation depend on the intensity and frequency of the fire (Lehmann et al. 2014). Intensity could be low at Aberdares such that they do not have much effect on woody species diversity.

However, there was a significant difference in DBH between the woody species in the burnt sites and the unburnt sites with the unburnt sites having a higher DBH than that of the burnt sites. All the five burnt sites had a lower mean DBH than their corresponding unburnt sites meaning that DBH takes long to increase. DBH of a tree is crucial in estimating the amount of timber volume in a tree and also in predicting the age of a tree because diameter increment is the only constant non-reversible feature of tree growth (White 1998). This indicates that the fires at Aberdares led to reduce in the timber volume of the trees and also could lead to a wrong prediction of the age of the trees at Aberdares.

The height and canopies of the trees were also smaller in all the burnt sites. There was no any burnt site that the height and canopy had recovered. This means that the fires at Aberdares had a negative effect on both height and canopy. The negative impact of fire on DBH, height, and canopy of trees affects the carbon storage ability of tree because carbon is allocated preferentially to the new leaves and roots and then to storage and stem diameter growth (Waring and Pitman 1985). This means that the fires at Aberdares contribute to global warming, by releasing carbon dioxide to the atmosphere during the fires and by reducing the carbon storage.

Herbaceous plants

The data showed that fire causes a decrease in the herbaceous plant species diversity, but one year later, burnt sites had regenerated the species diversity of the burnt areas were diverse than the unburnt areas. The fire burnt almost all herbaceous plants, except Micromera imbricata, Oplisnemus compositus, and Erica arborea. Fire tends to favor species that can tolerate heat stress. Immediately after a fire, the percentage of bare ground is increased which made the land prone to erosion depending on its topography and weather.

In all the other sites except the one that was burnt in 2014, the species diversity of the herbaceous plants on the burnt sites was higher than on the unburnt sites, an indication that fire triggered the recovery of herbaceous plants. The statistical analysis showed that vegetation cover and their height differs significantly between the burnt sites and the unburnt sites. In the sites that had been burnt recently, the height of the vegetation was shorter than the height of the vegetation in their corresponding unburnt sites. In the sites where vegetation had already recovered, the height of the vegetation was even more than the unburnt sites. Fires triggered the regrowth of the herbaceous vegetation, and one year later, the vegetation was taller in the burnt areas other than the site burnt in 2014.

Fires also had the same effect on the number of individuals as the cover and height. The sites that had already recovered had a higher number of individuals compared to the unburnt areas. Only the locations that were recently burnt had fewer numbers of individuals. This was an indication that fire has a positive long-term effect on the herbaceous vegetation. It triggers regeneration of pioneer species whose seeds could be lying dormant in the soil or on the soil surface.
Effects of fires on animals

Effects of fires on mammals

The burnt sites that had not yet regenerated possessed fewer animals when compared to the unburnt sites. No animal was found in the site that was burnt in 2014 as the data was collected several days after the fire. They had emigrated out of that area as a consequence of the fire since no vegetation could support the herbivores that support the rest of the food chain. No animals carcass were found at the site meaning that no animal succumbed to the fire.

The site that was burnt in 2013 also had lesser animals compared to the un-burnt site of the same year because the vegetation cover of that burnt site was less than the un-burnt site. Furthermore, animals prefer an area with higher vegetation cover where there are more resources.

Individuals were remaining in the burned forest deal with a different set of problems. Fires brought an immediate negative impact on the wildlife, which in turn can affect the tourism of the country considering that wildlife is one of the major attraction to tourists. Fire leads to the emigration of the wildlife from the burnt areas to the unburnt areas which will lead to the completion of resources in the unburnt areas leading to the exclusion of the weaker wildlife. This ends up in a reduction of the wildlife population.

Effects of fires on birds

All the burnt sites had fewer birds than the unburnt sites. The number of the birds in the other sites burnt in 2013, 2012, 2009 and 2002 had increased although they were still fewer than the unburnt sites. This could be as a result of the reduced canopy of the trees in all the burnt sites considering that vegetation structure and floristic composition influence the availability of food, the risk of predation and availability of nest sites.

Aberdares is an Important Bird Areas where many visitors go for bird watching. Fires can lead to negative impacts on the bird watching as a result of a decline in bird's diversity which can have disadvantages to the country's economy.

Effects of fire on soil properties

The fire affected mostly the upper layer at 0-15cm. Very few effects were observed only at 15-30cm. This probably because most fires that occur at Aberdares are less severe and cannot exert effects beyond 15cm deep as the effects of fires depend on the fire severity which is determined by the intensity and the duration of the fire.

pH

After two years, there was no much difference in pH between burnt sites and unburnt sites. This indicated that fire resulted in an increase in pH and it took almost two years for the pH to return to its initial levels. The increase in pH could be as a result of ash accretion. Certini (2005) suggest that the response depends on the amount of ash and buffering capacity of the soil. This rise in pH is because mineral substances are released as oxides or carbonates that usually have an alkaline reaction.

Nitrogen

The decrease in nitrogen in the recently burnt sites is as a result of nitrogen volatilization caused by fire. Nitrogen has low-temperature thresholds and is easily volatilized. Significant losses of nitrogen during the fires could adversely affect long-term site productivity in Aberdare forest ecosystem, particularly if nitrogen replenishment mechanisms are not provided for during post-fire management. Nitrogen is considered the most limiting nutrient in wildland ecosystems, and as such it requires special consideration when managing fire, particularly in nitrogen-deficient ecosystems (Maars et al. 1983)

Organic carbon

The organic carbon was high in the burnt sites than in the unburnt sites, and this was more evident at 0-15cm where there was a significant difference. This is a result of the rapid decomposition of organic matter on the soil during burning to release organic carbon into the underlying soil (Certini 2005). The results were similar to that of a study by Bird et al. (2000), which was carried out on tropical savanna sites in Africa. Low-frequency burning increased soil carbon of about 10%

The effect of organic carbon by fire is determined by the severity of a fire. Fire severity influences the amount of organic matter that is lost. Groeschl and others (1990) revealed that areas burned by a low-severity fire, the forest floor Oi and Oe layers were completely combusted, but the Oa layer remained. High-severity burning also consumed the Oa layer. Of the 10.1 tons/acre (22.6 Mg/ha) of Carbon present in the forest floor in the unburned areas, no Carbon remained in the high-severity burned areas compared to 9.3 tons/ acre (20.8 Mg/ha) Carbon that was left on the burned areas at low severities.

Potassium

Increase in potassium in the burnt sites could be due to rapid decomposition of organic matter during burning due to elevated temperatures releasing nutrients to the soil. The organic matter acts as the primary reservoir for several nutrients and, thus, is the source of most the potassium (Certini 2005).

Phosphorous

Phosphorous at 0-15cm was significantly lower in the burnt sites than in the unburnt sites. The differences were also observed in the sites that had been burnt less than two years ago but in the sites burnt more than two years ago did not have much difference between the burnt and unburnt sites. Just like nitrogen, phosphorous has low-temperature thresholds and is readily volatilized. This led to the decrease in the amount of phosphorous in the burnt sites.

Cation Exchange Capacity

As much as fire can make water-soluble cations available for plant uptake, light burns like the ones experienced at Aberdares do not affect the exchange system.
Conclusion

Fires occur every year at Aberdares during the dry season mainly due to arsonist when they want to ferry poles from the forest, charcoal burning, accidents during honey harvesting as the harvesters use fire to drive bees away, and clearing of the forest to create farmlands. Fires brought an immediate negative effect on the herbaceous vegetation but later leads to a positive effect after the vegetation regenerates. The sites that were burnt in 2013, 2012, 2009 and 2002 had more herbaceous vegetation and a higher cover than their unburnt sites. The cover, height and the number of plants increase with time with the site burnt in 2002 having the highest and that burnt in 2014 having the lowest. Animals are also affected by the fires. The decrease in vegetation led to a reduction in the wildlife population and diversity. Once vegetation regenerates, wildlife population and diversity tends to increase again. The sites burnt in 2013, 2012, 2009 and 2002 had more wildlife diversity than the unburnt sites since vegetation had regenerated. Loss of vegetation after a fire leads to the emigration of wildlife to the unburnt sites. All the sites burnt had fewer birds than the unburnt sites. This is as a result of the reduced canopy of the trees in the burnt forests. Immediately after a fire, the number of birds utilizing that area reduces drastically as a result of the reduced amount of food and destruction of their nests. Fires also affect the soil properties investigated: nitrogen, potassium, phosphorous, pH, organic carbon, and cation exchange capacity. Fire promotes an increase in pH, potassium, organic carbon and cation exchange capacity due to rapid decomposition of organic matter and leads to a reduction of nitrogen and phosphorous since these two elements are easily volatilized at a low-temperature threshold. Prescribed burning can be adopted by ecosystem managers where controlled fires can be used to burn an ecosystem to increase the herbaceous vegetation, despite the immediate negative effects of fires on species diversity and some soil properties. Burning leads to an increase in herbaceous plants after about one year.

REFERENCES

Ark R. 2011. Environmental, Social and Economic Assessment of the Fencing of the Aberdare Conservation Area. UNEP, Nairobi, Kenya.
Barnes RFW. 1996. Estimating forest elephant abundance by dung counts. In: Kangwana K. (ed.). Studying Elephants. Technical Handbook No 7. African Wildlife Foundation, Nairobi.
Black CA. (ed.). 1965a. Method of Soil Analysis, Part 1. Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling. American Society of Agronomy, Inc, Madison, Wisconsin USA.
Black CA. (ed.). 1965b. Method of Soil Analysis, Part 2. Chemical and Microbiological Properties. American Society of Agronomy, Inc, Madison, Wisconsin, USA.
Botkin DB. 1990. Discordant Harmonies: A New Ecology for the Twenty-First Century. Oxford University Press, Oxford.
Butynski T. 1999. Aberdares National Park and Aberdares Forest Reserves Wildlife Fence Placement Study and Recommendations. Africa Biodiversity Conservation Programme. Zoo Atlanta.
Certi G. 2005. Effects of fire on properties of forest soils: a review. Oecologia 143 (1): 1-10.
Chuvieco E (ed.). 2009. Earth Observation of Wildland Fires in Mediterranean Ecosystems. Springer-Verlag, Berlin.
Costanza R, d’Arge R, de Groot R, et al. 1997. The value of the world’s ecosystem services and natural capital. Nature 387: 253-260.
Gonzalez JR, Palahi M, Pukkala T. 2005. Integrating fire risk considerations in forest management planning in Spain—a landscape level perspective. Landsc Ecol. 20: 957-970.
Grier CC. 1975. Wildfire effects on nutrient distribution and leaching in a coniferous ecosystem. Canadian J For Res 5 (4): 599-607.
Groschel DA, Johnson JE, Smith DW. 1990. Forest soil characteristics following wildfire in the Shenandoah National Park. Virginia. In: Nodvin SC, Waldrop TA (ed.). Fire and Environment: Ecological and Cultural Perspectives; Proceedings of an International Symposium. USDA For. Ser. Gen. Tech. Rep. SE-69.
Kevin M. 2007. Quantitative Analysis by the Point-Centered Quarter Method. Department of Mathematics and Computer Science Hobart and William Smith Colleges, New York.
Kozlowski TT. 2002. Physiological ecology of natural regeneration of harvested and disturbed forest stands: implications for forest management. For Ecol Manag 158 (1): 195-221.
Lehmann CE, Anderson TM, Sankaran M, et al. 2014. Savanna vegetation-fire-climate relationships differ among continents. Science 343: 546-552.
Lesica P. 1996. Using fire history models to estimate proportions of old growth forest in northwest Montana, USA. Biol Conserv 77: 33-39.
Long DG, Morgan P, Hardy CC, Swetnam TW, Rollins MG. 2001. Mapping fire regimes across time and space: understanding coarse and fine-scale fire patterns. Int J Wildland Fire 10 (4): 329-342.
Maars RH, Roberts RD, Skjeftein RA, Bradshaw AD. 1983. Nitrogen in the development of ecosystems. In: Lee JA, McNeill S, Rorison IH (eds.). Nitrogen as an Ecological Factor. Blackwell, Oxford, England.
Mehlich A. 1984. Mehlich-3 soil test extractant: a modification of Mehlich-2 extractant. Commun Soil Sci Plant Anal 15 (12): 1409-1416.
Morgan P, Aplet GH, Hauffer JB, Humphries HC, Moore MM, Wilson WD. 1994. Historical range of variability: a useful tool for evaluating ecosystem change. J Sustain For 2 (1-2); 87-111.
Ng’anga EM, Kamande LM. 1990. The Vegetation of the Aberdares Mountain Ranges. Department of Resource Surveys and Remote Sensing, Ministry of Planning and National Development. Nairobi, Kenya.
Peech M. 1965. Hydrogen-ion activity. Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. American Society of Agronomy, Inc, Madison, Wisconsin, USA.
Sturtevant BR, Scheller RM, Miranda BR, Shinneman D, Syphard A. 2009. Simulating dynamic and mixed-severity fire regimes: a process-based fire extension for Landis-H. Ecol Mod 220 (23): 3380-3393.
Sutherland WJ. 1996. From Individual Behaviour to Population Ecology. Vol. 11. Oxford University Press, Oxford.
Swetnam TW, Allen CD, Betancourt JL. 1999. Applied historical ecology: using the past to manage for the future. Ecol Appl 9: 1189-1206.
Wade DD. 1993. Thinning young loblolly pine stands with fire. Int J Wildland Fire 3 (3): 169-178.
Warthaka JM. 1994. Monitoring human-elephant conflict through remotely located stations. Pachyderm 27: 66-68.
Waring RH, Pitman GB. 1985. Modifying lodgepole pine stands to change susceptibility to mountain pine beetle attack. Ecology 66: 889-897.
White J. 1998. Estimating the age of large and veteran trees in Britain. Forestry Commission Information Note 12. Surrey, UK.


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**Book**

- Rai MK, Carpinella C. 2006. Naturally Occurring Bioactive Compounds. Elsevier, Amsterdam.

**Chapter in book**

- Webb CO, Cannon CH, Davies SJ. 2008. Ecological organization, biogeography, and the phylogenetic structure of plant communities. In: Ecology of terrestrial communities (eds) C. Schnitzer S (eds) Tropical Forest Community Ecology. Wiley-Blackwell, New York.

**Abstract**

- Assaeed AM. 2007. Seed production and dispersal of Rhazya stricta. 5th Annual Conference of the International Association for Vegetation Science, Swansea, UK; 23-27 July 2007.

**Proceeding**

- Assaeed AM. 2008. Biodiversity for development of local autonomous government. In: Setyawan AD, Saturno (eds.) Toward Mount Lawu National Park; Proceedings of National Seminary and Workshop on Biodiversity Conservation to Protect and Save Forestry Environment in Java Island. Universitas Sebelas Maret, Surakarta, 17-20 July 2000. [Indonesian]

**Thesis**

- Sugiyarto. 2004. Soil Macro-invertebrates Diversity and Inter-Cropping Plants Productivity in Agroforestry System based on Sengon. [Dissertation]. Universitas Brawijaya, Malang. [Indonesian]

**Information from internet**

- Bhattacharya K, Song H, Oraki J, Collins CH, Barnett M, Arnold FH, Quake SR, You L 2008. A synthetic Escherichia coli predator-prey ecosystem. Mol Syst Biol 4: 187. www.molecularsystemsbiology.com. DOI:10.1038/msb.2008.24
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