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Environmental factors influencing structure and distribution of east African green heart (*Warburgia ugandensis* Sprague) in Mt. Kenya Forest

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Effects from past climate, natural disturbances and human activities are significantly impacting negatively on current day processes in tropical indigenous trees forests. Most of the indigenous trees mostly hard woods have been logged by human activities. *Warburgia ugandensis* is a tree that is highly valued for its medicinal properties, timber, poles and fuel wood. Consequently, its population and distribution has been on the decline due to environmental and anthropogenic impacts. There is no documentation on how environmental factors affect distribution and population structure of *W. ugandensis* in Mt. Kenya forest and without which conservation strategies may be impossible. This study purposes to determine the present distribution and population structure of *W. ugandensis* in Mt. Kenya forests. Study area was stratified into four blocks based on potential natural vegetation: moist montane, moist intermediate, dry montane and dry intermediate natural vegetation types. Dry montane was the only vegetation type with *W. ugandensis* and therefore four forest blocks were selected for this study: Kangaita, Kahurura, Ontulili and Gathioro forests. Belt transects measuring 25 m wide and 500 m long were marked and subdivided into 20 sub-plots of 25 by 25 m from which four sub-plots were systematically selected for sampling. Rainfall data for all the sampled blocks were obtained from meteorological records while altitude data was obtained by use of geographical positioning system (GPS). Data was analyzed by SPSS 11.0 (2001) statistical software. There was a significant negative correlation between rainfall and the population structure of *W. ugandensis*. The species was concentrated in the drier parts of dry montane forests while none existed in the other three potential natural vegetation types.

Key word: Distribution, population, structure, *Warburgia ugandensis*, diameter at breast height, canopy, height.

INTRODUCTION

Forests play a vital role in water catchment, improve soil fertility, regulate local climate and are vital carbon sinks and reservoirs. Assessing the distribution and structure of a particular forest plant species forms an important part

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of forest conservation. Climate change effects on forests include changes in the geographic range of certain tree species. According to Intergovernmental Panel on Climate Change (IPCC) 2007, there are significant transitions associated with shifts in forest locations and composition due to climate change.

Warburgia ugandensis is an indigenous tree species whose distribution as studied by Trapnell et al. (1966) indicated its presence in Eastern and South Eastern parts of Mt. Kenya forest. Issues of climate change and human exploitation of forest through logging, clearing for cultivation and forest farming through shamba system and PELIS contributed to a general decline of some specific indigenous tree species. The species has been rated 2nd among the highly threatened species after *Prunus africana*. Although a lot of information has been documented on deforestation of natural forests, information on the distribution and population structure of individual tree species and effects of environmental factors is lacking. Without such information, it would be difficult to apply appropriate conservation strategies to protect such species from disappearing. This study therefore investigated the current status of some of the most valuable species for the purpose of conservation. The results from this research are necessary in introducing the species into cultivated landscapes using PNVT as a criterion for ecological suitability (Mueller-Dombois and Ellenberg, 1974).

MATERIALS AND METHODS

This study was conducted in several forests around Mount (Mt.) Kenya (Figure 1) forests. The mountain is 5,199 m above sea level and lies on latitude 0° 9' 00'' S and longitude 37° 18' 00" E. The lower limit of the forest is between 2,000 and 2,500 m above sea level (Young, 1991). These altitudes are believed to affect the temperature and amounts of rainfall received in a given locality. There are differences in the vegetations on different aspects of the mountain (Figure 1). On the northern slopes, the dominant species is the East African juniper *Juniperus procera* (EWP, 2007), Podo, *Podocarpus milanjianus*, African Olive *Olea europaea* common in drier forest and at lower elevations. Precipitation commonly comes in two seasons in a year, the long rainsis in March to May and the short rains in October to November. Mount Kenya is underlain by Quaternary (less than 2 million years old) trachytic and basaltic lavas.

In addition, the lavas are covered by different strata of volcanic ashes, pyroclastics and fluvial-lacustrine sediments all of which are of variable ages (Jaetzhold and Schmidt, 1982).

Study area was stratified into four blocks based on potential natural vegetation types (Kindt et al., 2007); moist montane, moist intermediate, dry montane and dry intermediate natural vegetation type. Mapping of roads and foot paths used within Mt. Kenya forests was done by use of Global Positioning System (GPS) together with vegetation and climatic maps (Trapnell et al., 1966). *W. ugandensis* was sampled in dry montane forests in Kangaita, Kahurura, Ontulili and Gathioro. In each forest, base transects were either an established road, foot path or animal track cutting across altitudinal gradient as described by Caratti et al. (2006). Length of base transects varied depending on the terrain. At each sampling site, data was collected at a distance of 50 m from the forest edge into the forest to reduce edge effects from neighbouring farms. Belt transects measuring 25 m wide and 500 m long were marked with the starting points being 50 m from the base transect. Direction of the first belt transect was determined randomly by tossing a coin, where a head represented the left hand side of the base transect and the tail represented the right hand side. The rest of the belts were selected systematically by alternating left and right sides of base transect spaced at altitudinal intervals of 100 m above sea level. The belt transect was subdivided into twenty plots of 25 by 25 m from which four sub-plots were systematically selected for sampling starting from the 2nd sub-plot and then the others after a distance of every 100 m. The entire sub-plot was used in sampling *W. ugandensis* which has more than 5 cm diameter at breast height (Kindt et al., 2007). Rainfall data for all the sampled blocks was obtained from Nanyuki meteorological station, while altitude data was obtained by use of GPS. In each plot, data for number of trees, DBH, height and canopy diameter was collected along altitude and rainfall gradients. In the four sub-plots, all *W. ugandensis* with a height of more than 1.5 m was sampled for diameter at a breast height of 1.3 m. Tree height was determined by use of Suunto clinometer. Data was analyzed for analysis of variance and correlations between different plots, belts and between the dependent and independent variables.

RESULTS

W. ugandensis structure based on diameter at breast height (DBH) in different forests

The sizes of *W. ugandensis* trees varied in different forests in Mount Kenya ecosystem. Kangaita forest had a mean DBH of 0.23 m and was therefore larger than the same species in other forests studied. However trees found in the high altitude Ontulili forest were slightly smaller (mean DBH of 0.21 m) than those found in Kangaita forest but higher than those of Kahurura (mean DBH 0.14 m) and Gathioro (mean DBH 0.17 m) forests. There was no significant difference in DBH of this species among the four forests ($F_{[3, 214]} = 6.67$, $p = 0.077$).

W. ugandensis height in different forests

Ontulili and Kangaita forest had the tallest *W. ugandensis* trees with mean heights of 12.6 and 12.2 m, respectively. Kahurura and Gathioro forests had shorter trees with mean heights of 7.3 and 6.025 m, respectively (Table 1). There was a significant difference in height of trees of this species among different forests ($F_{[3, 214]} = 9.92$, $p = 0.046$).

Canopy diameters of *W. ugandensis* in different forest reserves

Canopy diameter of *W. ugandensis* averaged between 2.5 to 4.5 m in all the forests. Kangaita recorded the greatest canopy diameter of 4.5 m, Ontulili 3.9 m, Kahurura 3.1 m and Gathioro 2. 5 m (Table 1). The third belt in Kangaita had only two individual trees and

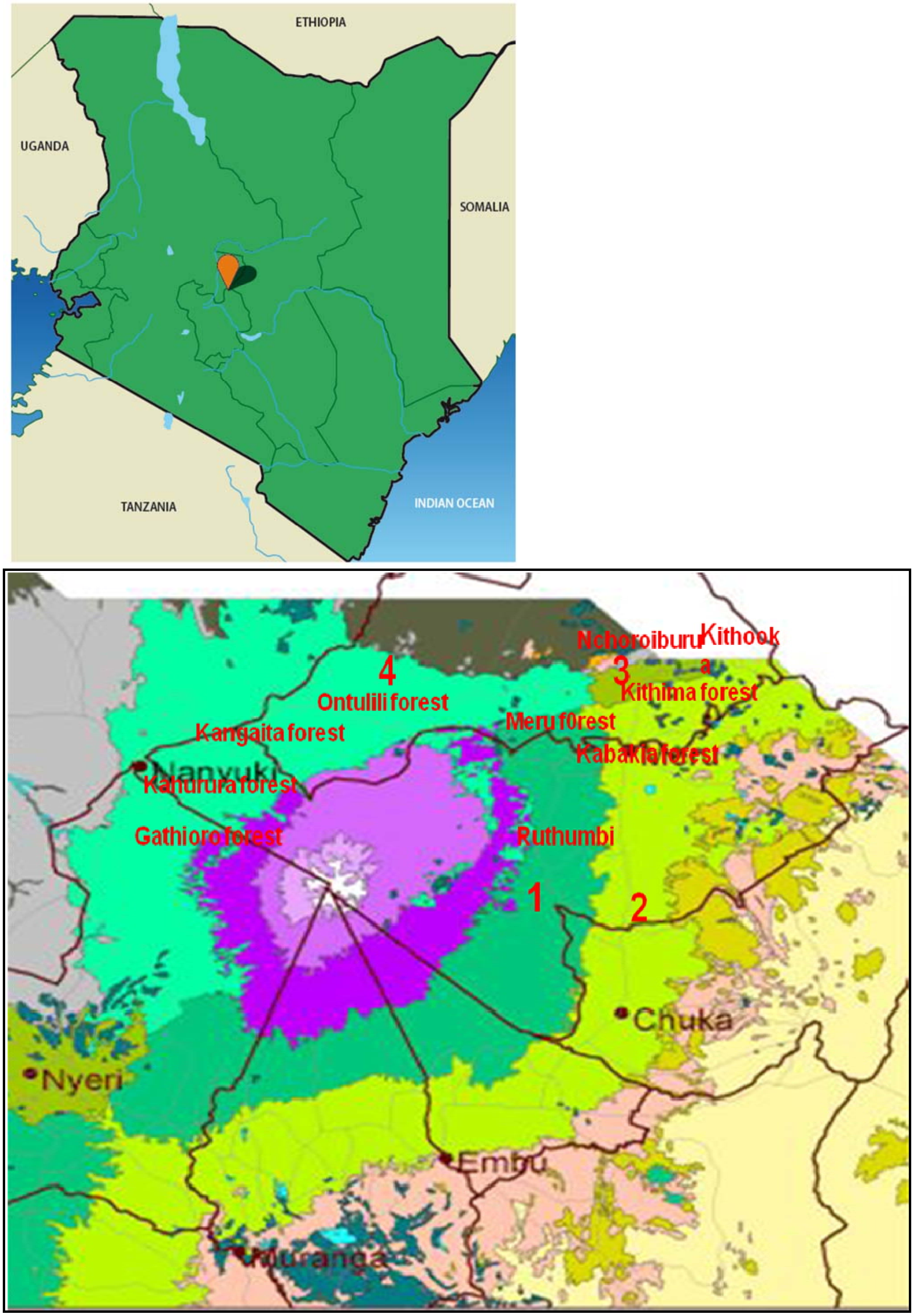

Figure 1. Mt. Kenya potential natural vegetation types adopted from Directorate of Overseas Survey (L.R.) 3006, Kenyan Government 1976. The lines on the map show road network. 1, Moist montane; 2, moist intermediate; 3, dry intermediate; 4, dry montane.

Table 1. Mean DBH, height and canopy diameter in different forests, altitudes and rainfall amounts.

Forest	Altitude (m)	Rainfall (mm)	Height (m)	DBH (m)	Canopy (m)
Kangaita	2080	72.9	12.7	0.26	5.1
	2171	74.6	11.7	0.19	3.8
Kahurura	2058	74.8	9.5	0.18	3.9
	2156	74.5	8.2	0.15	2.9
	2234	77.1	4.3	0.10	2.4
Ontulili	2155	71.3	15	0.26	4.3
	2254	72.8	10.1	0.15	3.5
Gathioro	2117	78.1	6.4	0.08	2.3
	2221	81.5	5.65	0.09	2.6

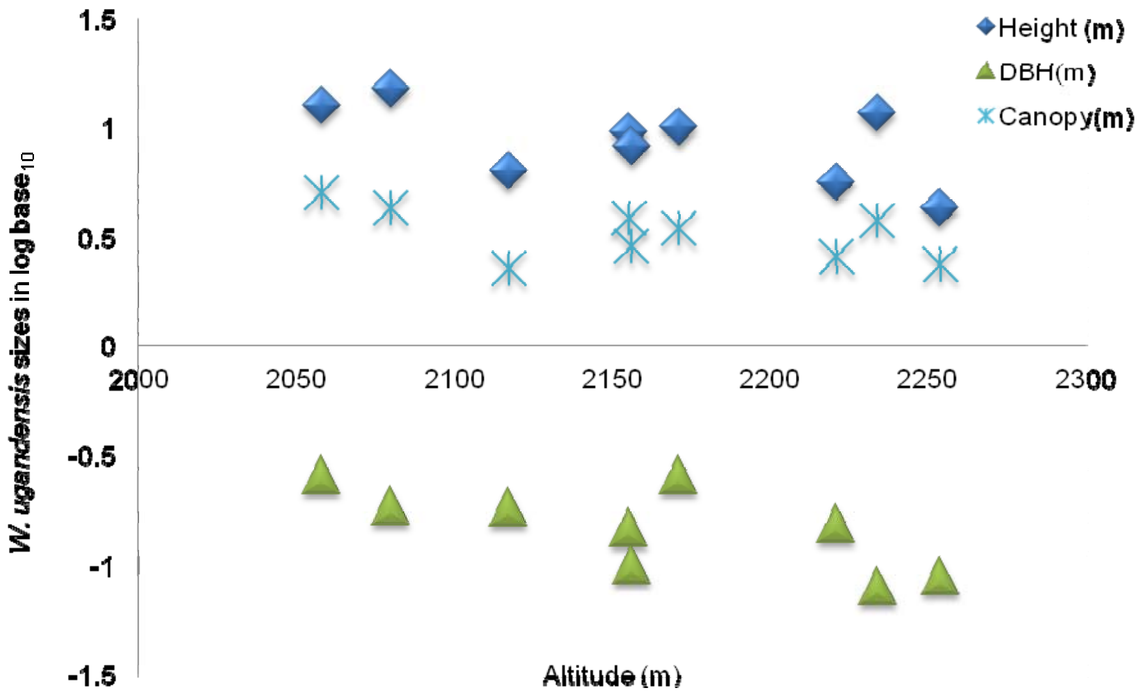

Figure 2. Sizes of *W. ugandensis* in relation to altitude ranging from about 2000-2300m asl.

therefore not included in the analysis since they were not representative of the real situation. Ontulili (2354 m asl) and Gathioro's (2321 m asl) belt three lacked *W. ugandensis*.

There was no significant difference in canopy diameter of this species among different forests ($F_{[3,\ 214]}$ = 5.932, p= 0.089). The canopy diameter appeared to have been influenced by the location of the tree among other associated forest tree species. *W. ugandensis* trees located in open areas tended to have larger canopies than those with tree neighbours of other species.

Trends in *W. ugandensis* sizes found in different altitudes

The findings of this study revealed that DBH of *W. ugandensis* decreased with increasing altitude in all the four forests (Figure 2).

The largest DBH was 0.26 m at 2080 m and 2155 m above sea level (asl) while the lowest was 0.08 m at 2117 m asl. To reduce the variation of height values, DBH and canopy diameter, the values were converted into log base ten. There was no significant correlation (r = -0.447,

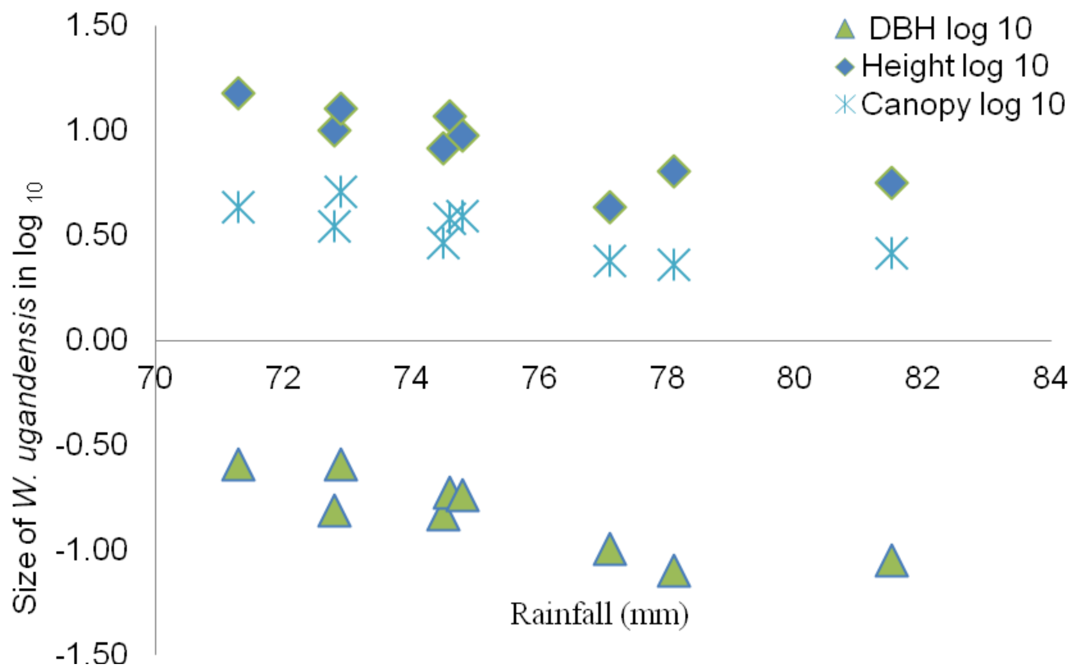

Figure 3. Tree sizes in relation to rainfall.

n=214, p= 0.228) between DBH and altitude.

Mean heights in relation to altitude

The findings of this study revealed that height of *W. ugandensis* decreased with increasing altitude in all the forests (Figure 2 and Table 1). In Kangaita, the mean heights were 12.7 and 11.7 m at altitudes 2,080 m and 2,171 m, respectively. This trend was also reflected in Kahurura where mean heights were 9.5 and 4.3 m at altitudes 2,058 and 2,234 m respectively. Equally for Ontulili the mean heights were 15 and 10.1 m at altitudes 2,155 and 2,254 m and in Gathioro, mean height were 6.4 m at 2,117 m and 5.65 m at 2,221 m asl. There was no significant correlation (r = -0.359, n =214, p=0.343) between height of trees and altitudes.

Canopy diameter in relation to altitude

The highest canopy diameter of 5.1m was recorded at an altitude of 2080 m asl while the lowest was 2.3 m at 2117m asl (Table 1). However, there was no significant correlation (r = -0.49, n=214, p=0.183) between canopy diameter and altitude.

Variation in sizes of *W. ugandensis* found in different rainfall regimes

Mean monthly rainfall ranged from 71 to 81 mm in all forests where *W. ugandensis* occurred (Table 1). DBH of *W. ugandensis* decreased with increasing rainfall in all the forests (Figure 3). Highest DBH was 0.26 m at 71.3 and 72.9 mm of rainfall and the lowest was 0.08 m at rainfall of 78.1 mm. There was a highly significant negative correlation (r = -0.840, n=214, p= 0.005) between rainfall and tree diameter at breast height. Diameter at breast height was higher in trees in lower rainfall range and as the rainfall increased the DBH decreased (Figure 3).

Tree height in relation to rainfall

Height of *W. ugandensis* decreased with increasing rainfall in all the forests (Figure 3). The tallest trees averaging 15 m were found at 71 mm of rainfall while the shortest trees with an average 4.3 m occurred at 77 mm of rainfall. There was a strong negative correlation (r = -0.84, n=214, p=0.005) between rainfall and tree heights. When the mean DBH, height and canopy diameter were converted to log base ten to reduce their variation, a general trend was noted where all sizes decreased with increasing rainfall (Figure 3).

Effect of rainfall on canopy size

The largest canopy diameter was 5.1 m occurring at 72.9 mm of rainfall and the smallest canopy diameter was 2.3 m at 81.5 mm of rainfall per month (Figure 3). Data collected indicated that areas with higher rainfall had smaller canopy diameter than areas with low rainfall (Figure 3). There was significant negative correlation (r = -0.75, n=214, p=0.02) between canopy diameter and rainfall.

DISCUSSION

The objective of this study was to determine the distribution and population structure of *W. ugandensis.* The study found that *W. ugandensis* did not occur in moist montane, dry intermediate and moist intermediate natural vegetation types and all sampled plants were obtained from dry montane forests, particularly in north west of Mount Kenya. This may be attributed to the uniqueness of dry montane's type of annual rainfall which ranges from 650 to 1500 mm in altitude of 1800 to 2500 m above sea level (Kindt et al., 2007).

Climate is the major determinant of distribution of vegetation types and plants species in the world as stated by Woodward (1987). Rainfall has affected the distribution of this species in that the species grows in areas with less rainfall and fail to exist in areas with a lot of it. Moist montane forest is probably too wet while intermediate forests are in lower altitude zones where forests have already been converted into agricultural land. This has affected the distribution of *W. ugandensis* by limiting it only to the forest reserves where its distribution is also limited by altitude up to about 2200 m asl. The variation in distribution of *W. ugandensis* in different forests may be due to variations in rainfall.

W. ugandensis structure has been described in relation to diameter at a breast height of 1.3 m, height of the tree and canopy diameter (Ogden, 1970). There was a trend with the tree DBH decreasing as the altitude increased in Kangaita, Kahurura and Ontulili. This may be attributed to decrease in temperature and water holding capacity of air and decrease in soil nutrients which decline with increase in altitude. This concurs with the work of Kapelle et al. (1995) which showed stem diameter of the different species of trees decreased with increase in altitudinal zonation of Quercus montane forest. Kitayama and Aiba (1994) and Priceton (1997) reported that plant stature declined with increase in altitude but no significant correlation between DBH and altitude. Rainfall, soil water and temperature are important in determining DBH increment (Chidumayo, 2005). In this study, the DBH declined significantly with increase in rainfall. Possible cause of this decline could be attributed to high levels of leaching and erosion of essential nutrients like nitrate and organic compounds from the soil by heavy rainfall. High levels of leaching and water logging reduce soil pH as described by Macintire et al. (1938). Impeded drainage causes water logging which influences plant structure development (Frankham et al. 1996) due to reduced aeration limiting the microbial activities and reducing nutrients availability. These results are consistent with findings of Soethe et al. (2008) who found that plant growth, correlates with nutrients availability.

Mean tree height decreased with increase in altitude and this was possibly caused by low soil nutrients and low temperatures which cause decreased rate of microbial decomposition and nutrients release for plant use. Reduced microbial activity could be linked to the decreasing temperatures as altitude increased. Decrease in tree height with increasing altitude was also reported by Kofidis and Bosabalidis (2008) whose work on *Nepeta nuda* L. and found that height decreased with altitude. Decrease in tree height could be explained by the shortening of tree stems at high elevations as reported by Smith (1980) who found that stem height decreases with increase in altitude in plant species occurring above tree line (ecotone containing upright trees more than 3 m tall). Decrease in plant height may also be associated with decreased solar radiation and sunshine which decreases the photosynthetic rate (Frankham et al., 1996). Shorter plants are able to obtain warmth from the ground for the purpose of photosynthesis.

Tree height decreased with increasing rainfall amount. There was a strong negative correlation between rainfall and tree heights. These findings are supported by Longino (1986), in their study on tropical liana which indicated a negative correlation between rainfall and height of shoot. This may be attributed to waterlogging of the soils which limit availability of nitrogen compounds, enhancing accumulation of phosphorus, loss of organic matter through erosion and low levels of pH (Longino, 1986).

Mean canopy diameter had a negative correlation with altitude. Higher altitudes had trees with smaller canopy diameter. Decrease in canopy diameter with increasing altitude is linked to decrease in nutrients and increase of phosphate compounds which tie up micronutrients like iron, copper and zinc (Busman et al., 2002).

There was strong significant negative correlation between canopy diameter and rainfall. Canopy diameter was also found to correlate with DBH and plant height. According to Chidumayo (2005), if DBH decreases with increase in rainfall, then canopy diameter would also decrease with rainfall increase. However, the possible cause of decline of canopy size with increase in rainfall amount may also be linked to the leaching, waterlogging, unavailability of nutrients and eroding levels of essential nutrients. Moreover, impeded drainage has negative influence on canopy development (Frankham et al., 1996). This may be due to poor root hair development and hence low absorption of essential nutrients, causing reduced growth.

Conclusions

This study shows that *W. ugandensis* exist in dry montane forests and population structure was mainly dependent on the amount of rainfall. However, changes observed in relation to altitude did not correlate with population structure. Changes in rainfall and corresponding changes in temperature, which are also linked to altitude variation, appeared to limit the distribution of *W. ugandensis* in Mt. Kenya forests.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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