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Analysis of phenophases that control *in-situ* establishment of *Ocotea usambarensis* Engl. in the southern slopes of Mt. Kenya Forest

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Abstract

The existence of Ocotea usambarensis in Mt. Kenya Forest is threatened by extensive exploitation of both wood and non-wood products and therefore requires urgent conservation measures to prevent further degradation. Assessing phenological phases and their sequence determine the species establishment. This study therefore investigated the phenology and establishment of O. usambarensis and its association with other plant species in Mt. Kenya Forest. Three plots that were at least 5 km apart measuring 100 m x 100 m within the natural forest with mature O. usambarensis species were purposely sampled on the southern slopes. Point centered quarter (PCQ) method was applied in determining species association. Flowering, fruiting, leaf fall and leaf flush were determined as the main aspects for phenological assessment. Data on environmental factors were monitored through the aid of automatic weather station while phenophases were observed and recorded through classes of intensities. Shannon Wiener diversity index was used to determine species diversity and importance while regression and correlation analysis were used to determine the relationships among environmental factors. There was significant variation (P<0.05) in flowering, litter fall and leaf flush. Mean flowering was 2.67 (42%) while no fruiting was observed during the study period. Monthly variations in humidity, rainfall and radiation were significant (P< 0.05) while for temperature and wind speed were insignificant. It was observed that Diospyros abyssinica was growing in close association with O. usambarensis playing the role of nurse species. With the absence of seedlings in most of the sites and the limiting environmental factors, promotion of vegetative propagation and enrichment planting would enhance conservation and restoration of the species in Mt. Kenya forest

Keywords: *Biodiversity, Conservation, Ocotea, Mt. Kenya and Phenology*.

Introduction

Ocotea usambarensis is (Camphor) a tree species with significant economic, environmental, social and cultural importance. The species is found in tropical forests which harbor between 50% and 90% of Earth's terrestrial plant species International Union for Conservation of Nature and United Nations Environmental Programme (IUCN & UNEP, 1992). *Ocotea usambarensis* was once dominant in the wet forests of the Eastern Aberdares and Mt. Kenya up to an altitude of 2,600 meters above sea level, but is now rare due to over-exploitation, low seed viability, browsing, game damage and poor regeneration (Gachathi, 2007). Germination of seeds is sporadic often taking 2-3 months and the trees mature in 60-75 years (Daniel et al., 2006). According to Bussmann (2001), large scale logging of Camphor trees predominantly destroys its regeneration leading to secondary forest types. The over exploitation, exploration and conversion of forest ecosystems to different land use systems normally result in the decimation of biodiversity and extinction of many valuable indigenous plant species and animals (Akotsi & Gachanja, 2004). The indigenous tree species of economic importance including *O. usambarensis* have low density in tropical forests which indicates their elimination due to the increasing demand for fuel wood, timber and medicinal use (Maina, 2013).

*Ocotea usambarensis*is is among the main targeted timber species for selective logging (Kleinschroth, et al., 2013). This is because of its valuable wood for timber (Gathaara, 1999). Its medicinal value and high quality timber has led to its overexploitation endangering this unique tree species. The extraction situation is compounded by the slow growth rate, low seeds viability, browsing by wild animals, game damage and difficult in seedlings propagation (Albrecht, 1993; Poorter et al., 1996). Other common species of large timber trees exploited in Mt. Kenya forest are; *Juniperus procera* (Cedar), *Olea europeae*(Wild Olive), *Hagenia abyssinica* (East African Rosewood), *Croton macrostachyus* (Croton), *Vitex keniensis* (Meru Oak) and *Ficus thonningii*(Strangler fig) (Mugumo (Beentje, 2008). Githae et al. (2015) reported that several native tree species of environmental and socio-economic value are threatened by human activities and therefore should be conserved. There is a wide range of biological diversity not only in terms of ecosystems but also in terms of plant species in Mt. Kenya ecosystem. According to Bussmann, (2001) 882 plant species, subspecies and varieties belonging to 479 genera and 146 families have been identified in Mt. Kenya forest and out of these 81 plant species are endemic (Gathaara, 1999). The identified main species in the gazetted indigenous forests include; *Calodendrum capense, Catha edulis, Cordia africana, Croton macrostachyus, Croton megalocarpus, Ficus thonningii, Hagenia abyssinica, Juniperus procera, Markhamia lutea, Milicia excelsa, Ocotea usambarensis, Olea capensis, Olea europaea, Olea welwitschii, Premna maxima, Prunus africana* and *Vitex keniensis*.

There are values attributed to Mt. Kenya forest by all the various groups of people living around the forest. The forest provides an important location for religion and other rituals for the people. Many tree species are considered sacred while others are used for both socio economic and environmental services. Its conservation preserves its vitality. Sustainable utilization of *O. usambarensis* can be achieved if adequate information on the regeneration dynamics is available.

The government policy aims at promoting commercial tree growing and on-farm species diversification (GoK, 2014).Tree planting has often focused on exotic species; however exotic species have failed to replace indigenous timber in places where high quality timber is needed for furniture and interior furnishings (Oballa and Musya, 2010). If Kenya is to earn more GDP from forest products, these indigenous species must not only be conserved but be improved and grown side by side with the exotic ones. Communities adjacent to Mt. Kenya forests depends on the forests for timber, fuel wood, grazing areas and non-timber forest products like honey harvesting, medicinal extracts and domestic water. There is ignorance amongst the surrounding communities on ecological aspects including multiple values of forest, the effect of forest over-use on their livelihoods and for those downstream and sustainable conservation strategies. Remnant trees are retained in the farm lands of the local people to improve livelihoods (Kewesa et al., 2015). Degradation of Mt. Kenya forest is mainly due to exploitation of indigenous trees for timber and other uses coupled with lack of local forest inventories (Rutten, et al., 2015). Information on the various aspects of establishment of the most demanded forest species is necessary for their domestication with the aim of easing pressure on their *in- situ* exploitation since *ex- situ* production could be achieved. Adoption and domestication of much sort for forest woody species including *Ocotea usambarensis* would in turn lead to the protection and restoration of natural forest habitats.

Ocotea usambarensis has prospects as a plantation timber tree providing wood of excellent quality. Marura and Lemmens (2008) observed that although the species provides valuable timber and has been over exploited, very little research has been done on its growth rates, phenological and regeneration responses to environmental cues. Kleinsclhroth, et. al (2013) reported that natural regeneration of *O. usambarensis* in Mt. Kenya forest is inadequate for the recovery of the valuable timber species and additional conservation measures should be considered. The farmers have not succeeded in planting the *O. usambarensis* seedlings on their farm due to lack of information on the species ecological requirements and management. The Kenya Forest Service and timber merchants have also not succeeded in establishing the *O. usambarensis* plantations for commercial growing. The specific fertility requirements for the seedlings establishment need to be ascertained for *ex-situ* management. This study was designed to establish the environmental factors that influence phenology, regeneration and establishment of *O. usambarensis* and inform the requirements for its conservation and management.

Materials and Methods

The study involved use of various materials and equipment: Automatic weather station (AWS) was mounted for monitoring the environmental factors, Global Positioning System (GPS) for marking the coordinates of the plots location and Diameter tape for measuring the DBH.

Study Site

The study was carried out in the southern slopes of Mt. Kenya forest. Mt Kenya Forest is located to the east of the Great Rift Valley, along Latitude 0' 10'S and longitude 37' 20'E. It bestrides the equator in the central highland zones of Kenya. The mountain is situated in two Forest Conservancies and five forest management zones namely Nyeri and Kirinyaga in Central Highlands Conservancy and Meru Central, Meru South and Embu in Eastern Conservancy. The climate of Mt. Kenya region is largely determined by altitude. There are great differences in altitude within short distances, which determine a great variation in climate over relatively small distances. Average temperatures decrease by 0.6 C for each 100m increase in altitude. An afro-alpine type of climate, typical of the tropical East African high mountains, characterizes the higher ranges of Mt. Kenya. The altitudes with the highest rainfall are between 2,700 and 3,100m, while above 4,500m most precipitation falls as snow or hail. Frosts are also common above 2500 m a.s.l. The study was on the altitude range of 1400-2400m a.s.l both for on-farm and forest establishment (figure 1).

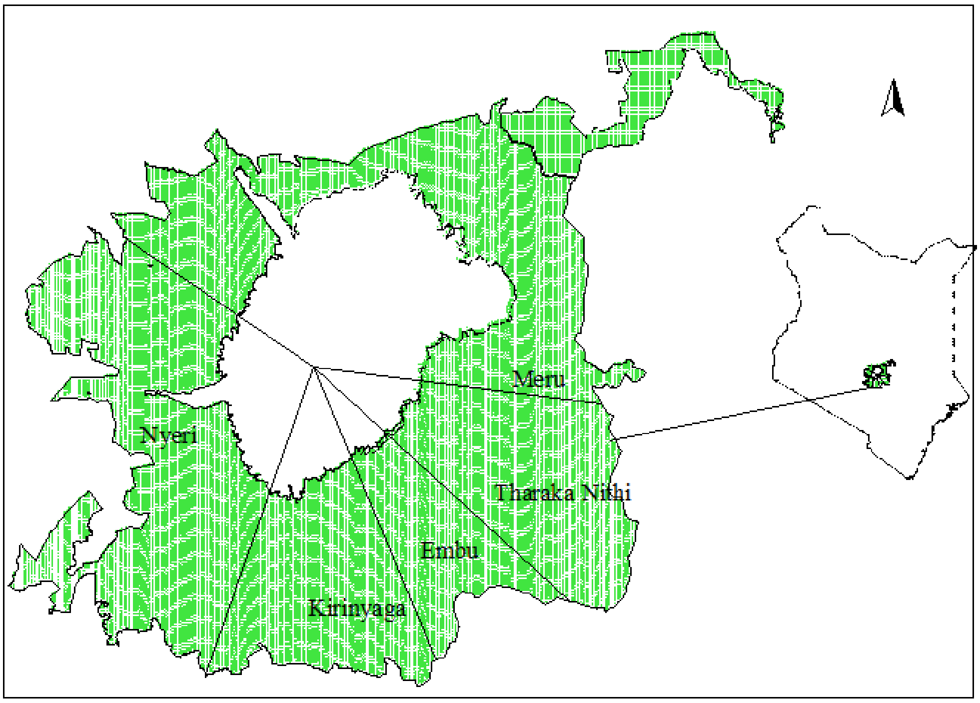

Figure 1: Map of the study area

Climate

Rainfall pattern in the Mt. Kenya ecosystem is bimodal and ranges from 900 mm in the north Leeward side to 2,300 mm on the southeastern slopes Windward side of the mountain (Survey of Kenya, 1966) with maximum rains falling during months of March to May and October to November. The driest months are January, February and September with the windward side experiencing the strongest effects of wind. The diurnal temperature range in January and February rises up to20 °C. The diurnal variation causes warm air to fall down the mountain during the night and early morning and rise up the mountain from mid-morning to evening. As a result, the upper part of the mountain is usually clear in the morning, clouded over from about 11.00 am to 5.00 pm and clear again shortly before dusk (Kenya Forest Service, 2010).

Phenological assessment of *Ocotea usambarensis*

Phenological events of mature *O. usambarensis* were assessed during the study period. Flowering, fruiting, leaf fall and leaf flush were determined as the main aspects for phenological assessment. During the peak flowering and fruiting, observations were done every fortnight. Leaf status, flowering (flower buds and open flowers) and fruiting (unripe and ripe fruits) were recorded using different classes of intensities; 0: (0%), 1: (1-25%), 2: (26-50%), 3: (51-75%) and 4: (>75%), with percentages referring to the proportions of each phenophase in the crown.

Regeneration assessment of *Ocotea usambarensis*

Three plots of 100 m x 100 m containing mature tree species of *O. usambarensis* were marked within the southern region of Mt. Kenya forest using Global Position System (GPS)GPS for phenologicaland biodiversity assessment. The plots were 5 - 10 km apart. Point centered quarter (PCQ) method was applied within the plot for biodiversity determination. The initial sampling points were purposely selected next to a mature *O. usambarensis* tree. Following a perpendicular line to either compass direction, other sampling points were determined at 20 m interval. The diameter at breast height (DBH) was measured for the nearest tree species on either direction of the point. The *Ocotea usambarensis* plants identified in the plots were grouped as; >30cm for mature trees, 10-30 cm for saplings and < 10 cm for seedlings. The status of regeneration was recorded as good if seedlings and saplings >mature trees, fair if seedlings >saplings and poor if mature trees >seedlings. The mature plants were marked for phenophases assessment.

Assessing environmental factors

Environmental factors that influence phenology were monitored in relation to phenological phases. Rainfall, temperature, relative humidity, radiation and wind speed were monitored for 12 months using Automatic Weather Station (AWS).

Data Analysis

Regression analysis was done to determine the relationship between the environmental factors whereas one – way analysis of variance (ANOVA) (Zar, 1996) at P≤0.05 was performed to describe the differences in growth variables. Mean separation was done using the least significance difference (LSD). Time series analysis was used to evaluate the phenophases and the environmental factors. Shannon-Weiner diversity index (Magurran1988) was used to determine species diversity. The Shannon-Weiner index was calculated using the following equation:

Results

The relationship between environmental factors and phenological behavior of *Ocotea usambarensis*

The variation in flowering, litter fall and leaf flush was significant (P<0.05) whereas there was no fruiting. Mean flowering was 2.67 (42%) while fruiting was 0 (0%). *Ocotea usambarensis* flowering was observed in all the mature species, however, the fruiting was rare. Seedlings were observed at the Chogoria site. The mean leaf fall was 1.67 (17%) while the Mean leaf flush was 2.33 (33%) (Table 1).

Table 1: Phenophases of *Ocotea usambarensis*

Species Location	Flowering %	Fruiting %	Leaf fall %	Leaf flush %
Kiang'ondu	3	0	1	2
Kiamuriuki	2	0	2	2
Chogoria	3	0	2	3
LSD (P<0.05)	2.67	0	1.67	2.33

0= 0%, 1= 1-25%, 2= 26-50%, 3= 51-75% and 4= >75%

Flower buds formed in January and opened in February while leaf fall occurred between March and June. Leaf buds formed in July and leaf flush was observed in September and October (Figure 2).

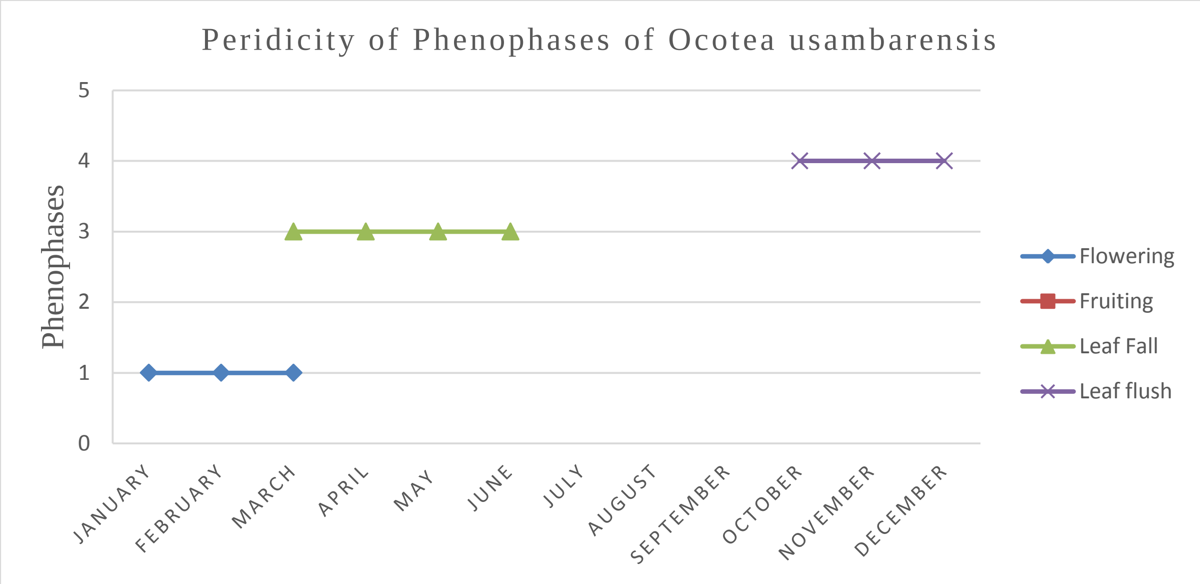

Figure 2: Periodicity of *Ocotea usambarensis* phenophases

Environmental factors that influence phenological behavior of *Ocotea usambarensis*

The environment parameters that influence phenology of a plant were investigated. There was significant (P< 0.05) monthly variation of humidity, rainfall, and radiation. However variations in temperature and wind speed were in significant (P<0.05) during the study period. The mean monthly records indicated the congruence with the phenophases of *O. usambarensis* (Table 2).

Table 2: The monthly mean values of environmental factors

Month	Humidity	Rainfall	Radiation	Temperature	Wind speed
November	64±7.9b	116.01±0.56d	348.58±21.42b	25.68± 0.82	1.32±0.23
December	65±8.3b	18.9±0.95b	315.68±22.46b	24.45±0.91	1.49±0.12
January	74±5.6c	12.3±0.45b	686.68±6.98d	21.98±1.31	1.59±0.08
February	56±10.1a	62±1.02c	408.98±18.13c	24.38±0.88	1.74 ±0.04
March	66±7.5b	131.8±3.45d	130.53±44.68a	23.37±0.63	1.64±0.70
April	59±9.7a	162.8±3.88d	136.62±43.12a	25.28±0.75	1.45±0.11
May	60±9.9a	29.88±1.01b	359.83±20.41b	24.67±0.91	2.05±0.02
June	71±5.3bc	1.04±0.01a	515.1±14.51c	22.59±1.10	1.93±0.03
July	63±8.1b	0a	629.1±8.22d	24.42±0.76	1.68±0.04
August	54±9.8a	0a	631.27±8.31d	24.96±0.86	1.82±0.03
September	68±8.2b	0a	642.30±8.45d	25.81±0.78	1.95±0.02
October	72±5.4c	78.54±2.21c	559.34±12.10c	24.27±0.90	1.88±0.03

Values followed by the same letter are not significantly significant at (P<0.05)

The relationship between the environmental factors

The regression analysis depicted a linear relationship (P <0.001) between the environmental factors (Table 3). The relationship between humidity and other parameters were computed with humidity as the dependent variable. There was a linear relationship (P<0.05) between humidity and temperature (Table 4). However, the relationship (P>0.05) was curvilinear between humidity and precipitation, humidity and Radiation and then humidity and wind speed. A low P-Value suggests that the humidity may be linearly related to other parameters. The high value of R^2= 0.8741 indicated that the precipitation, radiation, temperature and wind speed explains 87.4% of the variations of the humidity values.

Table 3: Regression relation for environmental factors

Source	Sum of Sqs	df	Mean Sq	F	p-value
Regression	1221.3862	4	305.34656	12.706448	<.001
Error	648.83253	27	24.030834		
Total	1870.2188	31			

Table 4: Linear regression and correlation with humidity as the dependent variable

Variable	Coefficient	St. Error	t-value	p (2 tail)
Intercept	218.30673	30.516514	7.1537244	<.001
Precipitation	-.0263778	.0347994	-.7579966	0.483
Radiation	-.0102188	.0109452	-.9336291	0.393
Temperature	-5.932943	1.0420372	-5.6936	0.002
Wind speed	-4.36393	5.2888808	-.8251142	0.447
R-Square	= 0.8741			

There was a linear relationship (P<0.05) between radiation and temperature. However, the relationship (P>0.05) was curvilinear between radiation and precipitation, Radiation and humidity and then Radiation and wind speed (Table 5).The high value of R^2= 0.7828 indicated that the precipitation, humidity, temperature and wind speed explains 78.28% of the variations of the radiation values.

Table 5: Linear regression and correlation with radiation as the dependent variable

Variable	Coefficient	St. Error	t-value	p (2 tail)
Intercept	4226.4333	3361.8277	1.2571832	0.264
Humidity	-14.52746	15.5602	-.9336294	0.393
Precipitation	-2.628165	.7334803	-3.583144	0.016
Temperature	-113.5835	94.719461	-1.199157	0.284
Wind speed	-29.51793	212.14883	-.1391378	0.895
R-Square	= 0.7828			

Effects of rainfall on Phenological phases (flowering, fruiting leaf fall and leaf flush) of *O. usambarensis*

Rainfall amounts and distribution plays a key role in determining the phenological phases of the species. Rainfall was distributed in all the months in varying amounts except in July Augustand September (Figure 3). The study area has two rainy seasons, the long rains falling between April and June and the short rains between October and December with a mean annual rainfall of 1600 – 2450 mm. (Abeney and Owusu 1999).

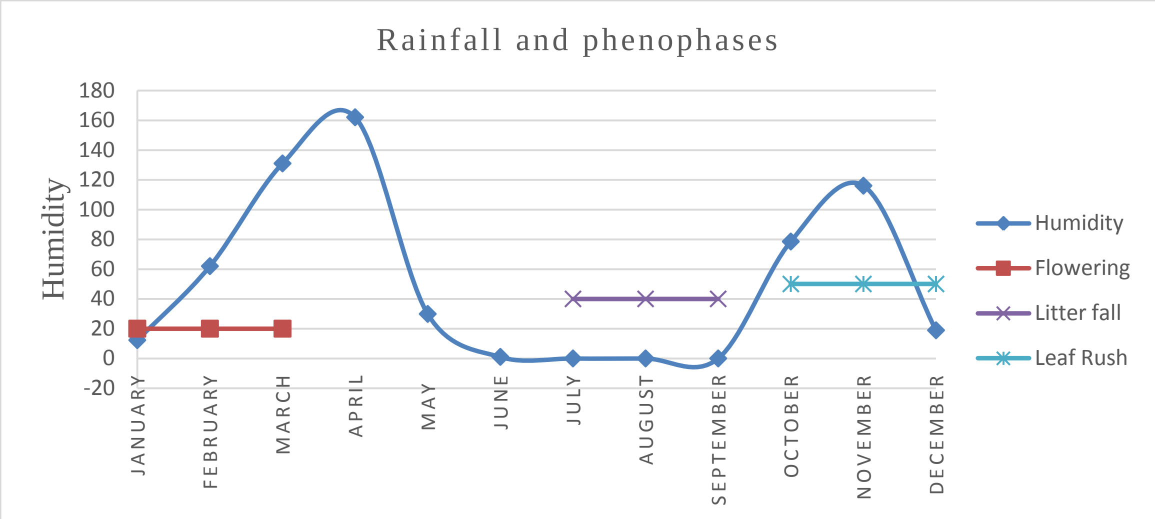

Figure 3: Rainfall and phenophases

Effects of temperature on Phenological Phases (flowering, fruiting and leaf fall)

The average temperature in the study area ranges from 21°C to 26°C during the day (Figure 4). Seasonal variations are distinguished by duration of rainfall rather than by changes of temperature.

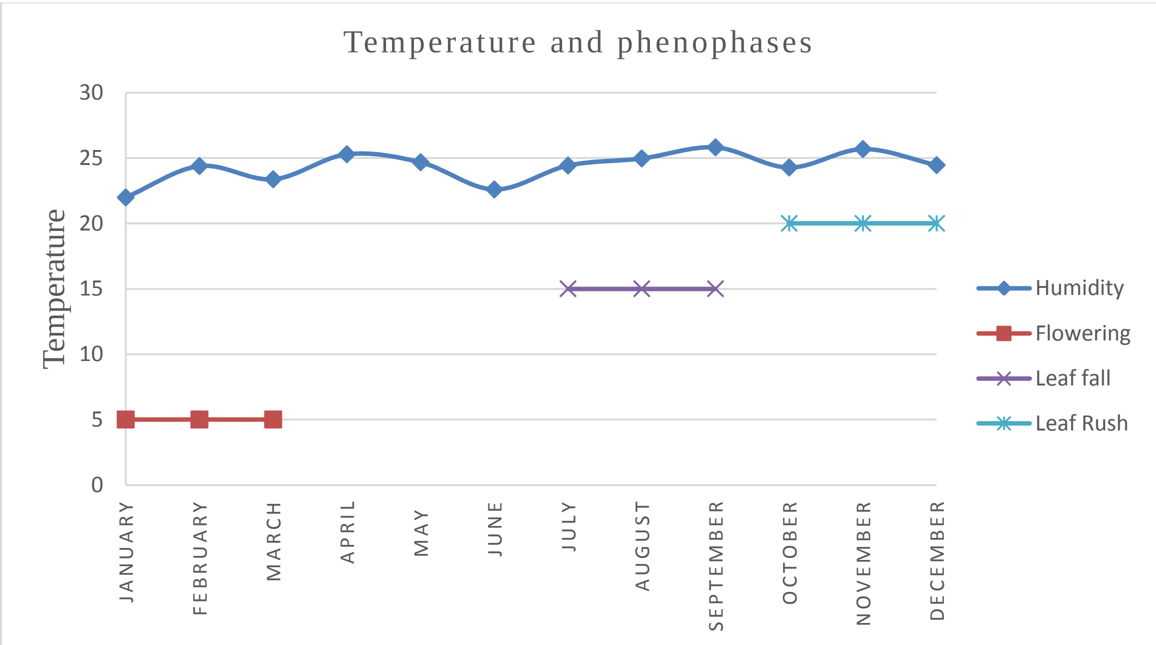

Figure 4: Temperature and phenophases

Effects of Humidity on Phenological Phases (flowering, fruiting and leaf fall)

The highest (74) humidity was during the month of January while the lowest (54) humidity values were recorded in august. The highest humidity coincided with the onset of flowering while reduction in humidity was during the leaf fall (Figure 5).

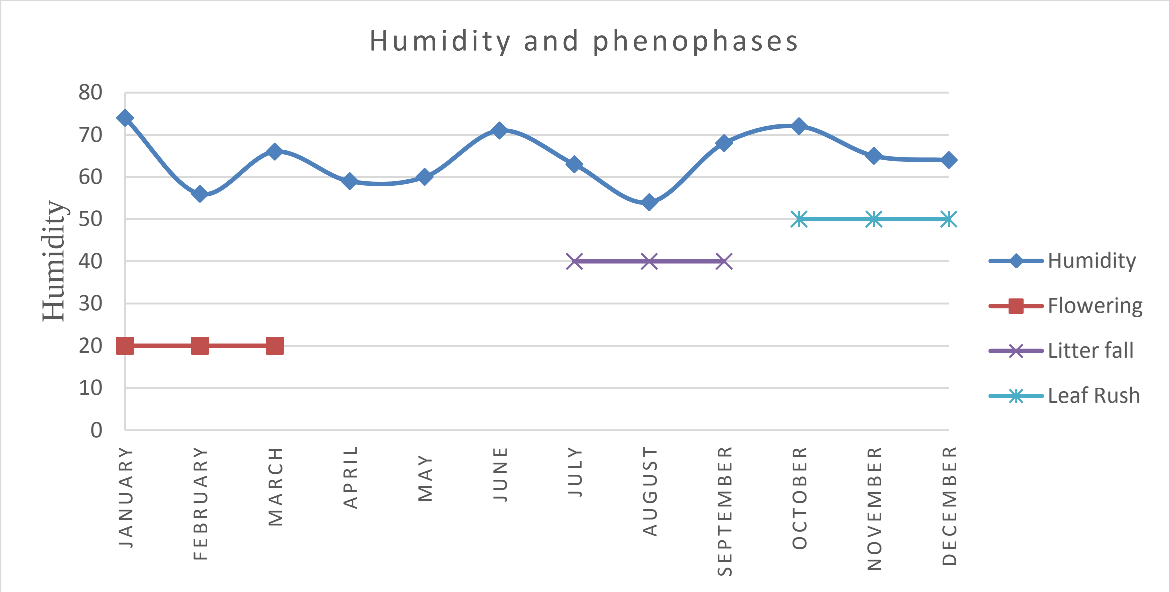

Figure 5: Humidity and phenophases

Effects of solar radiations on Phenological Phases (flowering, fruiting and leaf fall)

The average solar radiations received were low during the month of April at 130. 53 and highest at 642.3 during the month of September. Flowering occurred during the low radiations. Shedding of leaves also occurred during the low radiations period, however, fruiting coincided with exponential increase of radiations received.

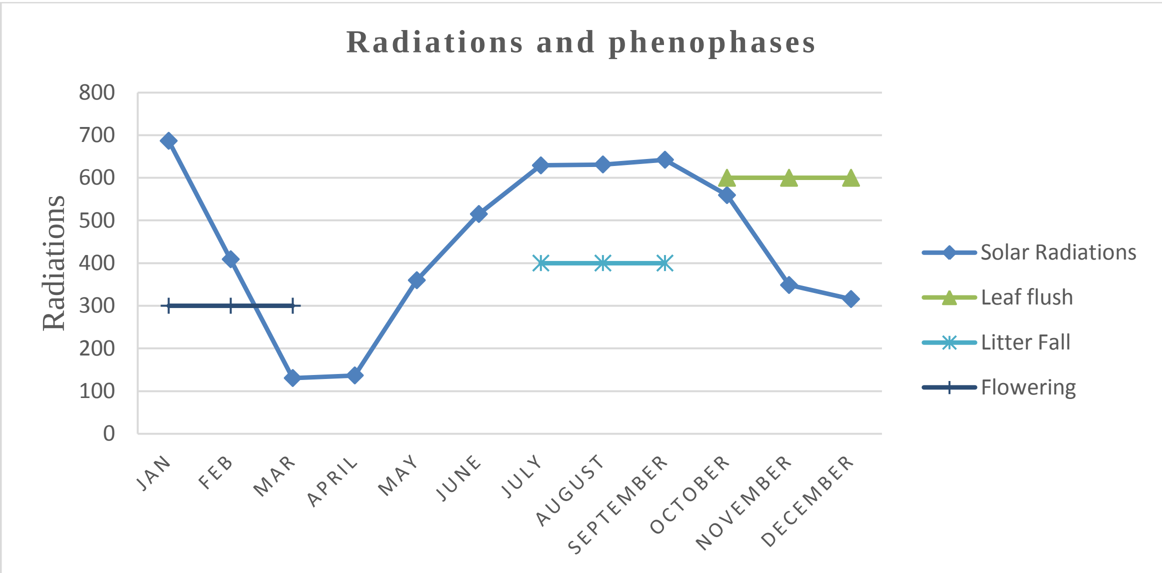

Figure 6: Radiation and phenophases

Effects of wind speed on Phenological Phases (flowering, fruiting and leaf fall)

The overall wind speed was steady with insignificant variation. However, the wind speed was highest during the month of May and June during which seed shedding and leaf fall was occurring (Figure 7).

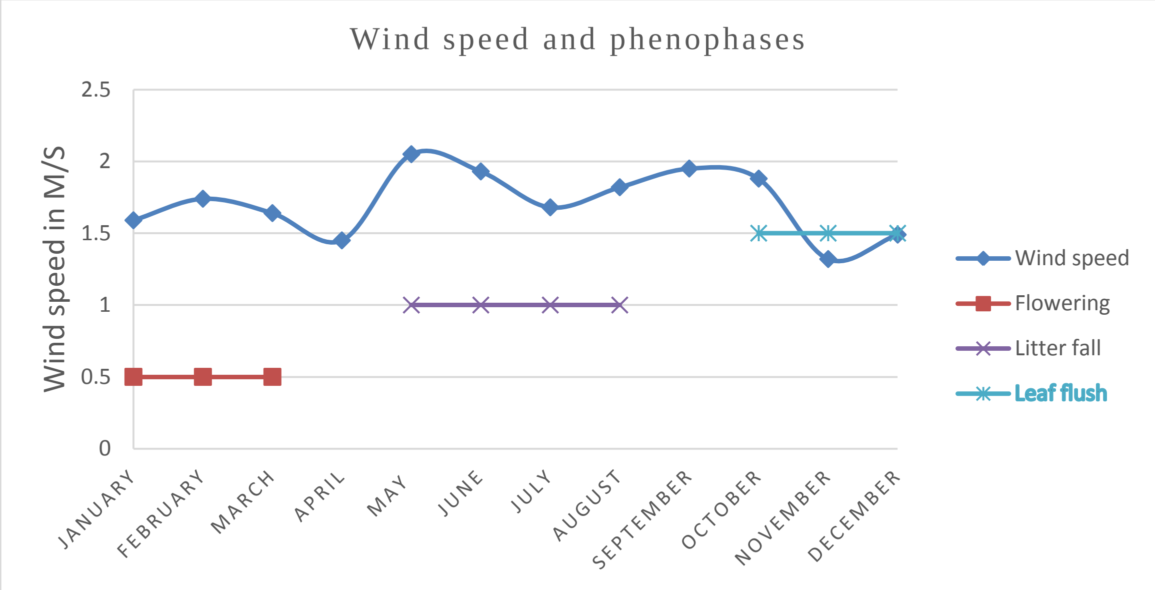

Figure 7: Wind speed and phenophases

Overall mature trees of *Ocotea usambarensis* are more than the regerants in the study area (56.52%). Forty six percent of the mature species were found in Chogoria forest while 30% was found in Kiangondu forest and 23% in Kiamuriuki forest. Eighty six percent of the seedlings were found in Chogoria forest. There were no seedlings and saplings in Kiamuriki (Table 6). Fair regeneration was observed in Chogoria whereas regeneration in Kiang'ondu and Kiamuriuki forest areas was poor. Natural regeneration through seed germination was seldom. The seedlings observations were mainly of root suckers and not seed germination.

Table 6: Distribution of *O. Usambarensis* within the study area

Species Location	Mature %	Saplings %	Seedlings %
Kiang'ondu	30.77	0.00	13.33
Kiamuriuki	23.08	0.00	0.00
Chogoria	46.15	100	86.67
Overall	56.52	4.35	39.13

Mature – DBH = >30cm, Sapling – DBH = 10cm - 30cm and Seedling – DBH =<10cm

Discussion

Influence of environmental factors on phenological phases of *Ocotea usambarensis*

Phenology is the periodicity or timing of recurring biological events. In the case of the study, phenological events involved flowering, fruiting, leaf fall and leaf flushing. The schedule of phenological events has important effects on plant survival, reproductive success, regeneration and establishment.

Influence of environmental factors on flowering of *Ocotea usambarensis*

Phenological phases varied with the environmental factors prevalence. Flowering of *O. usambarensis* occurred in the month of December to February. These findings concurred with the observation by Okeyo (2008) that in Chogoria forest flowering of *O. usambarensis* occurs in February. During this period the rainfall received was minimal and the relative humidity relatively high. The period is normally preceded by the short rains season which is characterized by increased vegetative growth. The hormonal activity for flowering favours low humidity and relatively high temperatures.

The *O. usambarensis* plants are proliferous in flowering; however formation of seeds that can develop to augment regeneration is rare. This is partly due to the dioecism characteristic of *O. usambarensis* and the limiting environmental factors. The curvilinear correlation between rainfall and humidity indicates the need to understand their role in controlling phenophases of plants.

The study established that absence of seedlings in most of the sites even with observed flowering indicates that most of the flowering *O. usambarensis* plants were males. The female plants and the male plants should be at a transmittable distance to enhance pollination and subsequent reproduction of viable seeds. Travis (2009) reported that *O. usambarensis* produces seeds every ten years and that fresh seeds are recommended to be used for sowing. The germination rate is often low, up to 45 %because seeds are often heavily attacked by insects. The seeds usually start germinating in 30 – 45 days, but germination may take up to 90 days Bussman (2001). Kowalski and Van (2000) reported that, propagation of Ocotea by seed is difficult as the flowers and fruits are attacked by fungal diseases and insects and the fruits quickly loose viability in storage. Tonin (2006) also observed that storage of Ocotea seeds decreased their viability and vigor.

Dry season flowering in tropical forests may be enhanced by the higher radiation as there was a significant positive correlation with mean monthly temperatures. Flowering was significantly correlated to mean monthly temperature. Decrease in temperature during the rainy season was followed by significant increase in the flowering individuals one month later. Flowering phenology may also be triggered by the humidity (Augspurger, 1981; van Schaik et al., 1993; Sakai, 2001; Anderson et al., 2005). The strong correlations shows the importance of environmental factors in regulating flowering of *O. usambarensis*. According to Frankie et al. (1974) wet season flowering in tropical dry forests is low.

Influence of environmental factors on fruiting of *Ocotea usambarensis*

Under favorable environmental conditions, effective fruiting follows flowering. Seed formation is dependent on the physiological aspect of the plant and the prevailing environmental factors. *Ocotea usambarensis* is proliferous in flowering, however fruiting is seldom. Low and sometimes lack of fruiting may be due to unpleasant environmental conditions that do not favor fruiting and insects attack on flowers of *O. usambarensis*. Fruiting formation of *O. usambarensis* occurs between February and May during which time the long rainfall and autumn conditions prevails. The seed maturity occurs during the period when moisture is high to favor germination.

Ocotea usambarensis seeds are sensitive to desiccation and should be sown fresh. Pretreatment of seeds is not necessary and under ideal conditions, seeds germinate in 30 – 45 days and the expected germination rate of mature, healthy and properly handled seeds is 45 %, Bussman (2001). Gachathi (2007) reported that germination of *O. usambarensis* seeds is sporadic often taking 2-3 months. The seeds usually start germinating in 30 – 45 days, but germination may take up to 90 days, Bussman (2001).The seeds should be picked, cleaned and sown immediately since they are recalcitrant. Tonin (2006) observed that storage of *O. usambarensis* seeds decreased their viability and vigour.

Solar radiations and Temperatures are generally low during the period of seed maturation to reduce the incidences of drying and subsequent loss of viability. The rainfall season ensures increased moisture content which is a requirement for germination. Ocotea seeds in the wild are parasitized and the regeneration potential is reduced.

Effective *O. usambarensis* establishment both vegetative propagation for *in-situ* and *ex-situ* programme should be considered. Jaenickle and Beniest (2002) reported that a piece of plant material can grow to form a new plant that contains the exact genetic information of its own source plant through vegetative propagation.

The individuals' plants that flowered seldom produced fruits implying that fruit production is controlled and influenced by changes in environmental factors. The flowering conditions differed with the fruiting condition which indicates reduced reproductive success in this species. Abortion of immature fruits due to self-pollination among out-crossing populations has been reported in several tropical tree species (Sakai et al., 1999). Regenerated young seedlings on the forest floor were located far away from the crown of the mother trees and mainly sprouting from the roots. Fruiting phenology and reproductive success of *O. usambarensis* was influenced by both environmental and soil factors.

Influence of environmental factors on leaf fall and leaf flush of *Ocotea usambarensis*

Ocotea usambarensis is partly deciduous. Leaf fall and leaf flush of the deciduous species are annual and strictly seasonal, and leaf fall peaks during the long dry season when the temperature is high. The periods of leaf fall and leaf flush were overlapping. Annual pattern and strong seasonality accords with leaf fall and leaf flush. During the periods of low rainfall and high temperatures the plant shed some of its leaf. The shedding of the leaf coincides with the flowering period. The leaf fall forms the floor layer that enhances moisture conservation in readiness for seed shedding and germination. The physiological process also reduces the chances of transpiration thus concentrating the chemical energy to the seed development.

Temperatures, solar radiations and humidity were relatively high at the period of leaf fall for which additionally prepares the plant for leaf flushing at the onset of the rain season (Figure 2). The wind speed was also high during the period to facilitate the leaf fall and spread on the floor surface. The findings agrees with the report by (Justiniano and Fredericksen, 2000) and cloud forest in Hawaii (Berlin et al., 2000) that Leaf fall of deciduous species in a Bolivian dry forest began at the beginning of the dry season and continued until the beginning of the rainy season. The significant correlation between leaf fall and mean monthly temperature suggests that leaf fall is an adaptation to reduce the effect of water stress in the dry season. The seasonality pattern of peak leaf fall also agrees with reports from the Atlantic Rain Forest Trees (Morellato et al., 2000) where leaf fall consistently peaked during dry seasons when there was high water stress (Anderson et al., 2005). Borchert (1984) argued that the timing of leaf fall is controlled by the water status of the plant.

Influence of environmental factors on regeneration of *Ocotea usambarensis*

The study established that the population structure of *O. usambarensis* is characterized by high proportion of mature individual with DBH> 30 cm and few regenerants with DBH<10cm, thus unstable. The regenerants were observed from the root system thus agreeing with Louppe, et.al, (2008) in their report that under natural conditions, *O. usambarensis* regenerates mainly by suckers because undamaged seeds are uncommon. After natural mortality of an old tree, the gap is first filled by fast – growing pioneer species, in the shade of which the *Ocotea usambarensis* suckers can establish, and after death of the pioneer species, they can develop into new trees, Bussman (2001). It was observed that in Mt. Kenya forest, *Diospyros abyssinica* was growing in close association with *O. usambarensis* playing the role of nurse species. Canopy opening through both anthropogenic and natural disturbance plays an important role in determining population structure of *O. usambarensis*. It was clear that a certain level of canopy opening significantly increases the density of young regenerants.

This study established that the number of seedlings was low and influenced by canopy opening which controls the light incidence. Kleinschroth *et al.* (2013) reported that regeneration of *O. usambarensis* in Mt. Kenya is generally low and negatively influenced by historical logging, and that natural regeneration was inadequate for the recovery of *O. usambarensis*, and recommended enrichment planting as additional conservation measures to promote the species. It was observed that a high percentage of old individuals and very low recruitment of *O. usambarensis* mainly as root suckers and few seedlings in previously heavily logged areas at Mt. Kenya.

Ocotea usambarensis is mainly harvested from natural stands, and the extent of plantations is very limited. Its regeneration should be enhanced through gapping *in-situ* as opposed to Bussman (1999) who proposed that several valuable and fast growing indigenous species including *Juniperus procera* and *Vitex keniensis* could be used for planting in gaps left by *O. usambarensis* either in mixture or as nurse trees to promote the regeneration of *O. usambarensis. Ocotea usambarensis* trees can be managed by coppicing to which they respond well at any age Palmer (2000) and Okeyo (2008). The rotation cycles is 60 to 70 years however can be reduced to 50 years with proper thinning regimes to finally 220 trees/ha. Newmark, 2002 reported that *O. usambarensis* is known to experience low sexual regeneration through seedlings while other studies found that vegetative regeneration through suckers was more important than sexual regeneration, because the density of root suckers was found to be 6 times higher than that of seedlings (Kleinschroth et al., 2013). The characteristic of *O. usambarensis* to produce many suckers after disturbance should be used to devise a management scheme for timber production (Willan, 1965). Although germination of sown seeds is fairly good (Msanga, 1998), seed viability is very short and therefore precludes the formation of a seed bank and dries out before reaching potential regeneration sites (Bussmann, 1999; Baskin and Baskin, 2005). *Ocotea usambarensis* is considered to be a climax species although it also exhibits characteristics of pioneer species. *Ocotea* regenerates from suckers, coppices and rarely from seed. At some stages of its growth it behaves as a light demander than a shade tolerant, Also, at any stage when camphor is felled, root suckers are produced which, although able to persist under shade, grow rapidly in half or full light (Mugasha, 1996).

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