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Table of Contents: Volume 10 Number 1, January 2018

ARTICLES

Determinants of vegetation type patch dieback in a semi-arid area, Tutume Sub-District, Botswana 1
Rabson Nthata and Shimane W. Makhabu

Litterfall dynamics in Boter-Becho Forest: Moist evergreen montane forest of Southwestern Ethiopia 13
Talemos Seta, Sebsebe Demissew and Zerihun Woldu

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Full Length Research Paper

Determinants of vegetation type patch dieback in a semi-arid area, Tutume Sub-District, Botswana

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Patch dieback of *Colophospermum mopane* (Kirk ex Benth.) Kirk ex J. Léonard, which was attributed to drought, soil surface condition and soil chemistry has been reported in South Africa. In Botswana, dieback of *C. mopane* and other species were noticed in 2012 in the North east part of the country (North West of Francistown). The causes of the noticed dieback were not known. The objective of this study was to determine the status and causes of that dieback. The study was based on field survey to determine species with dieback, the percentage number of dieback affected individual plants of each species and the areas affected. A questionnaire was also administered to get views from people living in the study area on what they thought caused the dieback. Rainfall and temperature data were obtained from Department of Meteorological Services. It was found that it was not only *C. mopane* that was affected but even other species such as *Dichrostachys cinerea*, *Combretum hereroense* and *Terminalia prunioides*. It appears that low temperatures combined with soils type are the major causes of the dieback. Dieback was mostly on tree individuals on heavy clay soils than those on loamy soils.

Key words: Francistown, plant dieback, vertisols, loamy soils, temperature, rainfall.

INTRODUCTION

The dynamics of vegetation structure in African savannas have been reported to be driven mainly by drought, frost, fire and herbivory (Ben-Shahar, 1996; MacGregor and O'Connor, 2002; Mosugelo et al., 2002; Holdo, 2006; Makhabu et al., 2006; Guldemond and van Aarde, 2008; Skarpe et al., 2014). Moisture limits woody plant growth whereas frost, fire and herbivory can partially or completely destroy plants (Guldemond and van Aarde, 2008). Fire and herbivory often interact together in driving vegetation changes (Ben-Shahar, 1996; Chafota and

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Owen-Smith, 2009; Mmolotsi et al., 2012). Woody plants deaths or partial death affects the vegetation structure and diversity. One of the problem affecting the vegetation is dieback. Dieback or decline is a common symptom or name of disease especially of woody plants, manifested visibly by progressive death of twigs, branches, shoots, or roots, starting at the tips/leaves or roots backwards due directly or indirectly to unfavourable biotic (disease, pests, parasites, etc.) and/or abiotic (soil, water, climatic, etc) environments (Cielsa and Donaubauer, 1994) including human factors (cultural and management practice). Diebacks of *Acacia xanthophloea* Benth [now *Vachellia xanthophloea* (Benth.) P.J.H. Hurte] has been reported in east Africa and it was attributed to both raised ground water table and increased soil salinity following a period of higher rainfall (Western and van Praet, 1973). MacGregor and O'Connor (2002) reported dieback of *Colophospermum mopane* (Kirk ex Benth.) Kirk ex J. Léonard in South Africa. Dieback of species, such as *Pterocarpus angolensis* DC. has been reported in Chobe Forest Reserves in Botswana and was attributed to elephant and fire damage (Mmolotsi et al., 2012). Some species, such as *C. mopane* coppice (develop new branches from the base of the main stem) after a dieback during the rain period, but some species do not recover. There are various factors that contribute to woody species dieback. MacGregor and O'Connor (2002) indicated that insect outbreaks, fungal diseases, climatic fluctuations, shifts in geomorphological or hydrological gradients, air pollutants, salinity, changes in land use and drought contribute significantly to woody species dieback. However, it is not yet known, which, amongst these factors, has major influence on woody species dieback.

Currently, there is lack of research on tree dieback in Botswana, which is hindering better understanding of species recovery and the causes of patch dieback. In 2012, some woody species, mainly *C. mopane,* were observed with signs of dieback in the North West of Francistown, Botswana. *C. mopane* is useful in many ways. Its heartwood is attractive, durable and extensively used for ornamentals, furniture and firewood. Poles from *C. mopane* are used in construction of huts and in fencing arable fields, kraals and homesteads (Madzibane and Potgieter, 1999; Mojeremane and Lumbile, 2005). The species is also browsed by cattle (Timberlake 1995) and game (Makhado et al., 2016; Stokke and du Toit, 2014). Caterpillars of the emperor moth, *Imbrasia belina* and *Gynanisa maja*, commonly known as mopane worms, feed on its leaves and are widely used as food for both humans and animals. The mopane worms are also of great economic importance as the local people sell them and get an income, which helps in alleviating poverty (Makhado et al., 2009; Mojeremane and Lumbile, 2005). Dieback of *C. mopane,* therefore negatively affects availability of *C. mopane* shoots/stems for use by people and animals. The main aim of this study was to quantitatively determine the intensity of 2012 dieback of *C. mopane* and other species in Tutume Sub-District, Botswana. In doing so we sought to characterise dieback through species composition and its relationship with climate (rainfall, temperature) and soil type, alongside local perception and attitude.

MATERIALS AND METHODS

Study area

The study was carried out in the outskirts of Tutume village (20°30' S and 27°03' E), about 100 km North West of Francistown, Botswana (Figure 1). The vegetation type in the study area is tree savannah dominated by *C. mopane*, *Dichrostarchys cinerea* (L.) Wight & Arn, and species of *Grewia, Combretum, Vachellia, Senegalia* and *Terminalia* being the major woody species. The study was conducted along three streams that are forming confluences with Mosetse River (Figure 1). The study area has an average annual rainfall of about 490 mm and average minimum and maximum temperatures of 13.7 and 31.1°C, respectively. The altitude of the study area is about 1000 m. The study area is mostly used for arable and livestock farming.

Sampling design

The study sites were along three streams, namely the Tenene (20˚41'340"S; 26˚57'190"E), Madingwane (20˚31'914"S; 27˚01'661"E) and Mosetse (20˚38'003"S; 27˚00'907"E) Rivers. In each site, 3 plots with *C. mopane* dieback and 3 plots with healthy mopane, each measuring 20 × 20 m were temporary marked. Location of plots was systemmatical done to include areas with and those without dieback. One corner of the plot was from South to North direction while the other was from East to West. The plot sides were marked with a danger tape. The layout of plots was the same in areas where there was a dieback and where the vegetation was healthy. A total of 18 plots were assessed.

Data collection

In each plot, the numbers of individual of each woody species with and without dieback were counted. Also, recorded were vegetation and soil types. The soil type was determined by the squeeze test. This involved grabbing a small handful of the soil in the hand and then rubbing some of the soil between fingers. If it felt gritty it was classified as loamy and if it felt slick and slimy it was classified as clayey. The colour of the soil was determined by comparing the colour of the soil with those on Munsell soil colour chart. Soil colours were classified into two broad group of being black or brownish.

Data of rainfall and temperatures for the years 2010, 2011 and 2012 and long term (1990 -2000) averages for Francistown were obtained from the Department of Meteorological Services. Temperature and rainfall data from Francistown (a town about 100 km South East of the study area) and Sowa town (a town within the study area) were used because the Department of Meteorological Services had no data of Tutume.

A questionnaire was also used to sample opinion of local residents on the occurrences and causes of dieback. In the

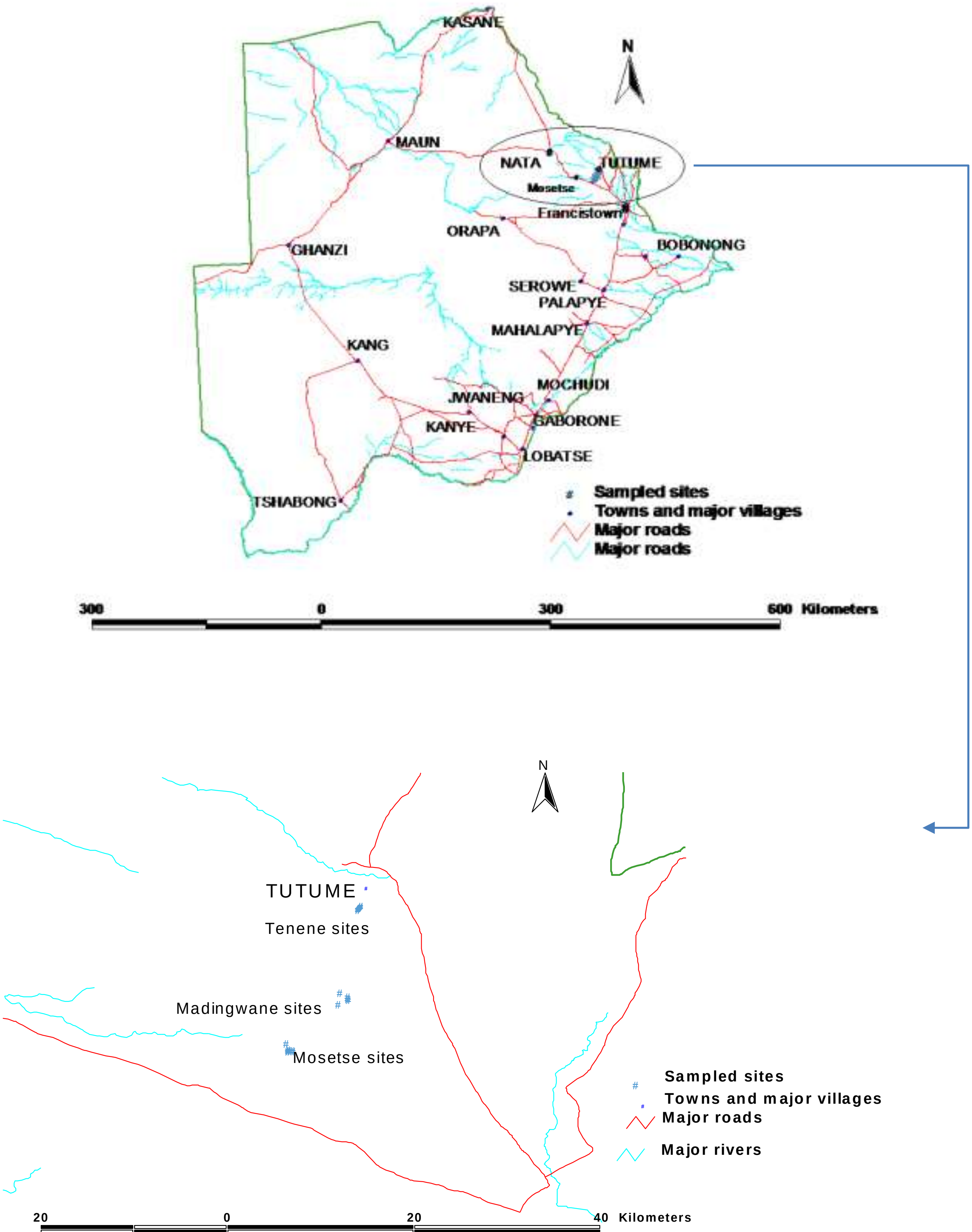

Figure 1. Map of Botswana showing study sites (upper map). Location of study sites within the study area (lower map).

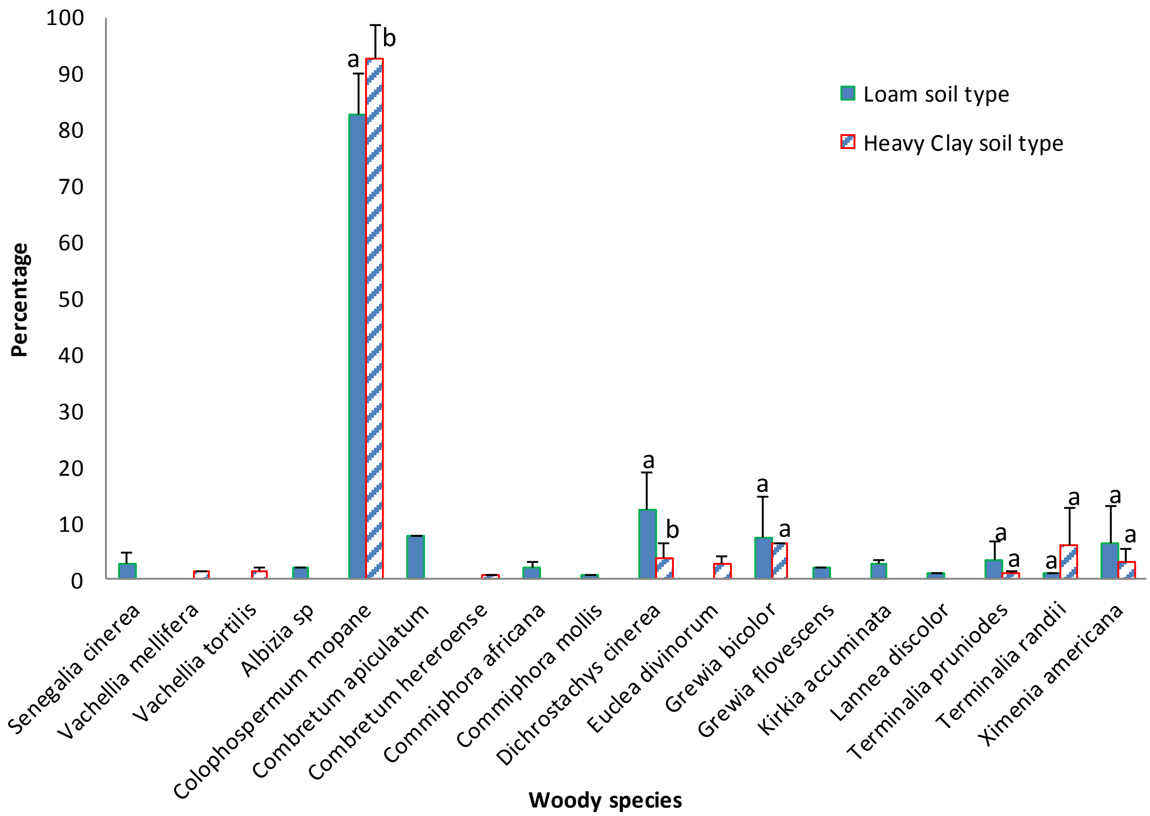

Figure 2. Relative abundances of each woody species recorded in the two different soil types in the studied sites. Species with same letter above the bars are not significantly different whereas those with different letters are significantly different. T-test was used to test the significancies of the relative abundancies.

questionnaire, the respondents were asked to provide their gender, age and how long they have been living in the area. They were some statements which they had to rate whether they strongly disagree (1), disagree (2), agree (3), and strongly agree (4). These were; I am aware of the importance of mopane tree to human life and ecosystem; I am aware that there has been dieback of mopane tree in this area; whether there has been drought in the past 2 years, the uses of *C. mopane*, whether there has been a dieback of woody species in the past, whether dieback has affected the grass biomass and whether dieback has affected availability of phane worms. The questionnaires were tested, revised and administered to 30 randomly selected residents' aged 18 years and above of Tutume village who have leaved in the village for more than a decade. All data collections were done in December 2013.

Data analysis

The data collected were analysed using the *t*- test to test for significances in mean number of plants of each species with and without dieback. Relative abundances of each species within a plot was calculated as the percent composition of a particular species relative to the total number of plants of all species within the plot. Densities of woody plants were calculated. Differences of answers provided by people through questionnaires were tested for significant differences using the Chi-square test. All statistical tests were done in SPSS for Windows v.16.0 (SPSS Inc., 2007 Chicago, IL, USA).

RESULTS

Soil types and woody species abundances in different types of soils

The study sites are characterised by two soil types, namely heavy clay (black cotton) and loam soil. The heavy clay soils were mostly blackish while the loam soils were brownish. The heavy clay soil type was mostly found along streams whereas the loam soil was observed further away from the streams. The heavy clay soil types were identified as being the vertisols with high shrink-swell potential that is normally characterized by wide, deep cracks when dry. *C. mopane* dominated on both soil types and was relatively more abundant on the clayey soils than on the loamy one (Figure 2). They were few other species which were found on both soil types and

Figure 3. *Colophospermum mopane* vegetation type with signs of dieback as observed in 2012 at Dinonyane cattle post in Tutume Sub-District.

they included *Dichrostachys cinerea* (L.) Wight & Arn., *Grewia bicolor* Juss., *Terminalia prunioides* C. Lawson, *Terminalia randii* E.G. Bakerand and *Ximenia americana* L (Figure 2). *D. cinerea* (L.) Wight & Arn. was more abundant on the loam soil type, whereas the abundance of other species did not differ between soil types (Figure 2). Other species were found only on one soil type (Figure 2).

Status of dieback

Woody species with dieback were observed in most parts of the Tutume Sub-District along major streams on heavy clay soils. The affected plants had most of their stems and side branches dead except for coppiced shoots (Figure 3). The area affected stretched all the way from Tutume village up to Nata. Some of the affected areas included Mosetse and Semowane rivers and the streams of Madingwane, Tikitiki, Matizha, Tenene, Dinonyane, Makgobula and Shomme. It was observed that trees with dieback signs were mainly on heavy clay soil and almost no signs of trees with dieback were encountered on loam soils, except for less than 5% of individuals of *D. cinerea, C. africana* (A. Rich) Engl. and *C. mopane* (Figure 4). Woody species with signs of dieback on the heavy clay soils included *Vachellia tortilis, C. mopane, Combretum hereroense* Schinz, *D. cinerea, Terminalia Prunioides* C. Lawṡon, *T. randi* E. G. Baker and *Ximenia americana* L. (Figure 5). These species had more than 70% of their individuals affected by dieback, except for *V. tortilis* (Forssk.) Galasso & Banfi, which had 33% of its individuals affected by the dieback.

In some section of the study area, some patches with dwarf (< 1.5 m) vegetation (Figure 4) were observed.

Residents' views on dieback

The administration of the questionnaire was not gender biased (X^2 = 0.13, P= 0.72). The respondents were 47% (14) men and 57% (16) females. Most of the respondents (90%) (X^2 = 19.2, P = 0.01) have been living in the area for more than 15 years.

The respondents in the study area were aware of the dieback of *C. mopane* in the area (X^2 =12.80, P = 0.002)

Figure 4. *Colophospermum mopane* dwarf vegetation type observed in some section of Tutume Sub-District in 2013.

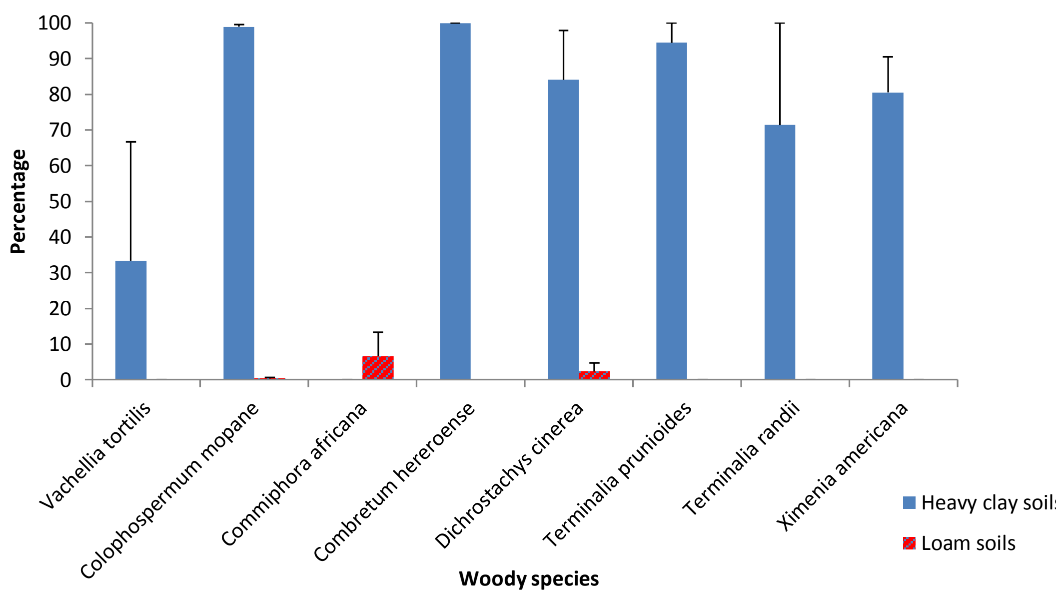

Figure 5. Percentage number of plants with dieback of each species under the two soil types cartegories.

and they agreed that there has been severe drought in the area for the past two years (X^2 = 19.33, P = 0.012). Respondents were aware of the importance of mopane tree to human life and the ecosystem (X^2 = 18.2, P =

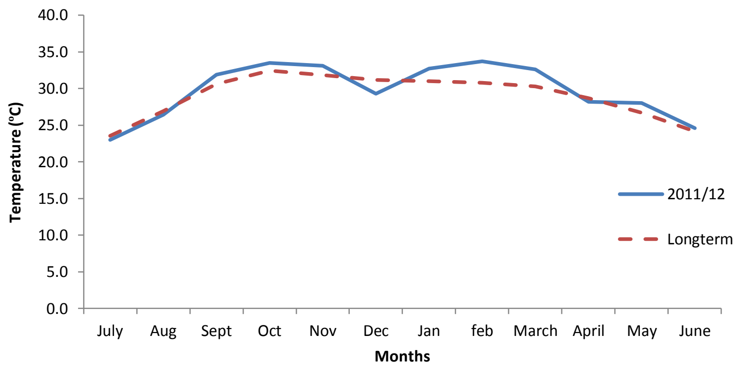

Figure 6. Mean maximum temperatures for Francistown from July 2011 to June 2012. The data was provided by the Department of Meteorological Services, Botswana.

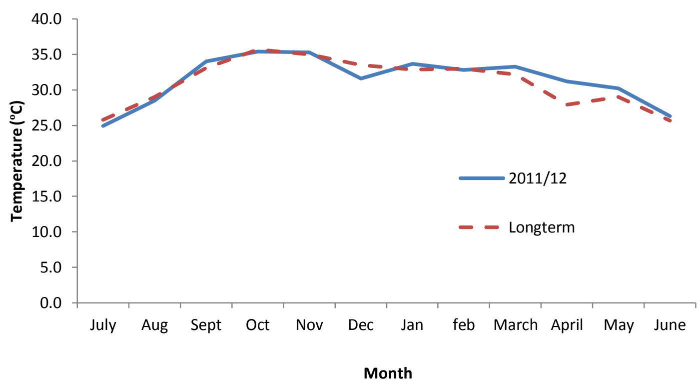

Figure 7. Mean maximum temperatures for Sowa town from July 2011 to June 2012. The data was provided by the Department of Meteorological Services, Botswana.

0.01). They reported that *C. mopane* is used as firewood; poles for construction of huts, fences, kraal; feed for animals and as food for edible mopane worms (*Imbrasia belina* or *Gonimbrasia belina* and *Gynanisa maja*). Other uses of *C. mopane* reported were that its wood is used to curve domestic utensils; its fibre is used for tying grasses during thatching; and is used as shade for people and animals. Most respondents (93.3%) said it was their first time to notice such a massive dieback of mopane vegetation like the one of 2012 (X^2 = 25.8, P = 0.01).

The respondents dismissed drought as the cause of mopane dieback in the area (X^2 = 10.80, P= 0.01). Most of them suggested that low temperature was the possible cause of the dieback of mopane (X^2 = 34.20, P = 0.001). High temperature (X^2 = 43.33, P = 0.001), soil type in which the mopane trees with dieback grow (X^2 = 60.93, P = 0.00) and drought (X^2 =18.20, P = 0.00) were also dismissed as possible causes of the dieback, respectively.

The respondents indicated that the dieback did not affect the availability of the grass biomass (X^2 = 19.20, P = 0.001). They indicated that the dieback affected the availability of mopane worm in the area (X^2 = 13.33, P = 0.01), but did not affect the farmers (X^2 = 3.33, P = 0.07). They reported that abundance of mopane worms were lower than during years without a dieback.

Effects of rainfall, temperature and soil type on the dieback

Maximum temperatures

The mean long term maximum temperatures compared with mean maximum temperature for the year 2011/2012 in Francistown is shown in Figure 6, while that of Sowa town is in Figure 7. The analysis done with the paired t-test showed that there was no significant difference

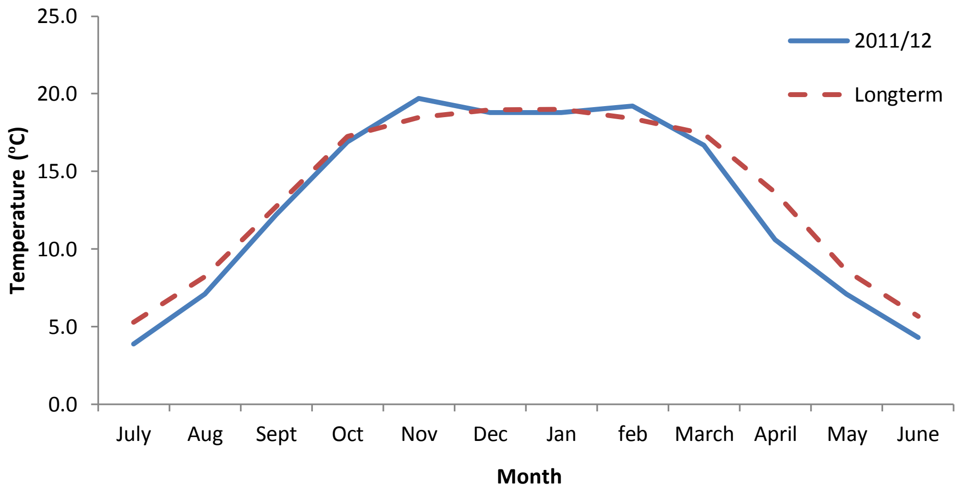

Figure 8. Mean minimum temperatures for Francistown from July 2011 to June 2012. The data was provided by the Department of Meteorological Services, Botswana.

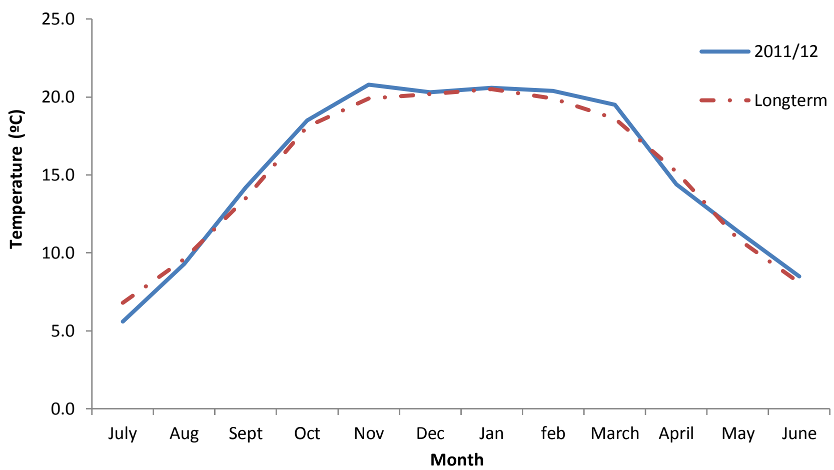

Figure 9. Mean minimum temperatures for Sowa town from July 2011 to June 2012. The data was provided by the Department of Meteorological Services, Botswana.

between the long term mean maximum temperature and the maximum temperature for the year 2011/2012 for Francistown (t = 29.00, P = 0.062) (Figure 6) and Sowa town (t = 1.895, P = 0.071) (Figure 7).

Temperatures

The long term minimum temperatures and that of 2011/2012 are shown in Figure 8 for Francistown and Figure 9 for Sowa town.

There was a significant difference between the long term and 2011/2012 minimum temperatures in Francistown (t = 2.17, P = 0.05) (Figure 7) and in Sowa (t = 2.45, P = 0.04) (Figure 8).

The results of daily minimum for June, July and August 2012 shows that there were some days during the three months where temperatures were below 0°C in Francistown (Figure 10) and Sowa town (Figure 11). On the 11th of June 2012 temperatures were low for both Francistown (-4.6°C) and Sowa town (-4.7°C). The low temperatures were also experienced on the 8th of August

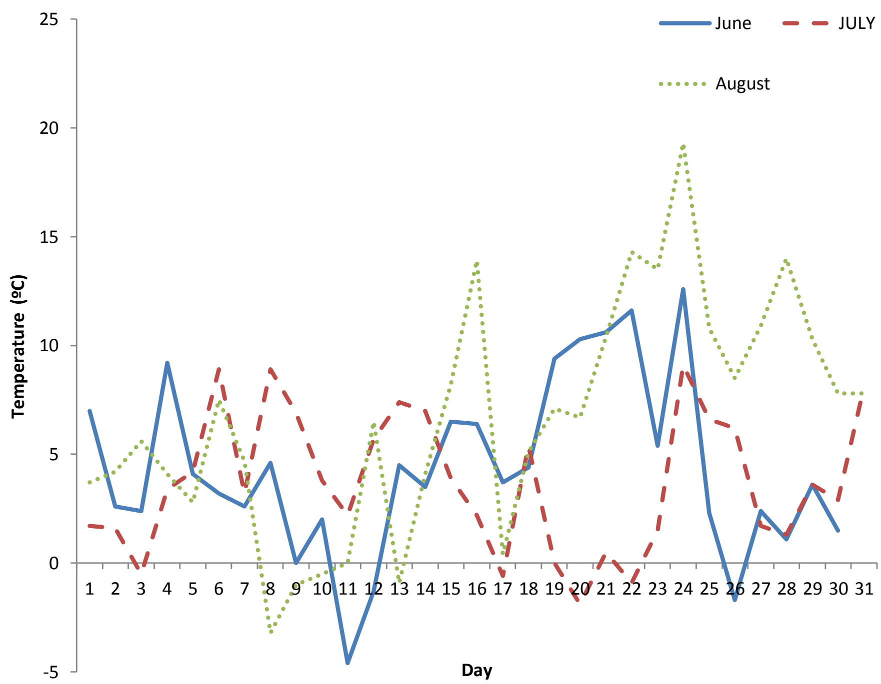

Figure 10. Daily minimum temperature for June, July, and August 2012 for Francistown. The data was provided by the Department of Meteorological Services, Botswana.

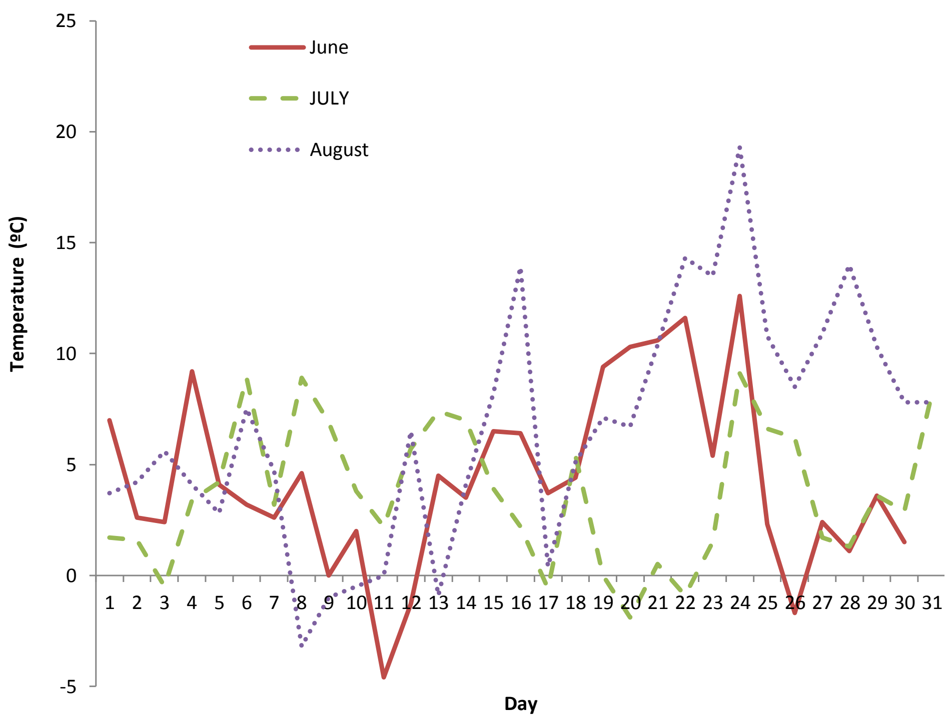

Figure 11. Daily minimum temperature for June, July and August 2012 for Sowa town. The data was provided by the Department of Meteorological Services, Botswana.

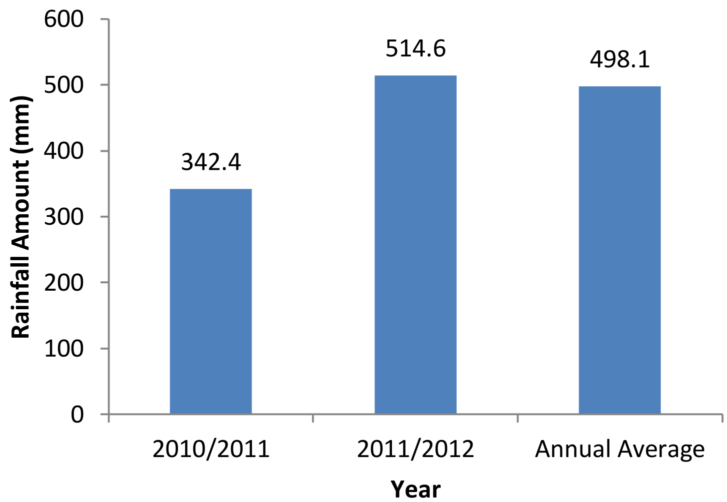

Figure 12. Annual rainfall amount for Tutume Village and its long term annual average.

2012 for both Francistown (-3.2°C) and Sowa town (-3.4°C).

Rainfall

The amount of rainfall received in the study area in 2011/2012 rain season, just before the dieback occurred, was a bit above the annual average rainfall (Figure 12) though the year was characterized by drought. This might be because a significant amount of rainfall was recorded in Tutume village in November 2011 (171 mm) and December 2011 (201 mm). Thereafter, there was very little rainfall recorded at the beginning of the 2012. The rains in 2011/12 were even more than of the previous rain season, 2010/2011 (Figure 12)

DISCUSSION

The dieback of *C. mopane* in the Tutume area was interpreted to have occurred during the years of severe drought period of 2010 to 2012. Though the analysis of data from the questionnaire indicated that there was severe drought two years prior to the dieback, the analysis from the same questionnaire indicated that drought alone was not the cause of the dieback. However, drought may place trees close to their limit for coping with water stress despite the deep root systems of the trees (Hernández-Santana et al., 2009).

High temperature was another factor, which was suspected to have caused dieback of *C. mopane*. Persistent high temperature lead to global-change-type drought situations that may kill trees (Millar et al., 2007). The analysis from the questionnaire and the Department of Meteorological Services temperature data, however, do not suggest high temperature as the cause of dieback of *C*. *mopane* in the Tutume area. The results indicated that there was no significant difference between the mean high temperatures for the year in which the dieback occurred and two years prior to the occurrence of the dieback.

Low rainfall is another factor which was suspected to have caused the drought that might have led to the dieback of mopane trees in the area. The rainfall amount, however, was indicated to be above the long-term average for the area, hence, rainfall amount alone might not have caused the dieback. However, the amount of rainfall received in the area during the year in which the dieback occurred, acting together with the type of soil and low temperature, might have caused the dieback. This agrees with findings by MacGregor and O'Connor (2002) in South Africa, who reported that *C. mopane* dieback was caused by a number of abiotic factors, such as soil water availability, drought and rangeland degradation.

The suspicion that dieback of mopane tree could have been caused by the soil type in which the trees were growing was confirmed by the results, which indicated that the dieback occurred mostly on the heavy clay soils than on the loamy soils. The extent of dieback of different species varied on the two soil types and that was similar to what has been reported by O'Connor (1999).

This study has indicated frost as the most likely cause of dieback in the area. Two abiotic factors may act together and cause dieback in plants (MacGregor and O'Connor, 2002). In this case, the soil type in which the trees were growing, the amount of rainfall received in the area and low temperatures, acting together might have caused the dieback. Heavy clay soils retain a lot of water than loamy soils. Therefore, trees that grow in heavy clay soils have more cell juices than those in loamy soils because the soils have retained a lot of water during the rainy season. When temperature goes below 0˚C, that is freezing point, the trees with a lot of juices may freeze causing damage to the cells of the trees, hence, causing the dieback.

Another scenario might be that the injured cells due to low temperatures make them vulnerable to attack by microorganisms, such as bacteria and fungi, that cause diseases to the plant, resulting in the dieback. Low temperatures that lead to freezing have been reported as a major environmental stress that can limit the distribution of both wild and crop species (Pearce, 2001). Distribution of *C. mopane* has been reported to be limited by temperatures below 5°C (Makhado et al., 2014; Stevens et al., 2014). Frost might be the reason of the absence of wild *C. mopane* south of Radisele village in Botswana, while it dominates in areas north-eastern part of the country. Areas in the southern part of Botswana normally experience freezing temperatures during winter (June, July and August) whereas those in the northern parts rarely experience frost.

In the study area, there are some patches with dwarf (less than 1.5 m high) *C. mopane* vegetation along streams on vertisols. The causes of such dwarf mopane vegetation are not known. Elephants have been suggested of being capable of completely converting mopane woodlands to shrublands (Ferguson, 2014; Chomba and Banda, 2016), but in the current study area elephants are rarely seen. Findings of this study suggest that dwarf mopane vegetation might be the result of periodic diebacks of the vegetation. Studies have shown that severely browsed *C. mopane* by elephants coppice vigorously during rain season. However, the plants produce many coppiced branches after browsing rather than one big main stem. Mopane trees with dieback coppice when the conditions become favourable for growth, but since the main stem die as a result of dieback, the coppiced stems might not grow to greater heights but remain stunted/dwarfs. Other tree species, such as *Adansonia digitata* L. rarely recover after heavy browsing.

Conclusions

It is concluded that the dieback of *C. mopane* might have been caused by the soil type in which the trees were growing in, in addition to high amount of rainfall received in the area prior to the dieback and low temperatures during the winter season. The dieback occurred mainly on heavy clay soils compared with the loamy soils. It occurred along most streams and rivers in the study area. It is suggested that the dwarf *C. mopane* vegetation type found in some patches in the area have been kept so by occasional diebacks. However, further investigations need to be done to find out whether this suggestion has some support.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Litterfall dynamics in Boter-Becho Forest: Moist evergreen montane forest of Southwestern Ethiopia

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Litterfall in the forest is essential for balanced ecosystem processes. The present study determined seasonal variations of litterfall in the Boter-Becho forest, Southwestern Ethiopia. Based on forest disturbance level, two sites were selected: Low and high. Litterfall production in the high and low disturbed forest sites averaged 6.6 and 10.8 t ha^{-1} year^{-1}, respectively. Significant differences ($P<0.001$) in litterfall were manifested between wet (0.6 ton ha^{-1} month^{-1}) and dry (0.8 tons ha^{-1} month^{-1}) seasons. Higher litterfall was associated with the dry compared with the wet season. Both litterfall and its fractions including leaf litter, reproductive parts and twigs followed a multimodal distribution pattern. Litterfall peaked during March, April, December, January and February with maximum peaks during March and December respectively. Monthly rainfall and temperature directly influenced litterfall production. Litterfall was strongly but negatively correlated with rainfall compared to ambient temperature. Although the present study provided useful information on the effects of low and high disturbance on litterfall production of the Boter Becho forest, further studies are required to quantify and understand the impact of disturbance on nutrient cycling specific to this forest.

Key words: Seasonal variation, site disturbance, leaf litter, reproductive parts, twigs.

INTRODUCTION

Litterfall production is an important component of forest ecosystem functioning (Aragao et al., 2009; Clark et al., 2001). It transfers nutrients from aboveground biomass to the soil (Vitousek and Sanford, 1986). In the forest ecosystem, litterfall reduce bulk density, increase water holding and the cation exchange capacity of the soil. Xu et al. (2013) also suggested that greater litterfall inputs increase the soil carbon sink despite higher rates of carbon release and transformation. In addition, litter on the forest floor plays a significant role in determining the moisture status,runoff pattern and release of mineral elements accumulated in the aerial parts of the

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vegetation (Parsons et al,, 2014; Kumar and Tewari, 2014; Yang et al., 2005).

Litterfall production in the forest ecosystem is also essential in the exchange of carbon from terrestrial ecosystems to the atmosphere, and forms a major contribution to seasonal variations in the terrestrial carbon cycle of the tropical forest biome (De Weirdt et al., 2012; Bousquet et al., 2000). It also provides nutrient input and organic matter replenishment and hence, an important stage in habitat conservation (Rawat et al., 2009; Wurzburger and Hendrick, 2009).

Recent studies indicated that litterfall production in forest system formed an important source of nutrients and organic matter over the past decades (Carnol and Bazgir, 2013; Meier et al., 2005; Vitousek and Sanford, 1986; Vitousek, 1984). However, climate, seasonality, tree species composition, stand structure, soil fertility, elevation and latitude alter the litterfall production pattern between ecosystems (Aerts, 1997; Becker et al., 2015; Simmons, 1996; Vitousek and Sanford, 1986; Parsons et al., 2014). According to Spain (1984), the most extreme variability of litterfall is seen as a function of seasonality. He reported that individual species of plants have seasonal losses of some parts of their body and can be determined by the collection and classification of plant litterfall throughout the year. Qiu et al. (1998) also observed that abiotic factors such as rainfall, temperature and light play an important role in litterfall, flushing among dominant canopy species in the forest.

Other workers reported that seasonal litter production is highest in dry months and lowest in the wet months of a year particularly in tropical forests (Arunachlam et al., 1998; Sundarapandian and Swamy, 1999). According to Zhang et al. (2014), seasonal variation in litterfall production results in large variation in the amount of litter on the soil in most tropical forests. Zhang et al. (2014) and Scheer et al. (2009) also indicated that seasonal patterns of litterfall show unimodal, bimodal or irregular modes, and the litter peaks might occur in several months of the year. Consequently, this phenomenon may affect the dynamics of ecosystem carbon and nutrient cycling (Xu et al., 2004; Das and Ramakrishnan, 1985).

Ethiopia exhibits a wide range of ecological conditions ranging from arid lowlands in the east to rainforests in the west and southwest. Ethiopia is also known for high endemism of wild plants and animal species (FAO, 1996). It possesses high altitude Afroalpine vegetation in the central, south eastern and northern highlands. The Ethiopian highlands contribute to more than 50% of the African land area with afromontane vegetation (Tamrat, 1994).

Although many studies have been done on the Ethiopian flora and species diversity, studies related to litterfall and nutrient dynamics is lacking (Ambachew et al., 2012; Nigatu and Michelsen, 1994). Understanding litterfall and nutrient dynamics of Ethiopian Forests is important to their management. The objective of the present study was to determine the effects of seasonal variation on litterfall production and the effect of rainfall and temperature on litterfall components (total and fractions) under low and high disturbance conditions in Boter-Becho forest located in southwestern part of Ethiopia.

MATERIALS AND METHODS

Site description

Location

Boter-Becho forest (08°21'56.4" N and 037°16'25.4"E) is one of the national forest priority areas located in Jimma Zone of Oromia Regional State, Ethiopia (Figure 1). It lies in Chora Boter district of Jimma zone and 223 km southwest of Addis Ababa, the capital city of Ethiopia. The study site lies along a volcanic mountain ridge, running almost north to south, and rising to a series of small peaks, the highest of which is 3,100 m above sea level. The Eastern part of the ridge is sharply steep, but more gradual in western side. The hills are divided by numerous valleys. The forest is dominated by Acacia wood land in the lower altitude, high montane forest on slopes and in the valleys up to around 2 900 m above sea level. Most of the valleys along the forest ridge contain only seasonal water course but remain dry from December to March. Boter Becho forest covers approximately a total area of 32 000 ha (Figure 1).

Vegetation

The forest vegetation in Boter Becho comprises a mixture of tree species including *Olinia rochetiana, Polyscias fulva, Pouteria adolfi-friedricii, Schefflera volkensii, Syzygium guineense Subsp. afromontanum. Allophylus abyssinicus, Croton macrostachyus, Juniperus procera, Hagenia abyssinica* and other small trees that grade into an open *Erica arborea* zone around the highest peak. Moreover, it contains a number of medium sized trees and large shrubs, a mixture of *Podocarpus falcatus* and broad-leaved species as emergent trees in the canopy including *P. adolfi-friederici*. There are some patches of *Arundinaria alpina* in wet, sheltered valleys. There are several streams forming rivers in mountains of Boter-Becho and are drained by the Gilgel Gibe to the west, which forms a wide valley supporting the lower parts of the forest, and the main Gibe River to the north and east.

Climate

In order to construct the climate diagram of Boter Becho forest, the 15 years climate data (2001-2015) was obtained from the Ethiopian Metrological Service Agency (NMSA, 2016). Boter-Becho has a warm and temperate climate. According to the climadiagram depicted in Figure 2, Boter-Becho has mean annual rainfall of 1434 mm and mean annual temperature of 14.6°C. Boter-Becho possess unimodal rainfall pattern with long rainy seasons from March to September of which the highest rainfall is recorded during the months of June and August. The area posses short dry season from October to February where it gets relatively smaller rainfall. Mean monthly rainfall in the area is 183.6 and 29.6 mm in wet and dry season, respectively. Mean annual temperature is 14.9 and 14.2°C in wet and dry season respectively. The mean annual temperature

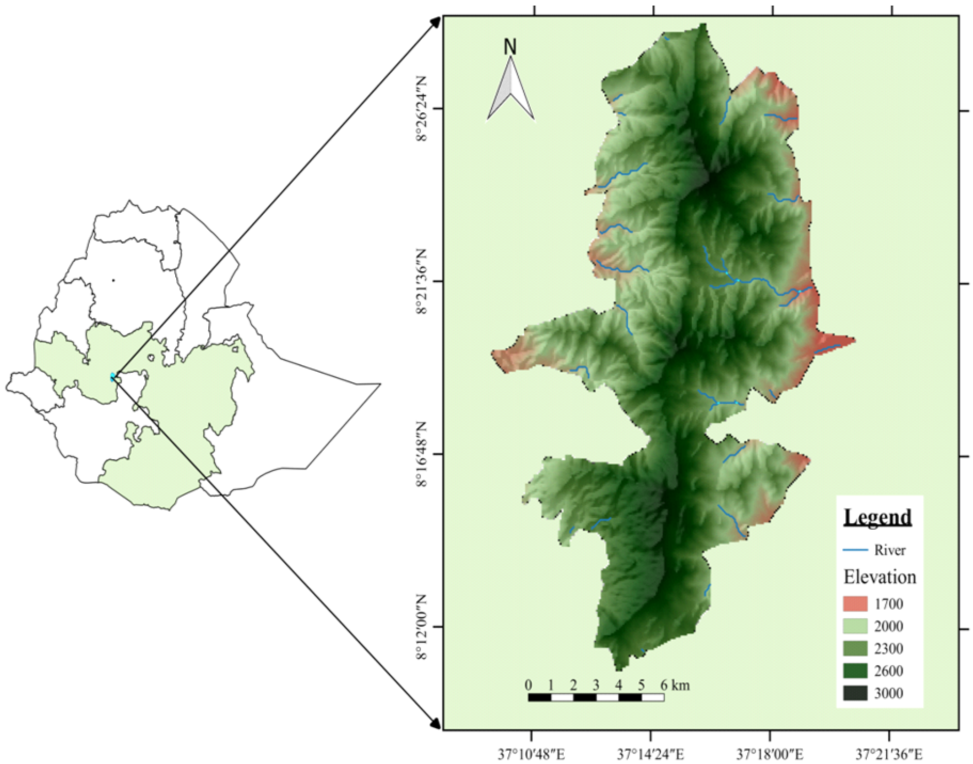

Figure 1. Location map of the study area.

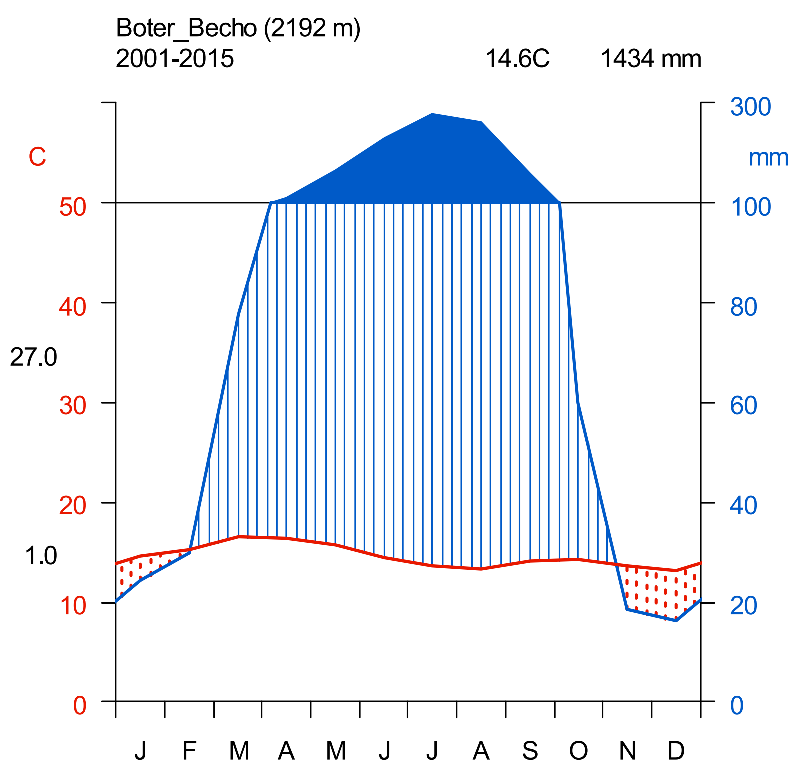

Figure 2. Climadiagram of Boter-Becho station from 2001-2014 (NMSA, 2015).

Table 1. Density, height and total basal area of tree species in LD site.

Scientific Name	LD site		
	Density	Height	Total BA
Allophylus abyssinicus	311.11	10.4 ± 2.9	29.26
Croton macrostachyus	140.74	18.9 ± 8.0	11.94
Chionanthus mildbraedii	296.31	3.68 ± 1.13	0.7
Ficus sur	85.15	16 ± 3.2	12.43
Macaranga capensis	88.91	18 ± 4.23	21.02
Milletia ferruginea Subsp. *darassana*	177.78	13.15 ± 4.11	12.8
Olea capensis subsp. *macrocarpa*	503.7	21.73 ± 3.49	32.13
Olinia rochetiana	214.81	10.9 ± 2.82	16.89
Podocarpus falcatus	311.11	16.13 ± 3.53	12.98
Polyscias fulva	133.33	11.32 ± 2.45	6.87
Pouteria adolfi-friedricii	162.96	19.2 ± 2.76	18.34
Schefflera volkensii	166.67	12 ± 3.72	14.87
Syzygium guineense Subsp. *afromontanum*	466.67	21 ± 4.22	33.56

Table 2. Density, height and total basal area of tree species in HD site.

Scientific name	HD site		
	Density	Height	Total BA
Albizia gummifera	200.00	15.3 ± 9.6	16.8
Apodytes dimidiata	77.70	15.4 ± 5.5	29
Brucea antidysentrica	125.90	8 ± 3.4	8.6
Calpurnia aurea	281.48	5.75 ± 2.11	2.1
Celtis africana	129.62	6.97 ± 3.7	2.86
Chionanthus mildbraedii	292.60	5.5 ± 2.3	0.81
Clausena anisata	251.85	3.7 ± 2.1	1.08
Croton macrostachyus	77.80	14.67 ± 3.76	4.88
Ehretia cymosa	92.59	4.3 ± 1.8	4.62
Milletia ferruginea Subsp. *darassana*	225.92	13.6±3.27	6.46
Oxyanthus speciosus	88.89	4.5±1.25	0.76
Podocarpus falcatus	59.26	21±4.3	6.62
Pouteria adolfi-friedricii	85.18	18±4.89	5.63
Teclea nobilis	125.90	5.3±2.3	1.2

of the area in the wet season is greater than in the dry season which drives the rapid ecosystem processes in the forest system. The climatic seasonality data presented in this section was used to determine the effects of seasonal variation on litterfall production reported in this study.

Sampling technique for site selection

A reconnaissance survey was conducted in December and January 2014 to observe the topography, type and different structural features of the Boter Becho forest. The forest is classified as moist evergreen montane forest where rainfall in the wet season is usually higher than that of dry season (Friis et al., 2010). The climadiagram of the area depicts that seven months of the year gets higher rainfall with the remaining five months receiving relatively smaller amounts of rainfall. Two local sites called ‘Bore’ and ‘Getemi’ within the Boter-Becho forest are hereafter referred to as low and high disturbed. These two sites were randomly selected on the basis of their level of disturbance. Characteristics of the low disturbance (LD) level includes no logging, browsing, grazing and relatively protected despite the human trampling that was observed throughout the area. In contrast, the high disturbance (HD) site shows features that include distinct human trampling, browsing and grazing by domestic animals, in addition to the illegal practice of deliberate cutting of large trees for either fuel or honey by local people. Another distinction between the two sites is the nature of the forest canopy which is distinctly half open in HD site compared to a half open to closed canopy in the LD site respectively. The density (no of stems ha^{-1}), mean of height ± sd (standard deviation) and total basal area (m^2 ha^{-1}) of dominant tree species in the study plots of LD and HD sites are given in Tables 1 and 2.

Figure 3. Litter trap for litter collection in the forest.

Litter traps preparation

For the litterfall collection, litter traps (1 m^2) made of wooden frame was constructed (Figure 3). The 1 m^2 traps were supported at each corner by wooden stakes so that at the rim they were 80 cm above the ground. Each trap consisted of a wooden frame which was suspended a net with a mesh size of 2 mm allowing for the rapid drainage of rainwater.

Sampling for litter-trap installation

Five plots of 900 m^2 (30 m × 30 m) each were randomly selected from *LD* and *HD* sites of the forest. Two litter traps were installed within each plot with a total of ten traps in each site of the forest. Litter traps were installed on 4th February, 2014 on all sites of the forest. Litterfall was collected at monthly intervals for 12 months (4th March 2014 to 3th February, 2015) giving a total of 240 collections throughout the whole sampling period. However, the average of two replicates in each plot was taken as one in each sampling period for data analysis.

Litterfall was transported to the laboratory where it was oven-dried at 80°C for 24 h to constant weight. Litter was then sorted into four litterfall fractions (components) including leaf, twigs < 2 cm in diameter, reproductive parts (flowers, fruits, and seeds) and fine litter/trash (any material passing through a 2-mm sieve, hereafter referred to as "other". These fractions were oven dried at 80°C to a constant weight and weighed on a digital balance.

Data analysis

The collections in each month were combined to obtain litterfall data per month. To calculate the amount of litterfall production per plot, all the oven-dry weights of the litterfall from a plot was added up to get the total litter mass (gram). Then, mass unit conversions were made to express the value in ton $ha^{-1}year^{-1}$ basis (1 g m^{-2} = 0.01 t ha^{-1}).

The mean monthly dry weights of litterfall in wet and dry season were compared between each other and also between low disturbed (LD) and high disturbed (HD) sites of the forest. A monthly dry weight of litterfall (ton ha^{-1}) from each site was analyzed for mean variation using independent samples t-test. The Percent contributions of each fractions of litterfall to the total litterfall were calculated. Simple linear regression analysis was used to determine the effect of mean annual rainfall and mean annual temperature on a given litter variables. Moreover, one way ANOVA was used to test the significance difference in different categories between the low and high disturbed sites of the study forest. Significance level was determined at 95% CI. All the statistical analysis was done using $R_{3.1.1}$ (R Core Team, 2013).

RESULTS

Litterfall production

Significant differences (P < 0.01) in litterfall production between the LD and HD sites were detected (Figure 4). Annual litterfall production in the LD and HD sites averaged 10.76 and 6.64 ton $ha^{-1}year^{-1}$ respectively (Figure 4). Litterfall production of the Botor Becho forest averaged 8.7 ton $ha^{-1}year^{-1}$.

Litter fractions: Leaf litter, reproductive parts, other, and twigs

The level of disturbance between sites significantly ($P < 0.01$) affected the proportion of litter fractions (Tables 3 and 4). Leaf litter in the LD and HD sites averaged 42 and 49% whereas both twigs and reproductive parts averaged 58 and 50% of the total annual litterfall, respectively (Table 4). Leaf litter contributed the most (45%) to litterfall production compared to reproductive parts (24.13%), other (15.92%), and twigs (14.95%), respectively (Table 5). The generally higher proportion of reproductive parts during March, April, December,

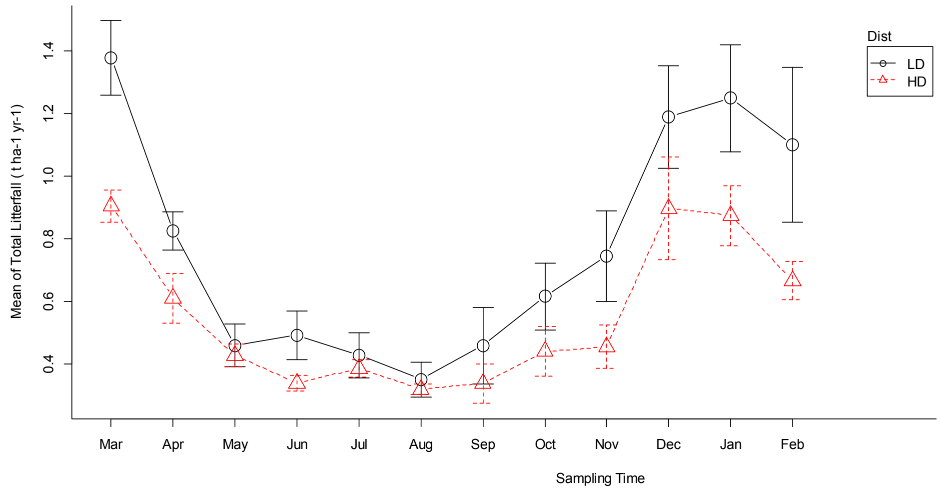

Figure 4. Monthly litterfall production associated with LD and HD sites. Vertical bars indicate the s.e. of the means.

Table 3. ANOVA test for the mean litterfall (t ha^{-1}) fractions between LD and HD sites.

Litter fractions	$F_{1,118}$	*P* value
Total litterfall	11.830	0.001**
Leaf	8.787	0.004**
Reproductive parts	26.04	< 0.001**
Twigs	17.118	< 0.001**
Other	8.436	0.004**

**Significant at P < 0.01.

Table 4. Annual litter fall variation in the study sites.

Sites	Litterfall (t ha^{-1}year^{-1})					
	Leaves	Rep. parts	Twigs	Other	Total	No. of samples
LD	4.54	2.69	1.60	1.92	10.76	60
HD	3.28	1.51	1.00	0.85	6.64	60
Total	7.83	4.20	2.60	2.77	17.40	120
Percent	45.00	24.13	14.95	15.92	100	

January and February in both LD and HD sites of the forest may indicate that flowering and fruiting is occurring in some of the forest species.

Apparently, both wet and dry seasons significantly ($P < 0.05$) affect litterfall production in the forest ecosystem (Table 5). Total litterfall in both sites followed a multimodal distribution pattern in which litterfall peaks occurred in March, April, December, January and February with higher peaks in March and December (Figure 4) where March indicates the onset of wet season and December indicates the onset of the dry season. The components and the total litterfall also showed significant difference between wet and dry season in the forest (Table 5). Monthly litterfall in the wet season averaged 0.5586 ± 0.04 ton ha^{-1} compared with 0.844 ± 0.06 ton/ha in the dry season.

The effect of climatic variables on litterfall dynamics

Both litterfall components and litterfall production were significantly correlated to mean monthly temperature and

Table 5. ANOVA test for the mean litterfall (ton ha^{-1}) fractions between wet and dry season.

Litter fractions	$F_{1,118}$	*P* value
Total litterfall	15.811	<0.001**
Leaf	10.983	0.001**
Reproductive parts	11.393	0.001**
Twigs	23.790	0.001**
Other	19.144	<0.001**

**Significant at P < 0.01.

Table 6. Coefficients of correlation (Pearson's) and R^2, *F* and *P* value between mass of litterfall and mean monthly rainfall of the *Boter Becho* forest.

Litter type	*R*	R^2	$F_{1,118}$	*P* value
Leaf	0.546	0.298	50.2	<0.001**
Rep. parts	0.516	0.266	42.87	<0.001**
Twigs	0.564	0.296	49.54	<0.001**
Other	0.494	0.244	38.11	<0.001**
Total	0.551	0.318	55.05	<0.001**

**Significance level at P<0.01, Rep.parts = reproductive parts.

Table 7. Coefficients of correlation (Pearson's), R^2, *F* and *P* value between mean monthly temperature and litterfall.

Litter type	*R*	R^2	$F_{1,118}$	*P* value
Leaf	0.293	0.086	11.073	0.001**
Rep. parts	0.258	0.067	8.443	0.004*
Twigs	0.077	0.006	0.712	0.400^{ns}
Other	0.070	0.005	0.576	0.449^{ns}
Total	0.215	0.046	5.716	0.018*

**Significance level at P ≤ 0.001, ns = not significant, * significance level at P<0.05.

mean monthly rainfall (Tables 6 and 7). The regression model explained (30.4%) of the variation in total litterfall in the forest. However, from the analysis rainfall had a relatively more significant ($P < 0.001$) effect on the amount of litterfall than temperature.

DISCUSSION

Litterfall production in the moist evergreen montane forest of Boter Becho averaged 8.7 ton $ha^{-1}year^{-1}$. Litterfall production in both the LD and HD sites of the forest peaked in March, April, December, January and February. Maximum litter production occurred during March and April. In both sites, the leaf litter fraction contributed the highest portion to total litter production followed by the reproductive parts fraction. Litterfall production was strongly correlated with both seasonal rainfall and ambient temperature.

The average litterfall production of 8.7 t ha^{-1} $year^{-1}$ reported in this study for the Boter Becho forest is in agreement with results reported by other workers (Staelens et al., 2011; Chave et al., 2010; Yang et al., 2005; Murphy and Lugo, 1986; Rai and Proctor, 1986; Singh et al., 1999; Vituosek and Sanford, 1986; Williams and Gray, 1974). Apparently, the amount of total litterfall production reported in this study is in range with that reported for other tropical moist forests; 3.6 to 12.4 t ha^{-1} $year^{-1}$ (Vituosek and Sanford (1986). Litterfall production ranging between 9.7 to 12.6 t $ha^{-1}year^{-1}$ for broad-leaved plantation species and natural forest found in southern Ethiopia (Ambachew et al., 2012) is in agreement with results reported in this study. In equatorial rainforests litterfall production ranged between 5.5 and 15.3 t ha^{-1}

year^{-1} (Williams and Gray, 1974). Our results also concur with those reported from China where litterfall production ranged between 4.89 and 11.45 t ha^{-1} (Wang et al., 2008).

However, in India where dry tropical conditions prevail litterfall production ranged between 4.88 and 6.71 t ha^{-1}year^{-1} (Singh, 1992) which is considerably less than values reported in the present study. This difference may be attributed to differences in forest environments e.g. dry or moist tropical forests.

In the present study, the leaf litter fraction averaged 46% of the total litterfall production. This is considerably less than that reported by Gawali (2014) for Indian forests (46%) located in the sub-humid tropics and Wang et al. (2008) for Chinese forests (68%), respectively. Evidence of the greater contribution of leaf litter to total litterfall production in tropical and temperate forests is reported by other workers (Ewel, 1976; Hoque et al., 2015; Kumar and Tewari, 2014; Oziegbe et al., 2011) who also highlighted the importance of leaf litter in nutrient cycling in forest ecosystems.

Seasonal patterns of litterfall production

The observed monthly variation in litterfall production under both LD and HD in the Boter Becho forest may be attributed to prevailing seasonal factors particularly rainfall and ambient temperature. According to Liu (2012), both rainfall and temperature are good predictors of litterfall. The highest variation in the amount of annual litterfall in the Boter Becho is predominantly due to rainfall pattern as it was highly significant compared to temperature. It has been suggested that rainfall may have a two-fold influence on litter production as it may induce water stress in dry periods which increases shedding of senescent leaves whereas heavy rainfall at some time of a year force the shedding of non-senescent leaves. This cycle of events provides a nutrient pulse through higher qualities of leaf litter (Cuevas and Lugo, 1998; Johansson 1995; Morrison, 1991; Parker, 1983; Gosz et al., 1976).

It is also known that litter production follows a seasonal pattern with lowest values during wet seasons and highest values in dry seasons in tropical forest ecosystem (Sanches et al., 2008; Zhang et al., 2014; Scheer et al., 2009). The results are in agreement with this seasonal prediction, because litterfall production across all levels of disturbance was higher in the dry compared with the wet season. Similar results were reported under tropical conditions within the dry season (Ewel, 1976; Gawali, 2014; Arunachlam et al., 1998; Sundarapandian and Swamy, 1999). As expected, disturbance affected the rate of litterfall production which was greater in the LD compared with the HD sites. Similar studies were done previously support this finding (Barnes et al., 1998; Didham, 1998).

Conclusion

It is concluded that litterfall production in the Boter Becho moist evergreen montane forest followed multimodal distribution pattern in which litterfall peaked in March, April, December, January and February with maximum peaks observed in March and December. It is also concluded that even if the mean annual air temperature in wet season was relatively higher than that of dry season, the dry weight of the total litterfall and its fractions in dry season were significantly higher in both sites of the forest. Of the fractions in the total litterfall in both sites, leaf litter contributed the highest portion followed by the reproductive parts in the forest. A seasonal and annual variation in litterfall production was mainly driven by rainfall variation. Accordingly, future changes in seasonal rainfall patterns in response to anthropogenic disturbance as well as climate change will likely have direct and indirect impacts for the litter dynamics of Boter Becho forest. Consequently, monitoring litterfall production of the Boter Becho forest does not only provide a biological gauge of its health status but also provides essential biological information for decision-makers to develop appropriate management measures for its conservation or sustainability.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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