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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

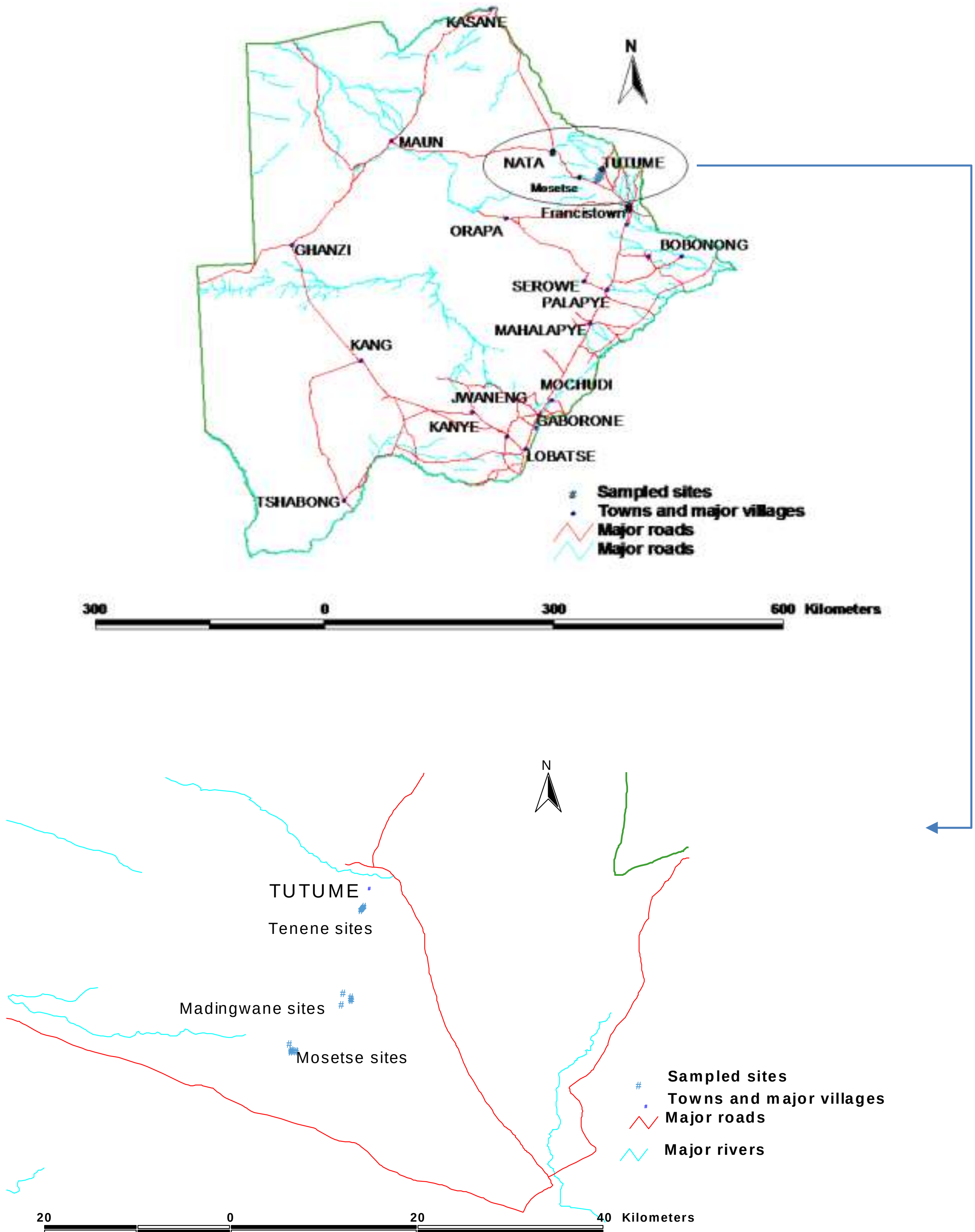

Figure 1. Map of Botswana showing study sites (upper map). Location of study sites within the study area (lower map).

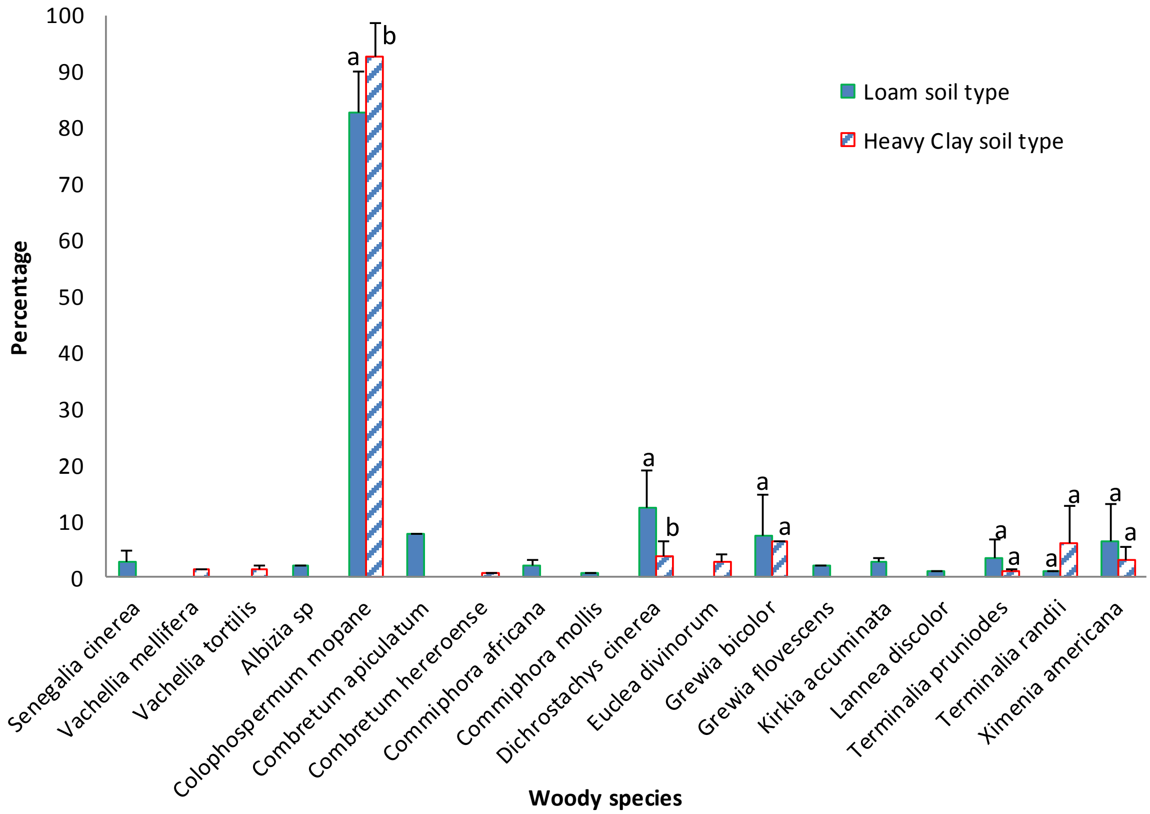

Figure 2. Relative abundances of each woody species recorded in the two different soil types in the studied sites. Species with same letter above the bars are not significantly different whereas those with different letters are significantly different. T-test was used to test the significancies of the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

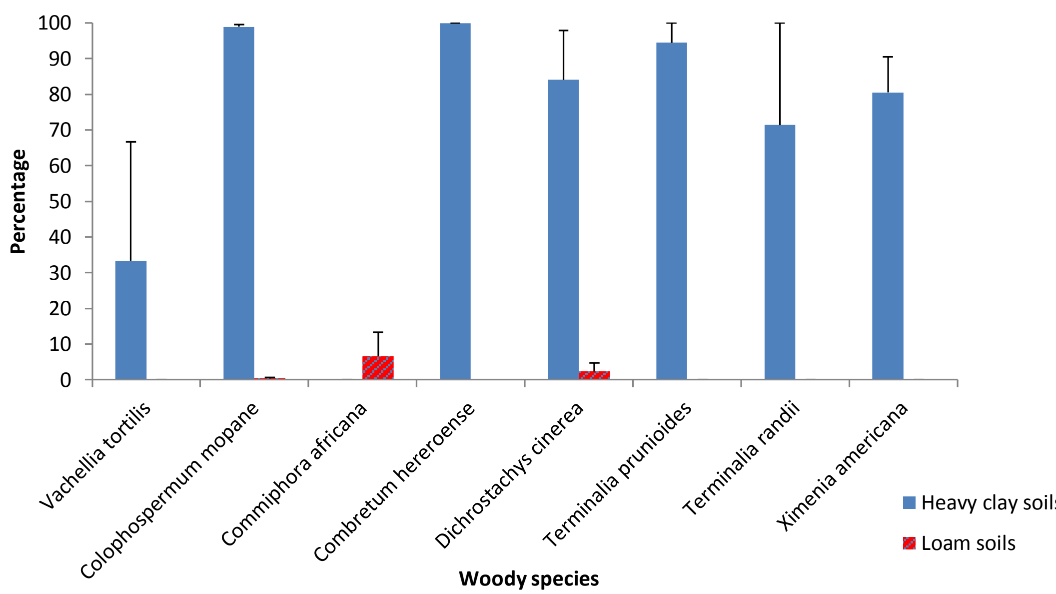

Figure 5. Percentage number of plants with dieback of each species under the two soil types cartegories.

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 =

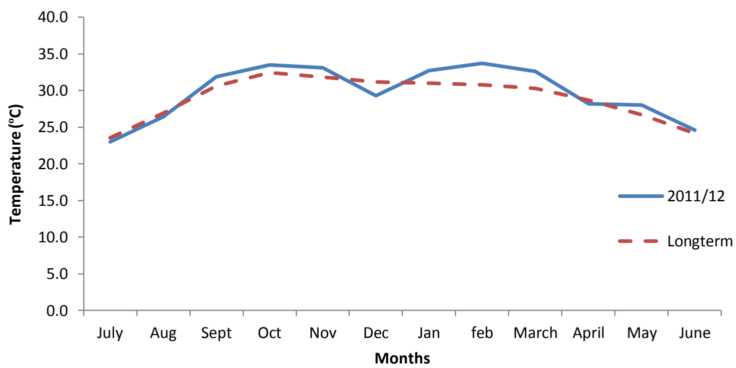

Figure 6. Mean maximum temperatures for Francistown from July 2011 to June 2012. The data was provided by the Department of Meteorological Services, Botswana.

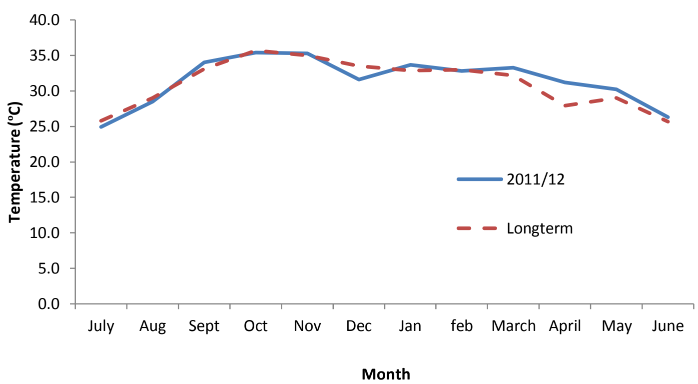

Figure 7. Mean maximum temperatures for Sowa town from July 2011 to June 2012. The data was provided by the Department of Meteorological Services, Botswana.

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

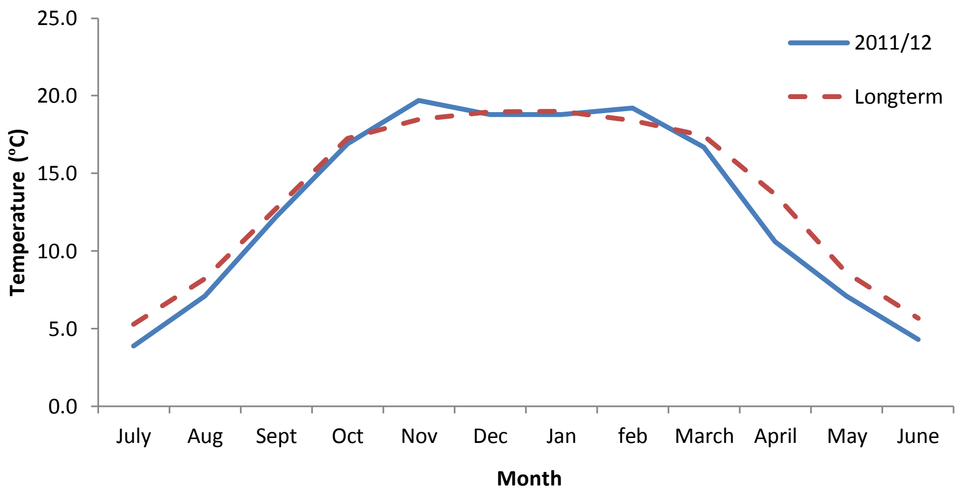

Figure 8. Mean minimum temperatures for Francistown from July 2011 to June 2012. The data was provided by the Department of Meteorological Services, Botswana.

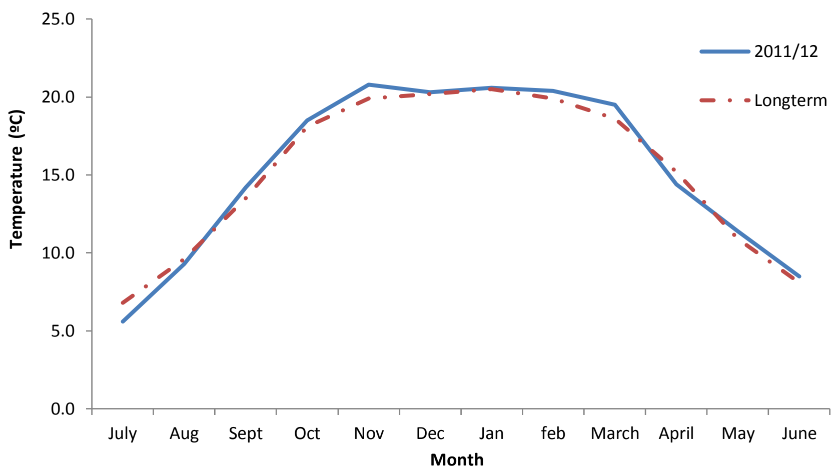

Figure 9. Mean minimum temperatures for Sowa town from July 2011 to June 2012. The data was provided by the Department of Meteorological Services, Botswana.

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

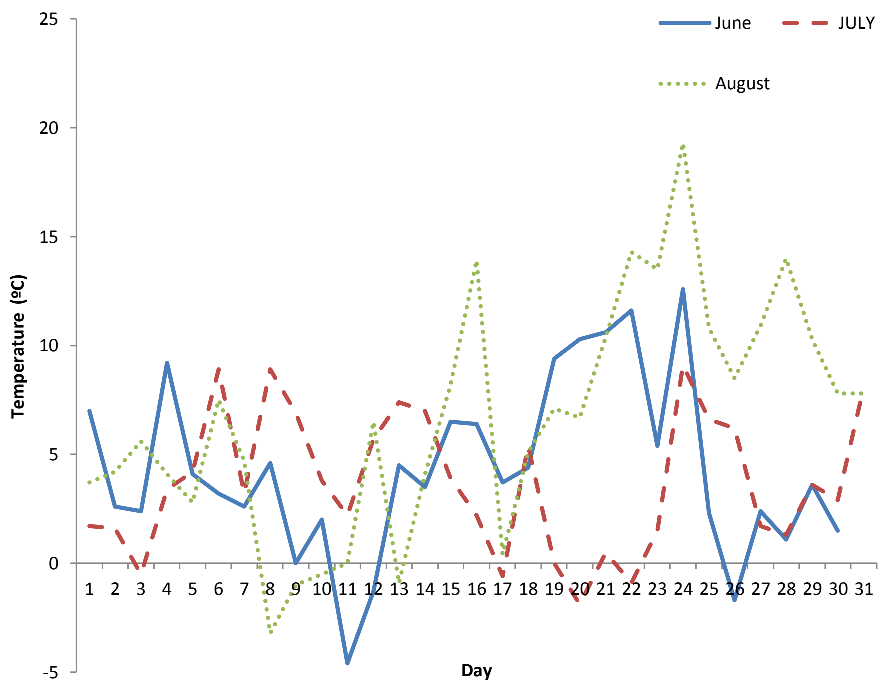

Figure 10. Daily minimum temperature for June, July, and August 2012 for Francistown. The data was provided by the Department of Meteorological Services, Botswana.

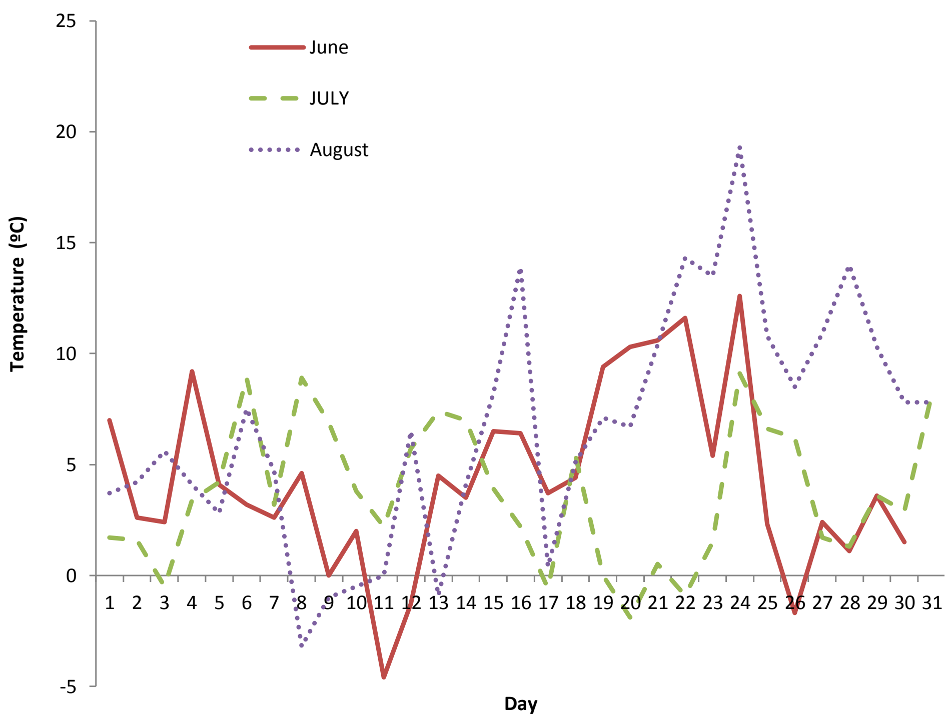

Figure 11. Daily minimum temperature for June, July and August 2012 for Sowa town. The data was provided by the Department of Meteorological Services, Botswana.

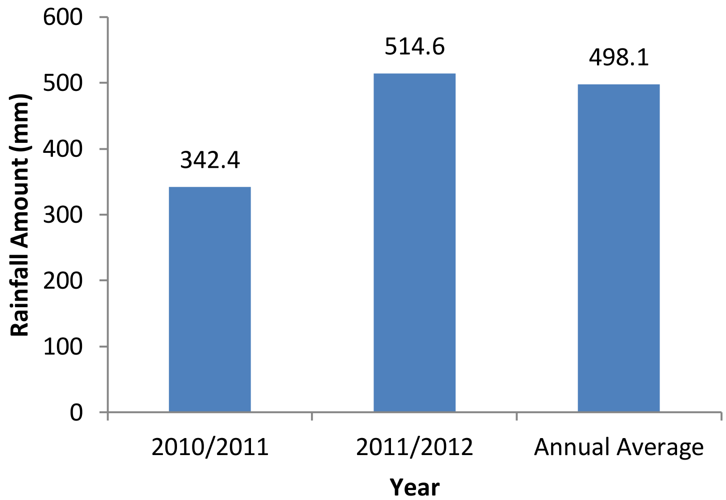

Figure 12. Annual rainfall amount for Tutume Village and its long term annual average.

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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