Pterocarpus angolensis growth rings and precipitation: A comparison between Zambezi and Otjozondjupa region, Namibia

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ABSTRACT

Pterocarpus angolensis is one of the most valuable species used for timber in Southern African countries. In Namibia, the species has been harvested for over 90 years for both commercial and domestic use. This is likely to lead to unsustainable management if efforts to understand the growth and response of the species to environmental conditions are not made. This study aimed to compare growth rings to precipitation in Zambezi and Otjozondjupa regions. Ten trees were sampled and from the disks, tree ring widths with two radii were measured with a microscopic device. Crossdating was carried out to construct the indexes, which was used to prepare the master of chronology. The findings show that the rainfall amount is not necessarily the limiting factor, as a weak correlation in both regions was found, regardless of the amount of rainfall received in the region. The results show a better correlation, though negative, between the months of September and December. Further studies are required that use precipitation data for stations near study sites and the consideration of other factors such as soil, temperature and fire regimes. The use of rainfall data from much less distance to the study site are recommended as well as the consideration of soil, temperature and fire aspects.

1 Introduction

Pterocarpus angolensis is a dry woodland Savanna tree species belonging to the family of the leguminous Fabaceae and can be found in Southern Tropical Africa regions. *Pterocarpus angolensis* is rated as one of the best and most generally used of all woods in Southern Tropical Africa (Palgrave, 2002; Vermeulen, 1990). The species is exceedingly used for timber wood to an extent that the concern for sustainability has been raised in many countries (Vermeulen, 1990; Mendelsohn and Obeid, 2005; Therrell et al., 2007; Van Holsbeeck et al., 2016). The popularity of the species can lead to unsustainable utilisation, which in turn will likely to have adverse impacts on the existence of the species.

To manage the trees and forests at large, dendrochronology studies have been used across the globe to understand how trees and other woody plants respond and relate to the site's environmental conditions. Annual tree growth rings archive the state of environmental conditions in which the characteristics of rings were formed (Fritts, 1976; Acosta-Hernández et al., 2017). To date, dendrochronological records form an important natural archive for studies of climate change and climatic reconstructions based on such records demonstrate the variations on the past temperature and rainfall aspects while also giving clues about future climatic patterns (Jonsson et al.,

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2002; Fritts, 2012; Novak et al., 2013; Nath et al., 2016; Anchukaitis, 2017). With the pronounced seasonality of rainfall, tropical and subtropical species can form annual growth rings (Zacharias et al., 2018). Changes from a wet season to a dry season result in the trees losing or producing new leaves, and new growth rings are formed in response to the wet-dry cycles (Gourlay, 1995; Worbes, 1999). Namibia has distinctive wet and dry season, and for the *Pterocarpus angolensis*, as a deciduous tree, its leaves fall during the dry-cold season (May to June) and new ones emerge during the dry season from September to December (Vermeulen, 1990; Fichtler et al., 2004).

As a result of intense logging (Siyambango, 1996), several studies aimed at understanding ecological dynamics have been carried out (Van Daalen, 1991; Van der Riet et al., 1998; Chisha-Kasumu et al., 2007; Strohbach and Petersen, 2007; Mwitwa et al., 2008; Moses, 2013; De Cauwer et al., 2014; Kayofa, 2015; De Cauwer, 2016; Graz, 2004). However, the dendrochronological aspect has been largely neglected. Only three studies have been carried out on growth rings of *Pterocarpus angolensis* in Namibia, with largely a focus on age, stem diameter and height (Worbes, 1999; Van Holsbeeck et al., 2016; De Cauwer et al., 2017) and only one study focused on the correlation of its growth rings to climatic factors but it focused on comparing the regions along the Northern borders of Namibia, namely Oshikoto and Zambezi region (Fichtler et al., 2004).

Despite *Pterocarpus angolensis* being in most abundance in the Zambezi and Otjozondjupa regions (Palgrave, 2002; De Cauwer, 2015), growth rings of *Pterocarpus angolensis* species have not been studied in the Otjozondjupa region. Furthermore, all other regions where species have been studied all fall within the same woodland vegetation structure, while Otjozondjupa region falls under different vegetation structures, namely the shrub-woodland mosaic vegetation structural class (Mendelsohn et al., 2002). A comparison of different environments is crucial to understand the growth dynamics for managing the species accordingly. Therefore, this study aimed at comparing the growth rings correlation between Zambezi and Otjozondjupa regions.

2 Materials and Methods

2.1 Study Area

In Namibia, the species is distributed over the north-eastern part of the country, mainly in Oshikoto, Ohangwena, Kavango, Otjozondjupa and Zambezi regions. It has an open, spreading crown and is found in three vegetation structural classes, the woodland, shrub-woodland mosaic and the wooded grasslands (Mendelsohn et al., 2002; Palgrave, 2002). This study was carried out at two sites, Otjozondjupa (19.535090 and -19.288380) and Zambezi (24.047720 and -17.659062) (Fig. 1). In these areas, the soils are Aerosols which are poor sandy soils. The annual rainfall ranges from 300 to 900 mm whilst annual temperatures range from 20°C to 22°C (Mendelsohn et al., 2002). In these regions, a medium sized tree can grow up to an average of 6 metres in height and can reach up to 20 meters under favourable conditions (De Cauwer, 2016).

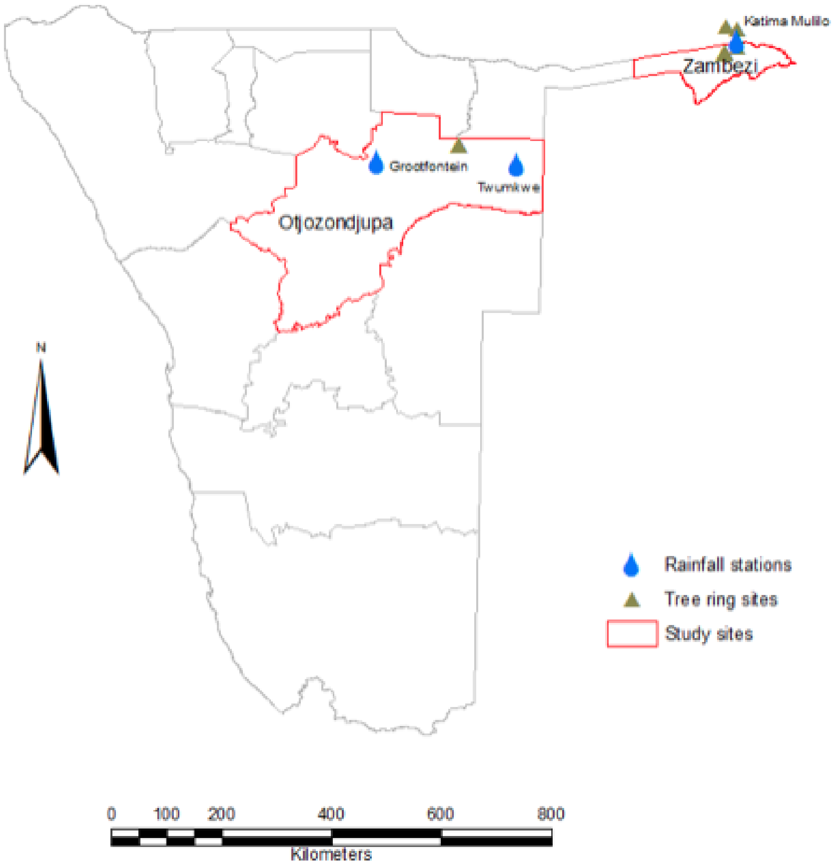


Figure 1: Study sites

2.2 Data collection and sample preparation

Trees were selected at random, using visual judgement of the best tree without defects. A minimum of at least 100 meters was used to locate the next tree to sample. Disks were cut off from the top of the boles ($1.3m$ height). Cross-sections of the disks were removed from the stump to reduce the weight of the disks for handling. The average diameter of the cross section of the stump was used to estimate the diameter of the sample disks which had to be removed from the stump. Samples of 10 trees from *Pterocarpus angolensis* were collected during the fieldwork, five from each region. However, due to transportation problems, one disk was destroyed and one of them was unable to have measurements taken due to defects in the sample. Therefore, only eight tree disks were left for analysis, five from the Zambezi region and three from the Otjozondjupa region. Disks need to be prepared for efficient cross dating and ring width measurements. Each sample was prepared for measurement using a razor blade, which gives a clean surface and clear ring boundaries. Pilcher (1989) and Fritts (1976) recommend that for sanding, ranges of grit sizes from 220 to 600 are quite satisfactory for most purposes. In this case, because of the hardness of the wood, the surface was sanded with grit sizes ranging from 100 to 800. This gives a fine surface to clearly identify the boundary of the tree rings.

The focus of this study is on rainfall and ring width and its relationship with tree ring width. Therefore, rainfall data were obtained from the Meteorological service in the Department of Transport of the Ministry of Works, Transport and Communication. The data were collected from stations that are close to the sites. Therefore the data came from two stations within the general area of the study site. For example, the closest rainfall stations in Otjozondjupa were Tsumkwe (20.5330, -19.5830) and Grootfontein (18.1330, -19.5670), which are 110 and $250\,km$ away from the site respectively. For Zambezi region, there was one station available within $50\,km$ to the site (Katima Mulilo) (24.2500, -17.4670). The rainfall records minimised the data that could be included in the analysis. The precipitation data from Zambezi region was from 1945 to 1978. There was a ten-year span of data missing from 1979 to 1989, hence the analysis concentrated only on available data. This reduced the number of data points to be tested from 57 data points to 29, that is, half of the data set. Similarly, the precipitation data available for Otjozondjupa region are from 1964 to 1999. There were no rainfall records in Otjozondjupa region but the number of rings was more than the rainfall records hence the analysis was restricted to the available rainfall records. Therefore the data included in the analysis was reduced from 78 data points to 33.

2.3 Cross-dating and measurement of ring widths

The fundamental principle of dendrochronology is crossdating, which is defined as the procedure of matching ring width variations (Nash, 2002; Fritts, 1976). This allows the identification of the exact year in which the ring was formed. Crossdating is important because it allows the identification of missing rings as well as false rings. During stressful years, for example drought, many species fail to produce rings, which leads to missing rings. On the other hand, species may produce double or false rings. This happens when the tree starts growing at the beginning of the growing season. When the stressful climatic conditions return at a certain time of the season, it leads to a general decrease in the rate of tree growth. If a favourable condition returns again during that growing season, the cells will begin to grow again (Nash, 2002), hence the structure and formation of the cells will look like those of two growing seasons, and thus it becomes difficult to distinguish from the true rings at the end of the growing season.

Crossdating is important in this study. It enables the comparison of the rainfall amount with tree growth during a particular growing period. Crossdating was done with visual observation and plotting ring width using Excel spreadsheet. This enabled the identification of the patterns in tree ring width within the two radii measured on each disk and between disks from the same site. Since the year in which the disks were cut was known, this served as a starting point for crossdating by observation. Identifying the year in which the ring was formed was possible from the outer tree ring, hence, working from the edge of the ring towards the pith of the ring from both radii, one is able to relate similar ring width, structure and formation of the ring. This also helped to identify the year in which the ring was formed.

To enable correlation of tree rings with rainfall data, crossdating of rings to the exact year and ring width measurement is crucial. Therefore, it is important to ensure that these figures are correct. The measurement of the ring width was done with a microscopic measurement machine in millimetres (mm). As in any measurement system, there is a possibility of machine and human error (Pilcher, 1989). The measurement of the tree ring boundary depends on the judgement of the operator (human error) while the machine measurement error is caused by the poor quality of screw threads or slippage on moving stage measurement machines (Pilcher, 1989). Because of this, four disks were remeasured. These samples were from the disks with narrower ring widths and some missing rings. The samples with wider rings were easier to cross date and measure. Crossdating prepared data to construct the index of each sample, which was used to prepare the site index, and this is called the master of chronology.

2.4 Master of chronology

After the crossdating and measurement, the two radii were averaged to obtain a ring width for each specimen (example in one sample per site in Table 1). The average was carried out for all specimens. This value was then used to estimate the expected growth in a specified year. The site indexes for Otjozondjupa and Zambezi regions date back to 1921 to 1999 and 1942 to 1999 respectively. The running means or sometimes called “moving averages" method was used to estimate the expected value. This method is used to study the variance (Fritts, 1976). Basically, moving averages are ring-width averages for a given number of consecutive rings. The sequence is moved ahead by one year and each time the average is computed (Fritts, 1976).

In this paper, the five-year average mean was computed. The first value is the mean of x_1, x_2, x_3, x_4 and x_5, the second is x_2, x_3, x_4, x_5 and x_6 and so on. The year of the central ring is assigned to the average in that sequence. The purpose of averaging is to smooth the year to year variability in proportion to changes occurring over periods greater than the five years duration (Fritts, 1976). The value of the running mean is used to compute the tree ring index for each specimen using the following formula:

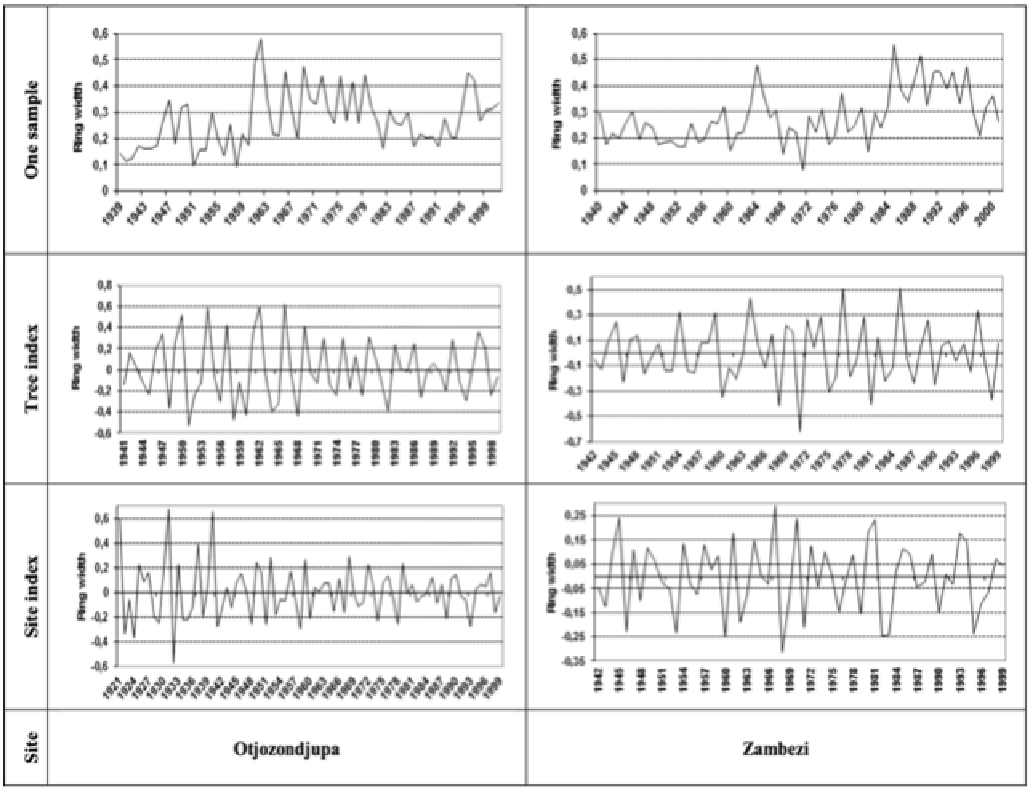
$$TI = (AV + EV - 1), \tag{1}$$

where TI = Tree Index, AV = Actual value, that is the average of two radii for each tree ring and EV = Expected value, that is, the five-year moving average. The tree index for each sample was computed.

3 Results

The values of the Tree Index have negative and positive values (Table 1). A negative value means that the growth in that particular year was below the average growth, while a positive value means that the growth in that particular year was above the average growth. The average Tree Index from the same site yields the Site Index, called the Master of Chronology. The results are used in section 3 to test for a correlation between precipitation data and the Site Index.

Table 1: Ring widths and indexes for each site



Correlation analysis was used to assess the relationship between rainfall and tree ring widths and the growth of the tree in that year. The value less than zero means that in that particular year, growth was below average. The test reveals that there is a negative correlation between the rainfall and tree ring growth, except for the last four months of the previous periods. Even though there was a positive correlation in these figures, it was not significant. Hence from this observation, it is concluded that rainfall is not the main limiting growth factor.

The coefficient of determination for Otjozondjupa region are more negatively related compared to those of Zambezi region (Fig. 2a–2c and 3a–3c). For the complete season, $R^2 = 0.0013$ in Zambezi while $R^2 = 0.0559$ in Otjozondjupa. The first four months (September - December) have $R^2 = 0.2143$ in the Otjozondjupa region, while $R^2 = 0.0257$ in the Zambezi region, and $R^2 = 0.0055$ in the Zambezi region compared to $R^2 = 0.0099$ in the Otjozondjupa region for the last four months (January - April) of the season.

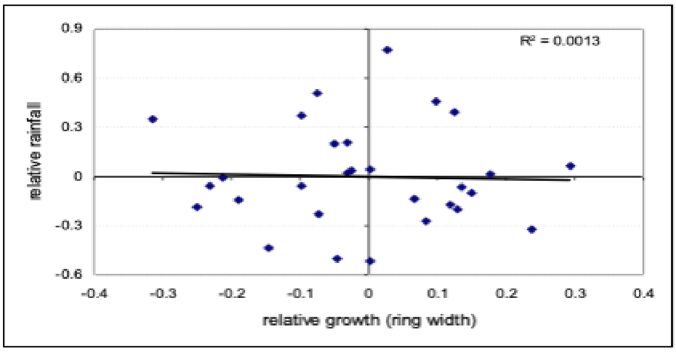


Figure 2a: Whole season period in Zambezi region, rainfall and tree ring width indexes

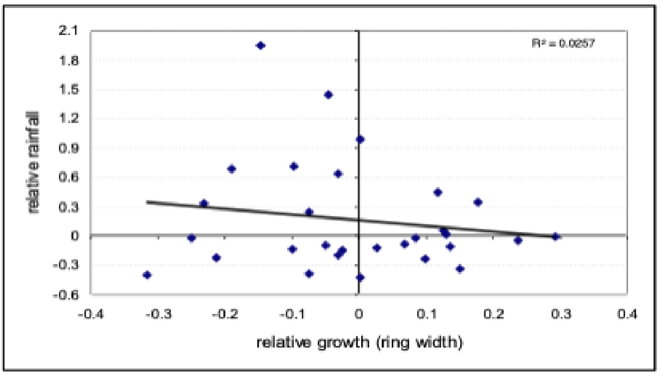


Figure 2b: First four months of the season period for Zambezi region, rainfall and tree ring width indexes

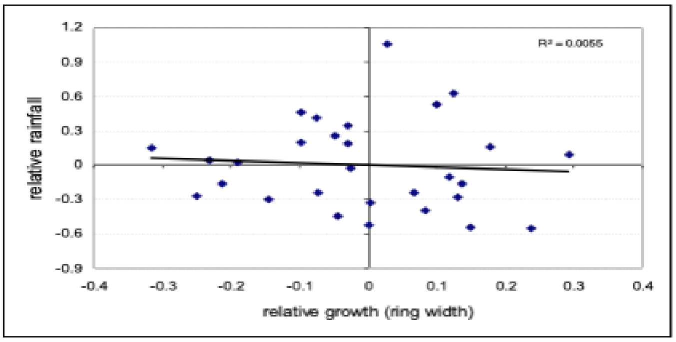


Figure 2c: Last four months of the season period for Zambezi region, rainfall and tree ring width indexes

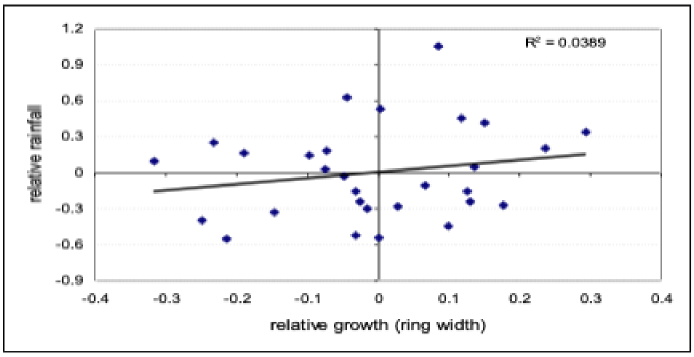


Figure 2d: Last four months of the previous season period for Zambezi region, rainfall and tree ring width indexes

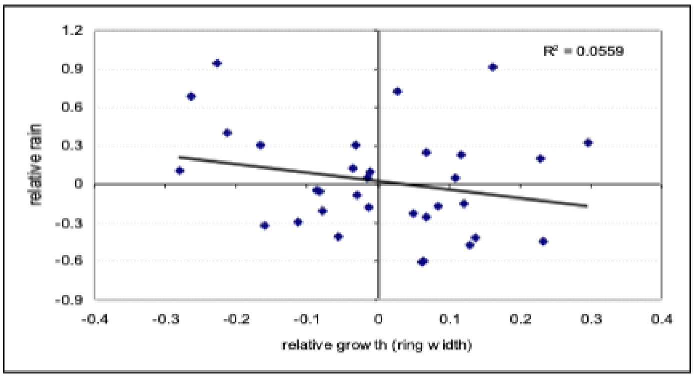


Figure 3a: Whole season (eight-month period) for Otjozondjupa region, rainfall and tree ring width indexes

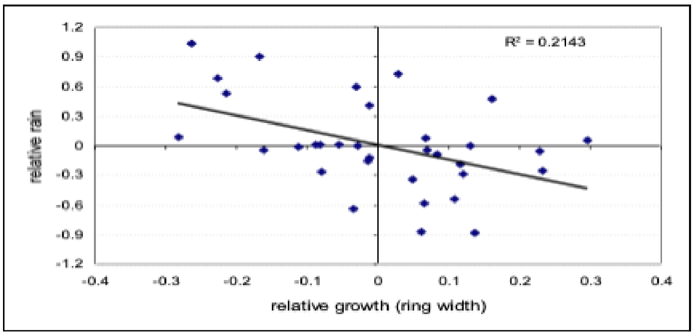


Figure 3b: First four months of the season period for Otjozondjupa region, rainfall and tree ring width indexes

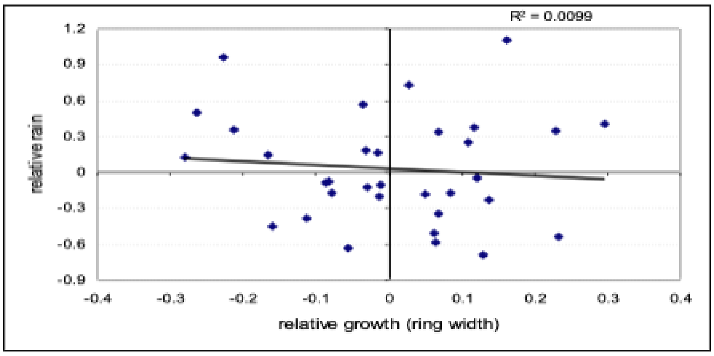


Figure 3c: Last four months of the season period for Otjozondjupa region, rainfall and tree ring width indexes

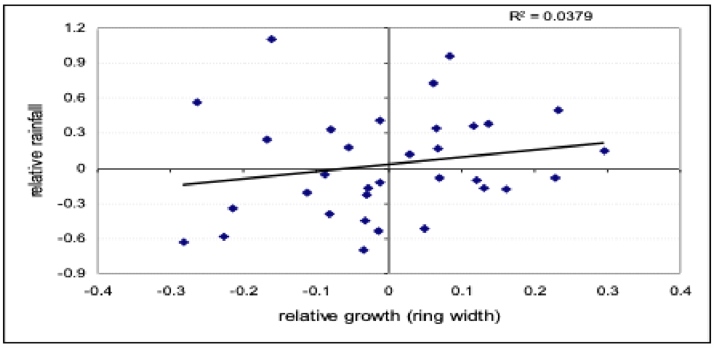


Figure 3d: Last four months of the previous season period for Otjozondjupa region, rainfall and tree ring width indexes

4 Discussion

The study assessed the relation of tree ring to the rainfall amount by comparing correlations in two regions with different rainfall amounts. All correlations were negative, except for the last four months of the previous season period in both regions. This implies that as the rainfall increases, the growth decreases. This is caused by rainfall extremes. There were a number of cases where the rainfall was far above the average. For example, in February 1958, Zambezi region had the highest rainfall record of $881\,mm$. This was the highest ever recorded in the set of data at hand. This contributed much to the coefficient of determination in Figure 2a and 2c, hence the negativity of the slope. Even though the tree growth was above average, it is relatively less compared to the amount of rainfall that falls in that particular year. In addition, there was a rainfall station in the Zambezi region which was only $50\,km$ from the sample site. One would have expected the correlation to have improved compared to Otjozondjupa region but still, there was a weak correlation. This suggests that testing will yield the same results regardless of distance from the rainfall station, even though rainfall within $40\,km$ can be variable through time and place.

Vermeulen (1990) argues that once *Pterocarpus angolensus* are established, they are capable of growing under extreme conditions. Vermeulen (1990) further describes the species growth characteristic as genetically controlled with the factors determining growth rate closely linked to those governing the size of the tree. A study carried out by Boaler (1966), as cited in Vermeulen (1990) revealed that there is great variability in the tree growth rates of individual trees. This means that each tree grows independently depending on the surrounding factors affecting it. Thus, external environmental factors play a very little role in determining the behavioural growth of the *Pterocarpus angolensis* and make it difficult to compare the effect of climate on the species because of variability growth within individual trees. This information supports the findings of previous studies, that more rain does not necessarily mean more growth. In addition, there is a river that runs to the north of the Zambezi region. If the species can survive on a water table of about $70\,m$ under the ground, trees which are closer to the river may be able to tap water from the water table even though there was not enough rain during the rainfall season. Furthermore, if growth is genetically controlled, high rainfall may not affect growth and only minimum rainfall may be required. Minimum rainfall was obviously achieved since there was no record on hand that shows zero rainfall in any year. This feature has been highlighted by other species such as the *Senegalia mellifera* Shikangalah et al. (2020) that grow in the same vicinity of *Pterocarpus angolensis* especially in Otjozondjupa region and the same trait is also demonstrated by similar species that are along the riverine such as *Faidherbia albida* (Bester, 2013; Sweet, 1998).

One of the most important parameters mentioned by Vermeulen (1990) is the strong taproot with a number of lateral roots that a species develops during the early development stage. These roots spread radially for about 6 to 8 meters (Vermeulen, 1990). This enables the species to efficiently utilise both above ground water during the rainy season and the water table during the dry season. For example, during the winter season, the temperature was a limiting factor, but not necessarily rainfall or soil moisture, and if there is enough soil moisture from the water table, the species will be able to start growing again in early spring when the temperature becomes favourable. This is the case of *Senegalia mellifera* as that species has an extensive root system with a length of over $30\,m$ deep (Namibia Agricultural Union, 2010). Fritts (1976) argues that most limiting conditions to plant processes can change throughout the year so that one particular climatic factor may be directly correlated at one time and totally uncorrelated at other times. For example, during the spring, growth may begin earlier in a warm year than in a cold year. In such cases, temperature would be directly correlated with ring width and later in the growing season when the temperature is higher, hot weather may be the limiting factor (Fritts, 1976). This is because hot weather can limit the production of enzymes and hormones that are necessary for certain plant processes to occur (Fritts, 1976), therefore temperature becomes inversely correlated with ring width.

Another possible factor that might affect growth is fire. The intensity and frequency of fire can play an important role in tree growth (Florence, 1996). There were no fire records in the area but the signs of fire were apparent during fieldwork in most of the plots. Fire may cause a significant reduction in the total growth of a stem if a substantial part of the foliage is destroyed (Fritts, 1976). Fire may also destroy competition in a strand of trees (Fritts, 1976), and open up a canopy to allow light to reach plants in the lower strata of the vegetation (Vermeulen, 1990). Vermeulen (1990) describes *Pterocarpus angolensis* as more fire resistant than other species that it is associated with, therefore it can survive fire and also capitalise on the ash nutrients that have been released by fire. Of course, during the fire period the growth will halt, but the growth response following the fire could be above average growth compared to the precipitation in that particular year.

Apart from weak correlation, there was a significant difference in ring sizes between trees and differences in growth on opposite sides of the same trees. Fritts (1976) states that this could result from variations in the structure of the forest stand, the stem, and competition from neighbouring trees. Fritts (1976) further states that this normally happens if climate is not a highly limiting factor of tree growth. This is attributed to the tree leaning on one side. Probably the response was due to climate as well as physical factors. However, the two radii from the same tree mentioned above have different responses. The average of these rings' width as a ring width sample rather than one radius. These two radii were responding differently in terms of growth. Therefore a weak correlation from such ring is expected. There is a need to test for correlation between individual tree rings as well as the radius with the precipitation data.

5 Conclusion

Four tests were made to compare available rainfall data and tree ring width. The season was divided into three rainfall seasons. Events of the season were during the first and last four months of the season, and the whole season (eight months). The fourth period was the last four months of the previous growing season. In all data that were tested in the two regions, there was a weak correlation between rainfall and ring widths in all four-rainfall periods. This means that rainfall is not a major limiting factor of tree growth and as such it cannot be regarded as the main factor in a growth prediction model. Therefore, considerations need to be given to other factors such as temperature, water table, soil moisture, fire, defoliation, humidity and availability of nutrition. Because individual trees responded differently in terms of radius, there is a need to test for a correlation between individual tree rings and the precipitation data. The correlations are generally low most of the year, and Zambezi has even lower correlations than Otjozondjupa region, despite Zambezi having the high rainfall and more favourable soil conditions. Data from Tsumkwe were used because it was closer to the sample site, which assumes that the two areas have a similar rainfall distribution. For more accurate results, rainfall data from the same area would need to be obtained, which is impossible in this case.

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