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Dendrochronology in Namibia: A Review

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Abstract

More than 64% of Namibia's land is occupied by the savanna ecosystems which are vulnerable to climate change and variability. These ecosystems partly consist of forest ecosystem patches which are prime sources of many livelihoods in the country. The effects of climate change are likely to drive the majority of the country's population to poverty if these resources are not sustainably managed. Therefore an understanding of forest dynamics and their responses to climate is important. Dendrochronology is a study that provides time-series data of climate change and variability, and the responses of trees to such changes. The data are used to reconstruct past events of climate and also to forecast possibilities. Dendrochronological studies have been carried out in Namibia, however, a review of such studies is lacking. This study thus aimed at closing this gap and carried out a literature review on the dendrochronological studies in Namibia. The review showed that the field of dendrochronology is relatively new and has been less applied in Namibia. There is a need for further dendrochronological studies in order to understand how the country can adapt better under the current and forecasted climate regimes. A focus on the marginal forests, encroachers and trees that are of indigenous use, is recommended. In cases of the absence of clear ring formation, which might be the case in arid to hyper arid, the use of staple isotopes is recommended.

Keywords: Dendrochronology; Climatic conditions; Growth rings; Semiarid ecosystems; Namibia

Introduction

Dendrochronology studies have been used by ecologists worldwide to understand the vegetation and environmental conditions of the surrounding, as trees record past conditions. Trees are sensitive to environmental abiotic and biotic factors. Abiotic factors such as temperature (severity of dry seasons) and amount of rainfall are the most important to the development of the vegetation structure [1-4]. Sensitivity to abiotic factors can be used as a sensor or proxy for climate as various tree species respond to climatic variations differently in the formation of their annual tree-rings, especially in areas with distinct seasonality of rainfall [1,5-9]. These features are more pronounced in the Northern hemisphere compared to the Southern hemisphere. However, Southern hemisphere trees also possess growth rings that correlate with rainfall [10,11].

Climatic conditions are characterised by erratic rainfall and recurring drought periods [12-14], reinforcing flood events, periods of drought and the rate at which evaporation might be occurring. Due to dry climate conditions that are so variable, the dense tropical forests, especially the indigenous forest, are becoming rare while bush encroachment is slowly taking over [15,16]. Namibia is known for its remarkable variety of species and habitats and ecosystems and it is also recognised as a dryland with biodiversity hotspots [15]. However, they are greatly influenced by the variability of the climate regimes, thus making the ecosystems more vulnerable. Forest resources do not only contribute to the national economy, but they are also crucial for reducing poverty in the country. As a result of poor rainfall, there is an increase in poor cereal harvesting and a rise of land degradation has been reported [15]. The dating and reconstruction of long past periods from tree ring patterns to monitor vegetation growth and productivity during extreme climatic periods and specific events such as fire, and to also forecast the possible climate conditions in the country is therefore of utmost importance. Studies have been carried out in Namibia on tree rings and dating, relating to environmental conditions. However, there has not been a review of such studies in Namibia. This review paper therefore aimed at closing this gap by exploring the work done and outlining further dendrochronological opportunities in Namibia.

Literature review

The study of tree annual growth rings by dating the ring formation to specific years is known as dendrochronology. Several terminologies have stemmed from the concept of dendrochronology, depending on the issues to be studied. This includes terms such as dendroclimatology for particularly for looking into past climate variability [17,18], dendroecology which is the broader science field for drawing environmental information from tree rings such as fires and insect outbreaks [19,20], dendrogeomorphology which is a subfield of dendroecology and focuses on geomorphological processes such as flooding, rock fall activities or landslides, and river related vegetation processes [21,22], and dendroarcheology which focuses on dating wooden material from archaeological sites [23,24]. Decdrochronology has also been used for studying snow avalanches, volcanoes eruptions and earthquakes [25].

The use of dendrochronological studies to understand various past environmental aspects is common and has been used for many decades around the world. According to Worbes [26], Hartig [27] has used it to look into the periodic wood formations in temperate regions, whereas Brandis [28] focused on sustainable silvicultural systems, and Coster [29] analysed the anatomical description of the woods [26]. The basic aspects, the applications and progress in technical developments have been explained and documented in various reviews (Rosendaal & Zuidema 2011; Scweingruber 1988) [26,30-32]. In tropical regions of Africa, an increasing number of such studies have been carried by several scholars [2,9-11,33-35]. Despite the early arguments about the lack of distinct annual rings due to the absence of low temperatures and the presence of dormant winter seasons faced by trees in Southern Africa, particularly in tropical regions. Steenkamp, Vogel, Fuls, van Rooyen and van Rooyen [34] analysed some species and showed that trees are responsive to seasonal climate variations and this lead to the formation of annual growth tree rings.

Methods and Materials

Settings

Namibia is located in the South West part of Africa and occupies an areas of 825 418km. The perennial rivers are only located at the borders, with Orange River at the South, Kunene at the North West while Kavango river and Zambezi river are the North-Eastern part of the country. The interior of the country consists of only non-perennial rivers. The average annual temperatures are observed to range from 16°C at the coast to 20°C and 22°C in the interior of the country (see Figure 1a) [36]. The maximum temperatures experienced are over 34°C and the minimum in the coldest months is less than 2°C [12]. The average annual rainfall varies from the coast with less than 250mm to an average of 600m in the areas with the most rainfall (Figure 1b). Of the total rainfall that the country receives, it is estimated that 83% of the rainfall evaporates, 14% ends up used by the vegetation, 2% goes to runoff and 1% recharges the groundwater [15,37]. Despite the fact that so much less rainfall contributes to groundwater recharge, around 80% of the country depends on the groundwater system.

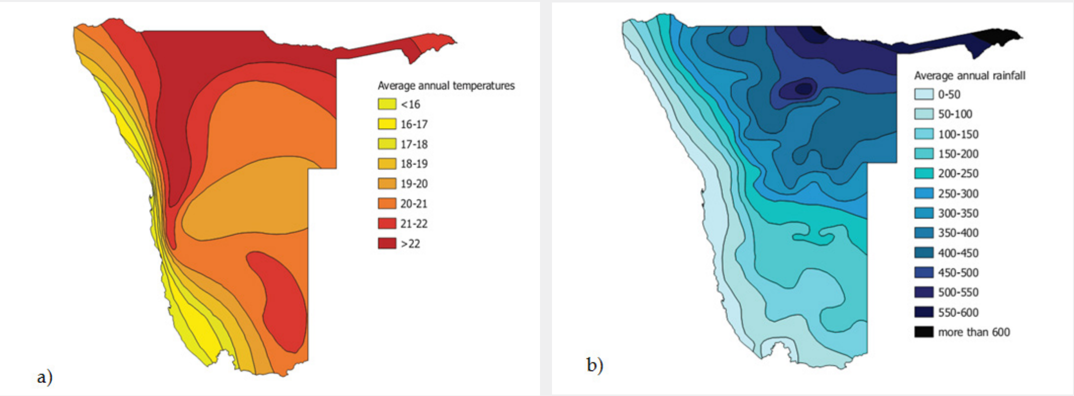

Figure 1: a) Temperature, and b) Rainfall of Namibia [36].

In the last country census [38], the Namibian population was estimated to be 2.1 million, and the current population estimation is 2.5 million, making the country one of the least densely populated in the world, with 3.13 people per square kilometre [39]. Traditional subsistence sectors are responsible for providing for the livelihoods, with main activities including mining, tourism, fishing and agriculture and at least 70% of the population depends on agricultural activities [40,41].

Arid to semiarid areas occupy at least 44% of the world land and these are responsible for nearly 38% of the global population [42-44]. These regions are climatically stressed by the limited rainfall, high temperatures and long dry seasons [45]. According to New [45], the mean temperature has increased by 0.25 degrees per decade since 1960 in Southern African semi-arid areas. Moreover, savanna trees, shrubs and grasslands cover most of the arid and semi-arid regions worldwide. Due to the sensitivity

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of vegetation growth to timing and variations in the local climate systems in Southern African tropical regions, savanna ecosystem functioning is greatly affected and in some parts of the region, the resultant changes are linked to decreased ecosystem productivity, thus land degradation [10,46,47].

At least 20% of Namibia is occupied by a desert region, 33% is arid, 37% is semiarid and 8% is covered by a sub-humid region (see Figure 2a) [48,49]. In Namibia, savannah trees and shrubs which are dominated by Acacia vegetation occupy up to 64% of the land; savanna broadleaved dry woodlands and forests cover 20%, and the desert region makes up 16% (Figure 2b) [50,51]. Forests around the country indicate that rare dense forests are generally scarce and they are described as dry, semi open to woodlands and these are largely located mostly in the deep Aeolian Kalahari sands (i.e. north-central-eastern part of the country) [54]. This is in spite of the fact that forest resources are used as a means to reduce poverty in communities around the country.

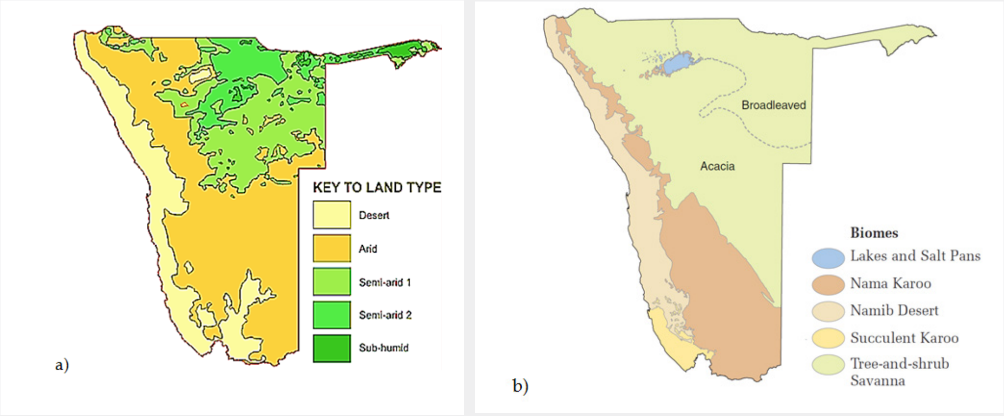

Figure 2: a) Land type regions [52] and b) biomes areas in Namibia [53].

Methods

The methodology employed in this study is a literature review. First, the study provided a background and a time line of dendrochronology. Furthermore, the study presented the climatic, vegetation and population on the semi-arid savanna ecosystems as a way to provide a Namibian context. In the results section, the first part presents a summary of dendrochronological researches carried out in Namibia in relation to their methods, species analysed, regions covered and their findings in terms of the tree ring observables. The second part presents the forecasted climatic regimes to show the importance of dendrochronology studies in the country. This is important as the majority of the population depends on the vulnerable ecosystems, particularly on agricultural resources. Climate change affects natural resources, and this is projected to worsen in the future, especially in semiarid to arid regions [55]. The discussion drew from a context of climate change, the application of dendrochronology in Africa, and the need to focus on specific issues that are outlined to be of great concern in Namibia.

Results

Studies on dendrochronology in Namibia

A search for studies in dendrochronology yield eight studies that are carried out in Namibia (Table 1). The studies were mostly carried out from the central-northern Namibia, covering mostly a rainfall gradient from the Kunene, Oshikoto, Kavango West and East, Zambezi and Otjozondjupa regions. Figure 3 shows how the ring rings are identified in one of the study. From these studies, sixteen (16) species of trees were examined and distinctive tree rings were successfully identified age determination was possible. These indicate that the species are responsive to climatic seasons. Using the staple-carbon isotope methodology, the trees showed responsiveness to inter-annual variability as two samples showed the same patterns (Figure 4). Climatic stress factors (wet and dry) induce the cambial dormancy and promote growth in woods [3]. This results in observable anatomical changes as the trees shed leaves and produce new leaves [63,64]. Large vessel zones are produced during the wet periods where water availability is in abundance, while the small vessel layers are defined by dry seasons due to the cambial activities being reduced under low water availability [64,65]. In addition to age determination, and analyses of growth rings responsiveness to precipitation, the latest study of tree rings in Namibia [56] also developed a master chronology for *Dichrostachys cinerea* and *Senegalia (Acacia) mellifera*, forming a basis for future dendrochronological studies of the two species in Namibia.

Forecasted climate conditions

New [45] carried out a study on the current state and modelled future climate conditions. Rainfall variability is evident within the last decades, with rainfall varying from 40% below and 70% above the average (Figure 5). Their results further showed faster increases in temperature over semi-arid areas in

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the future, indicating a warming rate of between 0.32 and 0.38 degrees per decade up to 2050 (Figure 6a) and projected trends ranging from 35 to 40% and higher than the warming for the wider Southern Africa region, which suggests that accelerated warming will become worse in the future, depending on future greenhouse gasses emissions. Their climate models also showed reduced total rainfall in the future; however, 25% of the model showed increased rainfall, which signifies rainfall variability in the future (Figure 6b). With specific reference to Namibia, rainfall is expected to decline with 10% in the southern part of the country and with 15% in the central regions [54]. For every 1% change in the rainfall, it is estimated that there will be 1.2% -1.6% changes in the carrying capacity, and around 1.3% changes in revenue from livestock farming [54]. Reduction on carrying capacity does not only affect the livestock, it also affects wildlife, tourism activities, and therefore livelihoods that directly and indirectly depend on it, and as well as the country's economy at large. A reduction on the rainfall also means less harvests from traditional subsistence farming which supports around 70% of the country's population.

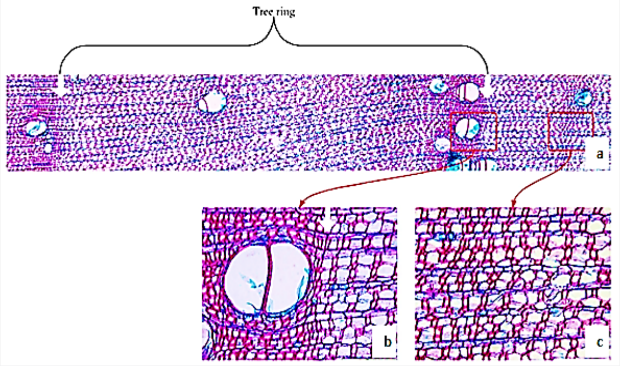

Figure 3: Micro images from Schinziophyton rautanenii from Kavango West region: a) entire ring at 25 x magnification, b) a ring boundary at 100x magnification, and c) a false ring at 100x magnification [59].

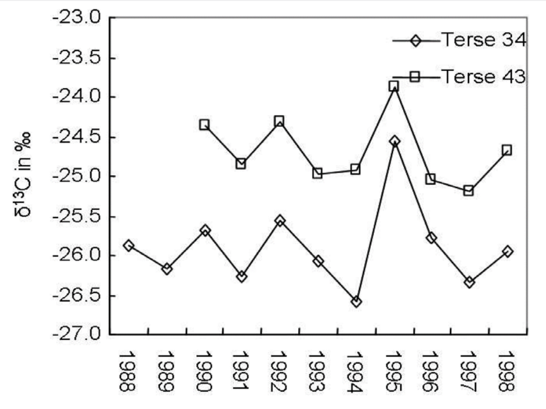

Figure 4: Inter- annual variability of δ13C profile of Terminalia sericea Terse 34 (older sample) & Terse 43 (younger sample) from Zambezi region [60].

Table 1: Studies on dendrochronology in Namibia.

Year	Title	Authors	Regions of Study Area	Method	Analysed Trees	Rings	Conclusion
2020	Growth ring formation of *Dichrostachys cinerea* and *Senegalia mellifera* in arid environments in Namibia	Shikangalah, Mapani, Mapaure, Herzschuh, Musimba and Tabares [56]	Oshikoto, Otjozondjupa, Omaheke	Growth rings on stem discs and their variability along rainfall gradient	*Dichrostachys cinerea* and *Senegalia (Acacia) mellifera*	Yes	Distinctive rings observed and responsive to precipitation, patterns more clear in *D. cinerea* than *S. mellifera*. Can be used as proxies for climate signals.

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2017	Determining age, growth rate and regrowth for a few tree species causing bush thickening in north central Namibia	Cunningham & Detering [57]	Kunene, Oshikoto, Otjozondjupa region	Growth rings on stem discs	*Acacia fleckii, Acacia reficiens, Acacia mellifera, Acacia tortillis, Colophospermum mopane, Combretum apiculatum, Dichrostachys cinerea, Terminalia prunioides*	Yes	Distinctive rings observed
2017	Predicting site productivity of the timber tree *Pterocarpus angolensis*	De Cauwer et al. [58]	Kavango West, Otjozondjupa	Growth rings on stem discs and cores	*Pterocarpus angolensis*	Yes	Distinctive rings observed and might be useful for climate signals at local scale.
2016	Annual diameter growth of *Pterocarpus angolensis* (kiaat) and other woodland species in Namibia.	Van Holsbeeck, De Cauwer, De Ridder, Fitchtler, Beeckman, & Mertens [59]	Oshikoto, Kavango West, Kavango East, Zambezi region	Growth rings on cores and stem discs	*Pterocarpus angolensis, Terminalia sericea, Baikiaea plurijuga, Burkea africana, Schinziophyton rautanenii*	Yes	Distinctive rings observed
2010	Staple-carbon isotope time series from tropical tree rings indicate a precipitation signal	Fichtler, Helle, & Worbes [60]	Zambezi region	Growth rings on stem discs and inter –annual analysis of variability	*Terminalia sericea*	Yes	Distinctive rings observed, inter-annual variability clear
2007	Radiocarbon dating of a very large African baobab	Patrut et al. [61]	Otjozondjupa	Age determination by radiocarbon dating	*Adansonia digitata*	N/A	Tree older than 1200 years
2004	Climatic signals in tree of *Burkea africana* and *Pterocarpus angolensis* from semiarid forests in Namibia	Fichtler, Trouet, Beeckman, Coppin & Worbes [10]	Oshikoto & Zambezi region	Growth rings on stem disc	*Pterocarpus angolensis, Burkea africana*	Yes	Strong responses to relative humidity and temperature at Ondangwa. At Katima only *angolensis* is more responsive to climate variables.
1999	Growth of Trees from Namibia- A Dendrochronology Study	Worbes [62]	Oshikoto, Zambezi region	Growth rings on stem disc and radiocarbon dating	*Pterocarpus angolensis, Terminalia sericea, Baikiaea plurijuga, Burkea africana, Colophospermum mopane, Combretum collinum, Lonchocarpus nelsii*	Yes	Distinctive rings observed, *Terminelia sericea* hashigh increment in Katima but low at Oshikoto

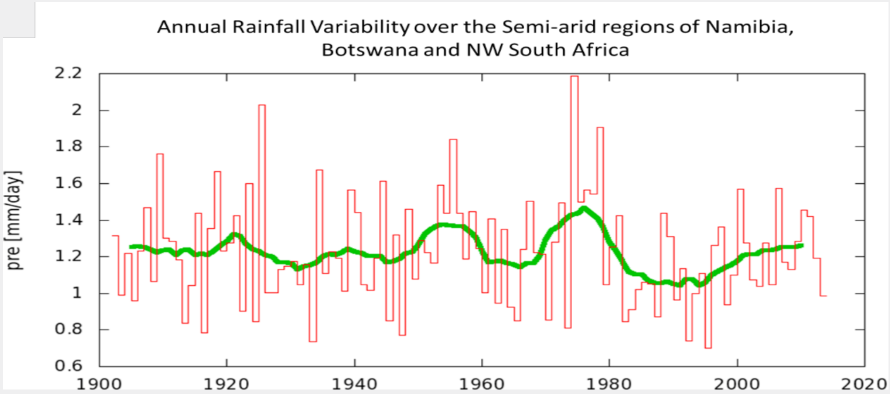

Figure 5: Annual rainfall variability over semi-arid of Namibia, Botswana and North-west South Africa [45].

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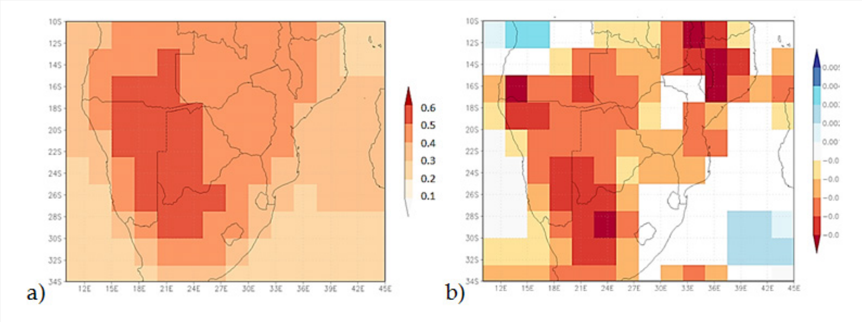

Figure 6: Regional climate forecasted trends out to 2050: a) temperature, and b) rainfall [45].

Discussion

According to Gebrekirstos et al. [30], the application of dendrochronology in Africa is mostly for the reconstruction of climate change history, extreme events, geomorphological related events, and this can also be used to assess the feedback systems, teleconnections, impacts on growth and resilience of species (Figure 7). This in the end gives quantified changes that can be used to make decisions on adaptations, mitigations and sustainable management of the resources.

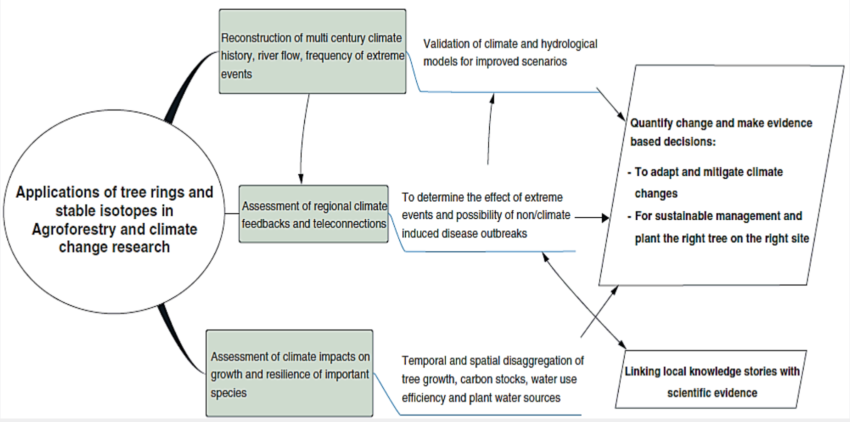

Figure 7: Possible application of dendrochronology in Africa [31].

The above outline application of dendrochronology is significant to Namibia. This is because climate change, global warming and rainfall variability, especially when it comes to the reduction of rainfall, have great impacts on the Namibian vulnerable recourses. First, the high temperatures promote more aridity conditions; the variability either leads to flooding events or drought periods. In addition, the various resources (water such as the groundwater system, water from surface flow; agriculture and land use including settlements areas) are significantly vulnerable to these conditions. The ecosystems are highly marginal and any relatively small changes are likely to lead to the systems to go beyond the limit point of viability, may may lead to a possibility of irreversible conditions.

Namibian forests are rare and found largely along riverbanks and mostly on remote locations. These forests support the majority of livelihoods in the country, especially in rural communities. They are also a way of "healing the dryland and protecting them from desertification and droughts" [54]. The use of dendrochronology to understand their responses to climate variability Could yield evidence based that can be used to understand their adaptation strategies and resilience mechanisms. Based on Table 1 species such as *Pterocarpus anglensis* and *Terminelia sericea* are more responsive to climate signals in Oshikoto region [10] and in Zambezi region [62,64], respectively. However, the ring growth were much better in Oshikoto region than in Zambezi region. It is less understandable for the former species to have better growth ring in Oshikoto region with less rainfall than in the Zambezi region with high rainfall amount and as temperatures are more or less the same in the two regions. Therefore, other factors such as soil and root structures have to be understood in studying dendrochronology, to be able to set up proper sustainable strategies in areas of concern.

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Acacia mellifera (*Senegalia mellifera*) and *Dichrostachys cinerea* are the most aggressive encroachers and are furthermost widely distributed encroachers in rangelands in Namibia [66-68]. They are responsible for nearly 40% of the encroached lands in rangelands and at least 15 million hectares in communal lands [69-73]. Increased temperature favours the encroachers such as *A. mellifera* due to their tap roots system that can tap onto deep moisture during drought period [74,75] and the increased carbon dioxide concentration in the atmosphere also favours them due to their C_3- photosynthetic systems that fixed carbon in elevated CO_2 conditions [76,77]. That results in less loss of energy through photorespiration, therefore fast growth and recuperation from damages [78,79]. The impacts of encroachers are greatly affecting savanna ecosystems, biodiversity and groundwater systems, and even contributing to desertification [66,80,81]. Based on Table 1, only two dendrochronology study has focused on the aggressive encroachers through analysing the growth rings and showed that they are responsive to precipitation and could be used for climatic signals. Studies using these species are therefore needed to reconstruct long period of climatic conditions.

Conclusion

A literature review on dendrochronology studies shows that the field of dendrochronology is relatively new and less applied in Namibia. This is in spite of the country being one of the most arid in the Southern Africa region, which makes the ecosystems most highly vulnerable the effect of climate change. This is worrisome when considering that such effects eventually impact livelihoods due to their high dependence on agriculture resources. The need for dendrochronology studies is therefore critical to understand the long, past and possible future environmental dynamics relating to the various resource the country depends on. Time series data analysis is necessary to understand their adaptation systems in relation to the climatic conditions, and understand forest ecosystems. The study recommends a focus on the marginal forest resources, further researches on encroachers to possibly save the drylands and trees that of indigenous use in Namibia.. There is high potential to expand the understanding on the species used by past studies as many of them were limited to a few areas and regions, and to a few (16) species. Vegetation need to be understood, especially in arid and hyper-arid areas such as around and in urbanised landscapes for sustainable management and planning of urban forests; along river banks (especially the ephemeral rivers as they support at least one-fifth of the Namibian population); in conservancies and other human- wildlife environments and lastly in areas of agricultural importance and communal lands where indigenous trees are vital to livelihoods. Clear ring formation growth ring determination might be difficult in the arid to hyper-arid environments, therefore the use of staple isotopes from cellulose to reconstruct past climate regimes, is recommended. Another method is the use of xylem anatomical features. This method focuses on functioning, growth and climatic-growth interactions, therefore providing information on most tree resistant to the impacts of climate change.

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