Woody vegetation resource changes around selected settlement along aridity gradient in the Kalahari, Botswana

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This paper investigated changes in economically important woody vegetation resources around seven settlements located along an aridity gradient in the Kalahari. Available data at different rainfall levels were analysed for different vegetation aspects. Total woody plant density and number of species at each site increased with increasing rainfall level, while individual species density differed at each site irrespective of rainfall, due to other factors, for example, land use as indicated by high stump densities around old and high population settlements. Drought resulted in high mortality of certain species, increasing availability of fuelwood resource in the form of dead wood. However, prolonged drought from climatic changes could result in browse shortage, a vital resource in the Kalahari. There was generally low wood resource availability throughout the studied gradient, without any distinct relation to rainfall, reflecting the influence of other factors such as soils, land use and natural variability.

Keywords: rainfall; gradient; resource; woody vegetation; species; mortality; drought; Kalahari; settlements; land use

Introduction

Woody vegetation found around settlements constitutes a valuable resource in Botswana, providing various kinds of products (Sekhwela *et al.*, 1992; Sekhwela, 1997; Watson & Dlamini, 2001). It is an important source of browse for livestock, fuelwood and other wood products, and non-timber forest products. The use of such resources has been found comparable throughout Botswana and in the Southern African region (Sekhwela, 2000). In Botswana, exploitation intensity has been found to vary depending on the population, level of economic development and other factors such as commercialization of products (Kgathi, 1984; World Bank, 1991). The effect of environmental conditions and climate on availability and the level or impact of exploitation is not widely considered, and yet Parry (1989) and Sekhwela *et al.* (2000) recorded high mortalities of some economically important woody plant species in

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some areas of the Kalahari because of drought. The availability of wood products was also found to differ depending on rainfall level, and woody vegetation structure, particularly in the Kalahari (Sekhwela *et al.*, 2000).

This paper has investigated changes in woody vegetation structure along aridity gradient around seven settlements in the Kalahari area of Botswana. The main aims were to highlight how the common woody plant species along the gradient respond to changes in available moisture (rainfall), and how the woodland structure may have been affected by land use as depicted by indicators of removal. Combined with human population, the information can be used to assess the potential of such resources to sustain current activities in the face of a variable climate and increasing land-use pressure.

Methods and Materials

Available woody vegetation data around the settlements have been analysed for woody plant species composition, physiognomic structure and other aspects in relation to known land-use types. Average annual rainfall ranges from 250 mm in the south to around 500 mm at the end of the studied spatial continuum (Table 1 and Fig. 1). Data were mainly available from Sekhwela (1994, unpublished data collected in 1993), with some from Sekhwela (1997, 2000—data collected in 1995/96). Except for Sekhwela (2000) where data were collected on one side of the settlement in 45 different small plots ($50 \times 50\,m^2$) within a large one ($400 \times 400\,m^2$), the rest of the data were collected as outlined in Sekhwela (1994, 1997).

Briefly, in the case of the latter, sampling started at the edge of the village along four belt transects, with sample plots of $25 \times 25\,m^2$ laid randomly along and from the center of the transect. In each plot, woody plant species names were recorded together with height and stem diameter at 20 cm above basal swell. Stumps were also counted in each plot. From this information, plant density, species composition and other aspects of woodland structure were determined.

Results

Vegetation structure

The density of the individual economically important species differed between the sites, with some sites recording higher densities than others that receive more rainfall,

Table 1. *Demographic and other characteristics of settlements studied in the Kalahari, Botswana*

Settlement	Code	Settlement started	Population (1991)	Average rainfall ($mm\,yr^{-1}$)
Tsabong	Tsb	Unknown (old)	3352	250
Khokhotsa	Khok	1984	620	330
Khakhea	Kkh	Unknown (old)	1750	340
Inalegolo	Ina	1989	367	340
Chobokwane	Chob	1993	192	350
Grootlaagte	Grot	1982	345	400
Xhana (Maun)	Xha	1950s	315	500

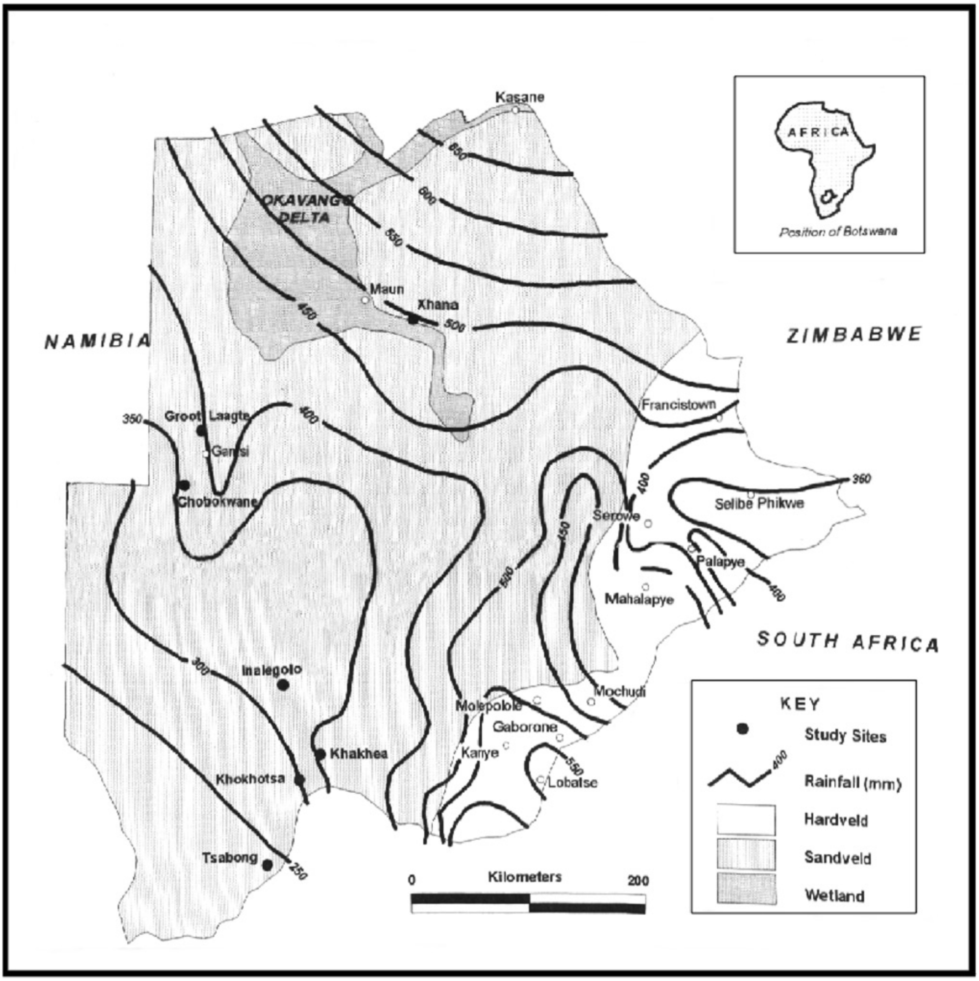

Figure 1. Study sites, rainfall and land systems in Botswana.

while some species do not occur in other sites (Table 2). No species depicted a trend of increasing density with rainfall amount, but the overall woody plant density shows an increasing trend with increasing rainfall amounts (Fig. 2). The overall number of woody species recorded at each site exhibited a similar but less distinct trend (Fig. 2). They both show high correlation with rainfall with coefficient of determination (R^2) of 0·75 and 0·68 for the overall woody plant densities and the number of species recorded, respectively (Fig. 2).

The breakdown of woody plant density into bush and tree density shows bush density increasing with increasing rainfall (R^2 = 0·63), while tree density increases initially but drops and increases again to the highest point at 500 mm of rainfall (R^2 = 0·47) (Fig. 3). Tree density is generally lower than bush density, except at the highest rainfall site of the study. Trends of both bush and tree density with distance around a few selected settlements are dynamic, without a clear pattern (Fig. 4(a, b)). The settlement of Grootlaagte shows a decreasing trend in bush density up to 1·5 km, and thereafter increasing again up to 3 km (Fig. 4(a)). Around other settlements, bush density trend increases within the first 0·5 km, before decreasing into a dynamic trend. Tree density trends increased further up to 1.5 km around Inalegolo, (Fig. 4(b)). The

Table 2. *Average (±S.E.) plant density (ha^{-1}) of some economically important woody plant species around some settlements (see Table 1 for full names) in Botswana*

Species	Tsb (250 mm)	Khok (330 mm)	Ina (340 mm)	Chob (350 mm)	Grot (400 mm)	Xhab (500 mm)
A. erioloba E.Mey.	48±7	17±0	10±3	54±10	0	45±8
A. fleckii Schinz	16±0	0	0	58±11	7±2	4±1
A. luederitzii Engl.	37±3	3±2	6±2	64±14	18±15	124±11
A. mellifera (Vahl) Benth.	98±14	33±12	91±20	181±55	10±4	129±20
Bauhinia petersiana Bolle	0	0	0	328±47	23±4	0
Boscia albitrunca (Burch.) Gilg & Ben.	23±0	16±3	1±0	41±8	103±15	52±6
Dichrostachys cinerea (L.) Wight & Arn.	0	7±5	13±6	135±21	39±5	515±124
Grewia bicolor Juss.	0	0	142±17	0	94±2	105±12
Grewia flavescens Juss.	0	149±14	4±2	34±5	2±1	69±11
Terminalia sericea Burch. ex DC.	0	29±9	18±12	163±36	151±15	34±4
Ziziphus mucronata Willd.	16±0	0	78±21	80±32	0	1±1

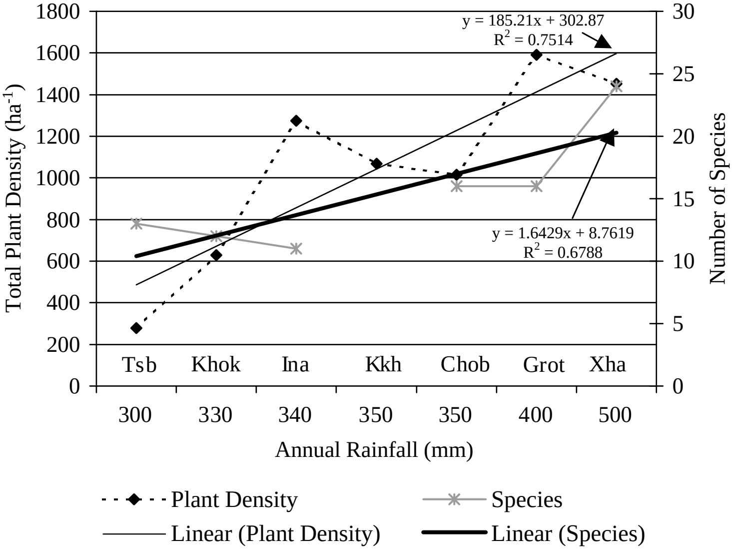

Figure 2. Woody plant density and number of species around settlements at different rainfall levels in the Kalahari, Botswana (see Table 1 for full names of settlements).

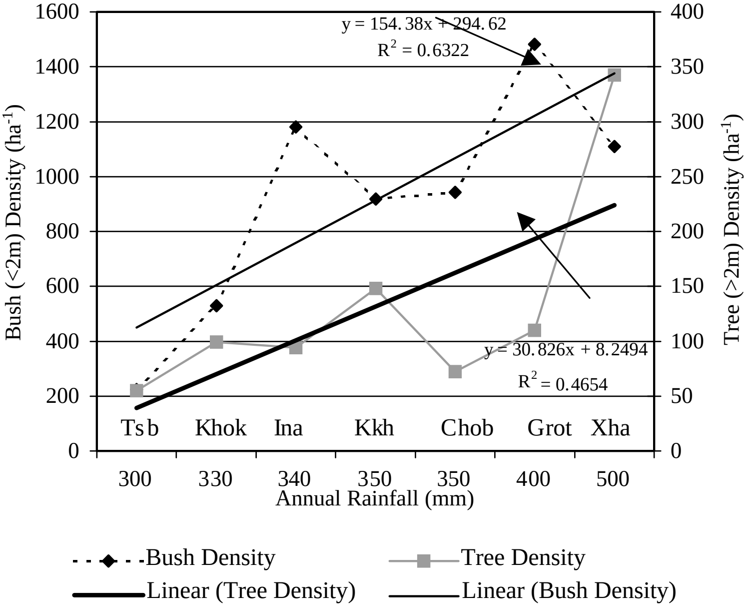

Figure 3. Tree and bush density around settlements at different rainfall levels in the Kalahari, Botswana (see Table 1 for full names of settlements).

trends of tree density depicted a slightly Opposite pattern of decreasing in the 0.5 km zone, and then increasing slightly, but dynamically (Fig. 4(b)). Once again, Grootlaagte depicted a contrary trend to the other settlements, with tree density increasing initially before decreasing (Fig. 4(b)). However, all settlements showed generally increasing trend in tree density with distance between 6 and 9 km distance from the edge of the settlements (Fig. 4(b)).

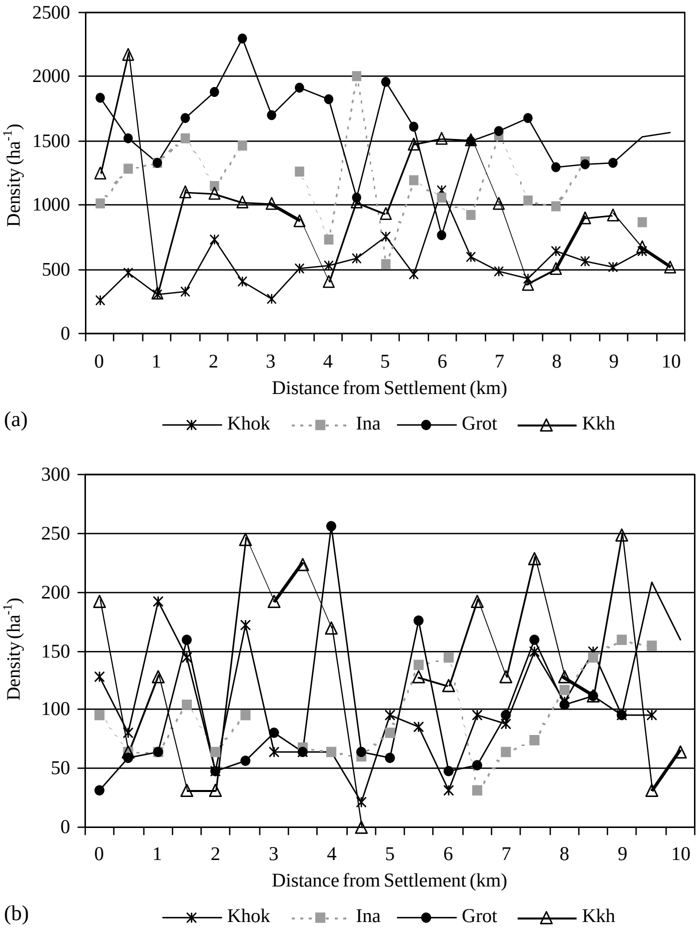

Figure 4. Woody plant density with distance around four settlements in the Kalahari, Botswana: (a) tree and (b) bush (see Table 1 for full names of settlements).

Resource availability

The analysed stump size classes recorded around settlements show that the most used stem diameter size classes range from 3 to 12 cm, accounting for 65% of the cut stumps (Fig. 5). Resource availability in terms of the known important woody plant species is depicted by the density of the stem size classes for this range (3–12 cm) around some settlements along the rainfall gradient for each species (Fig. 6). The trends are dynamic, without any rainfall-related patterns. Some areas with low rainfall like Tsabong recorded higher densities at certain distances away from the settlement than relatively higher rainfall areas like Chobokwane for species like *A. erioloba* (Fig. 6(a)). There was, however, generally low availability in all the species in the vicinity of the settlement, with the exception of Khokhotsha in the case of *A. erioloba* which depicts a decreasing availability with distance from the settlement (Fig. 6(a)). The trend of all woody species recorded around Khakhea settlement shows a stem size class of 3 cm depicting a trend comparable to that found in Khokhotsa and also widely occurring (Fig. 7). The older and high population village of Tsabong (Table 1) shows even lower stem densities of this species and *Acacia mellifera*, while *A. luederitzii* is generally scarce around all settlements surveyed (Fig. 6(b, c)).

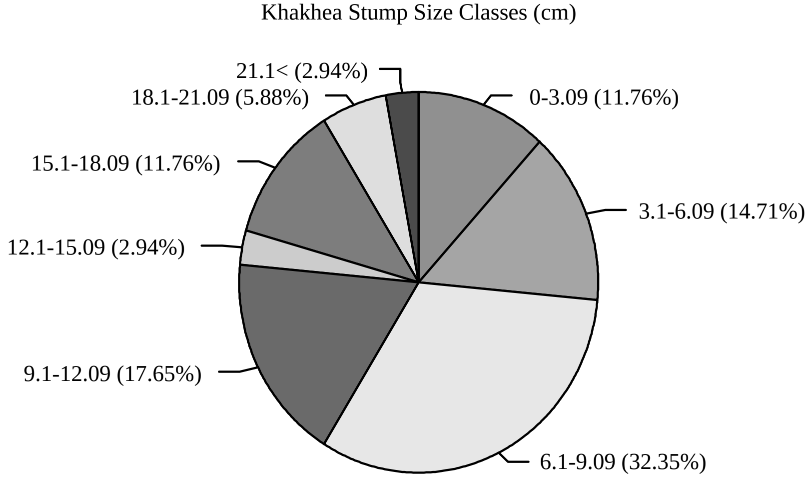

Figure 5. Diameter size classes of stumps recorded around Khakhea in the Kalahari, Botswana (source: Sekhwela, 1997).

The most important resource, fuelwood, is generally considered synonymous with dead fallen or standing trees (wood) in Botswana, and availability tends to increase with increasing distance from settlements. This trend is not clear in this study as most settlements had generally low availability of these resources, except for the settlement of Inalegolo which shows a slight increase in availability with distance up to 3 km (Fig. 8). Inalegolo depicted higher availability of standing dead trees throughout the entire distance up to 9 km away from the settlement. The settlement of Xhana (Maun) had 121 dead trees per hectare (Sekhwela *et al.*, 2000). Tsabong and Chobokwane showed relatively lower and sporadic occurrence of dead wood, even at great distances from the settlement (Fig. 8).

Utilization

The stumps recorded around settlements have been used as indicators of removal, with sizes showing the preferred size classes (Fig. 5). The density is expected to be higher around the settlements, but the trend is not clearly shown in this study, with sporadic and sometime dynamic trend around some settlements (Fig. 9). In fact, Khakhea shows an increasing density with distance from the settlement up to 3 km, while other settlements show higher density spots within a 2 km distance around the settlement (Fig. 9). The relationship with rainfall gradient is not visible from these results.

Discussions

Vegetation structure

Different aspects of vegetation reflect the effects of rainfall on the vegetation structure at each settlement along the rainfall gradient. For instance, the number of species increases with rainfall, and it accounts for 68% of the variation. This is consistent with general observations by a study of the Southern African region (O'Brien, 1993) and compiled case studies in Botswana (Sekhwela, 2000). Rainfall was found to be a

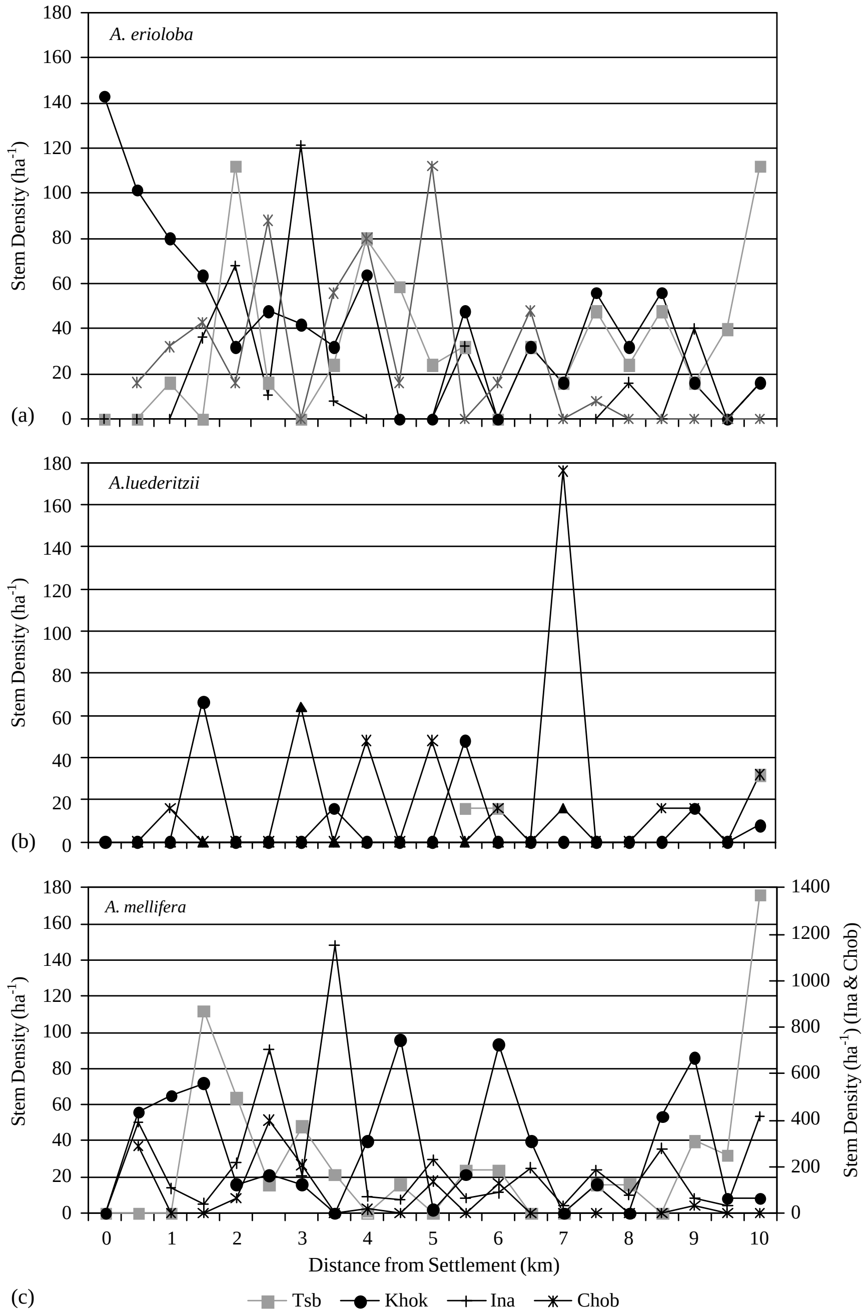

Figure 6. Stem density of three economically important species: (a) *A. erioloba*, (b) *A. luederitzii* and (c) *A. mellifera*, with distance around four settlements in the Kalahari, Botswana (see Table 1 for full names of settlements).

predominant determinant of savanna woodland floristics when sufficient gradient is sampled (Witkowski & O'Connor, 1996), which is the case in the current study given the generally uniform Kalahari sand substrate. Coughenour & Ellis (1993) found rainfall to be the primary controller of woody canopy cover, while species composition

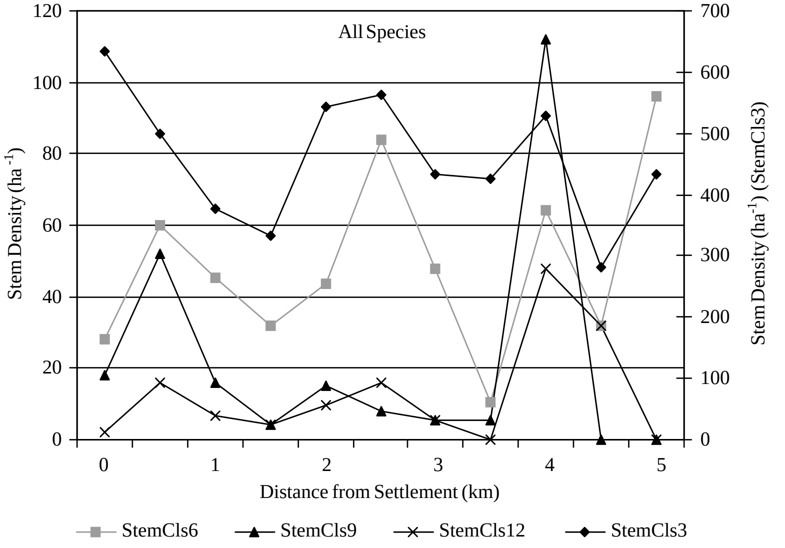

Figure 7. Stem density of commonly cut diameter sizes 3–12 cm with distance for all economically important species around Khakhea in the Kalahari, Botswana.

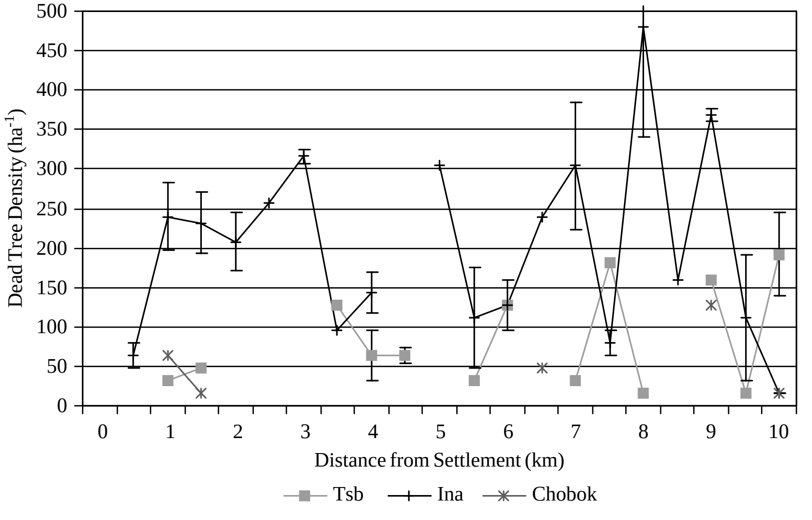

Figure 8 Mean density (±S.E.) of all dead trees with distance around three settlements in the Kalahari, Botswana.

was related to elevation, substrate and drainage (landscape pattern) in a dry tropical ecosystem in Turkana District, Kenya. They found fire to cause marked reductions in woody cover. Unlike the current study area with relatively uniform Kalahari sandy substrate and less variable elevation, their area had variable substrate and elevation. Complex interactions of precipitation, soil characteristics and topography in determining species distributions and abundance were observed in the same district (Pattern & Ellis, 1995). Changes in clay content and relief resulted in different

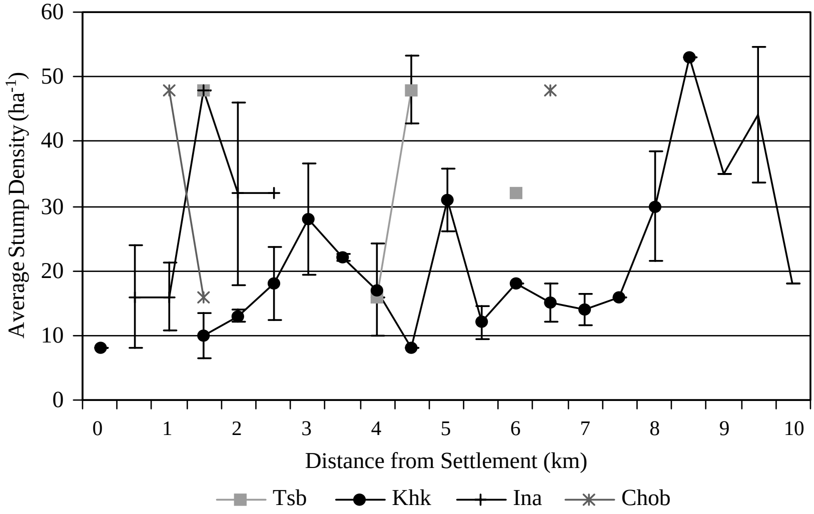

Figure 9 Mean density (±S.E.) of stumps with distance around four settlements in the Kalahari, Botswana (see Table 1 for full names of settlements).

densities of the different *Acacia* species across a rainfall gradient, which they attributed to different responses of each *Acacia* species to variation in rainfall, soil and relief, due to species morphology or life history (Pattern & Ellis, 1995).

In the current study, the trend displayed by the overall plant density with rainfall, though not very distinct, indicates the influence of soil moisture availability as depicted by rainfall accounting for 75% of the variation in the overall woody plant densities. The low densities in some places could reflect the impact of harvesting which decreases the actual tree abundance (Shackleton, 1993; Kgathi *et al.*, 1994; Sekhwela, 1997). For instance, Khakhea as one of the oldest settlement with relatively high population had a high and increasing trend of stump density with distance (Fig. 9) (Sekhwela, 1997). On the other hand, Chobokwane had a low population, but had some localized areas of high stump density mainly due to the fringing commercial farms that were fenced with poles extracted from the area. This could explain the low tree population despite the relative high rainfall. Woody plant density was also found to be reduced by woodcutting around settlements in other countries in the region (Liengme, 1983; Campbell & Du Toit, 1994), creating small-scale patterns. Such impacts will distort patterns that could be due to the influence of moisture availability and other abiotic factors. However, Gonzalez (1999) found rainfall and temperature to override local anthropogenic factors in explaining the overall changes in vegetation, in which he observed 33% and 23% decline in species richness and tree densities, respectively, in 48 years.

Apart from land-use impact, natural factors such as drought could also contribute to vegetation structure changes where there is high tree mortality as observed in this study at Inalegolo, and at Xhana (Sekhwela *et al.*, 2000). Parry (1989) also found high mortality of *A. erioloba* and *A. luederitzii* in the central Kalahari and other places, and attributed this to drought. These species are generally deep rooters with access to deeper soil water storage, and hence buffered against seasonal droughts (Sekhwela, 2000). For instance, *A. erioloba* has been found to root as deep as 45–60 m (Barnes *et al.*, 1997; Canadell *et al.*, 1997), but it had catastrophic mortality due to prolonged inter-annual drought of 1981–87 (Bhalotra, 1987). Jipp *et al.* (1998) detected significant depletion of plant available water at depth (4–8 m) at the end of seasonal dry periods in the forest ecosystem of Amazonia. Accumulation of such deficits due to incomplete recharge following persistent below average annual rainfall was found to eventually overwhelm the soil's buffering capacity against drought (Jipp *et al.*, 1998), resulting in catastrophic mortality observed in this study, despite adaptation of the species to arid environments. Sandy soils have relatively low soil water storage capacity, and greatest mortality can be expected when soil water reserves have been depleted to levels far below normal seasonal droughts (Borchert, 1998). This and mortality of adapted and other species due to drought, underscore the sensitivity and vulnerability of the Kalahari sand ecosystem to climatic changes with potential reduction in total annual precipitation. There is, however, need for more research in this ecosystem to ascertain the likely extents of such climatic shifts.

Resource utilization and availability

The use of stumps as indicators of removal is only useful while the stumps are present and coppicing or dead but still visible above ground. In the sandy areas where fuelwood harvesting is intensive or depleted in the vicinity of the villages, collectors uproot dead stumps for use as fuelwood. Such areas will no longer have any indications of removal particularly if there is heavy trampling by livestock, as it is always the case in such communal areas. There will be need to combine this type of indicators with other methods such as historical plant cover analysis which will show thinning over time as harvesting takes place around the villages. However, bush encroachment in response to removal of original trees and grass cover was found to be a common feature around high land-use foci (Dube, 2000), complicating the analysis for indicators of tree removal and utilization. Nichol (1989) also observed increase in woody species density in the vicinity of Kano city, Nigeria, following previous depletion due to fuelwood exploitation and prolonged droughts. However, microscopic analysis of different dates and scale aerial photography combined with ground surveys were found effective in detecting woody vegetation changes around settlements (Sekhwela, 1997; Dube, 2000).

The variable and generally low resource availability irrespective of rainfall levels indicates the influence of different other factors such as localized soil conditions and land use. For instance, the harvesting of wood at all recorded distances around Khakhea could account for the low and dynamic trend of resource availability of the preferred stem size classes 6–12 cm (Fig. 7). This is, however, complicated by natural variability due to adaphic and climatic factors. Coughenour & Ellis (1993) found differences in cohort structures (size classes) among woody plant species to be more likely due to different life history strategies suited to particular climatic patterns. Dube (2000) found the density of woody plants varying with soil type, but with fire having contributed to changes in woody vegetation structure in Haina veld areas in the northern parts of the Kalahari, Botswana. Trollope (1996) believes that the exclusion or lack of fire contributed to bush encroachment in southern African savannas, a view corroborated by Sweet & Tacheba (1985) who used fire to control bush encroachment on semi-arid savannas of Botswana. Fire is usually put out quickly close to settlements, and the high bush density recorded in this study is consistent with these observations.

The high mortality of trees around Inalegologo and at Xhana and other places due to drought (Parry, 1989; Sekhwela, 2000) is a good example of the impact of some of these factors, with high interaction between factors. Though dead wood present another resource (fuelwood), high mortality and removal with low regeneration may have resulted in the generally low densities of the preferred stem sizes, for example, in Khakhea, and fuelwood in all settlements except Inalegolo and Xhana.

Aridity gradient and climatic change

The existence of an aridity gradient does not appear to be important in the general status of resource availability in terms of satisfying the identified needs. It is rather more prominent in ecological terms, that is, vegetation structure and species distribution. There is, however, a distinct impact of extreme moisture shortages as experienced during drought, with high mortality even at the relatively high rainfall level covered in this study. This highlights the likely impact of climatic change with consequent extreme moisture shortages resulting in droughts. Though the resulting dead trees are a valuable fuelwood resource, prolonged droughts will also lead to low or no regeneration with consequent shortages of other resources such as browse. Borchert (1998) observed increasing deciduousness and delayed flushing in response to increasing length and intensity of seasonal water stress in dry forests of Costa Rica. Increasing aridity was found to concentrate phonological activity of woody vegetation community of South African savannas into a shorter time period (Shackleton, 1999). There were, however, no detectable shifts in the initiation of phonological activity in *Acacia* tree species growing in distinctly different rainfall areas in the Kalahari, Botswana (Sekhwela & Yates, 2001). Early phenological onset has been found to relieve starving livestock during dry and drought periods in some savanna areas in southern Africa, and delayed flush would lead to severe food shortages and livestock mortality (Hunt, 1954; Borchert, 1998; Sekhwela & Yates, 2001). Settlements that are highly dependent on woody vegetation resources such as the ones studied will be particularly vulnerable to negative climatic changes resulting in moisture shortages, and leading to droughts. Such conditions are focused for southern Africa which has been found to become increasingly dry with desertic areas to expand into large areas of Botswana (Hulme, 1996). Though there is uncertainty in the global climate scenarios and biome models used in the focus, the results of this study highlight a possible trend in this direction.

Conclusion

The woody vegetation aspects that reflect aridity gradient include total woody plant density and number of species at each site. There were, however, variable densities of each individual economically important woody species that were not related to rainfall level, reflecting the influence of other factors that included land use as shown by indicators of removals such as stumps. Resource availability in terms of identified use was found to reflect natural variability and the impact of land use than moisture gradient. The impact of drought was found to result in high availability of fuelwood but shortage of other resources in the short and long term, indicating the likely effects of negative climatic changes. Settlements in the Kalahari will be particularly vulnerable to such changes due to their high dependence on woody vegetation resources.

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