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Research Article

Changes in Herbaceous Species Composition in the Absence of Disturbance in a *Cenchrus biflorus* Roxb. Invaded Area in Central Kalahari Game Reserve, Botswana

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A-nine year study was carried out to investigate changes in herbaceous species composition in an area invaded by *Cenchrus biflorus* Roxb, an exotic invader grass species. The study ensued termination of livestock and human activities in the area when residents of the area were relocated to another area. Vegetation characteristics from the disturbed sites (previous occupied areas) and undisturbed sites (previously unoccupied areas) were determined. The results show that *C. biflorus* has high tolerance to disturbance. It comprised the larger proportion of grasses in disturbed sites at the inception of the study. However, it decreased in abundance with time in disturbed areas and was absent in the undisturbed areas, suggesting that its ability to invade undisturbed sites is limited. Perennial species successfully reestablished on the third year after termination of disturbance. The study reveals that *C. biflorus* invasion in the Kalahari ecosystem can be controlled by termination of disturbances.

1. Introduction

The slow and uncertain rate of return of herbaceous species composition to the original status after severe disturbance is a major problem in wildlife management areas and on rangelands [1]. It is a function of the range condition at any given time, which is assessed as a function of grass composition, biomass, and cover [2, 3]. The dynamics of range condition is affected by environmental factors and land use such as animal grazing pressure. Heavy grazing pushes the range condition to degraded status dominated by weedy or unpalatable grass and forb species typical of disturbed areas [3, 4]. This has been supported by various studies done in semiarid Southern Africa [5–7]. The studies showed that basal cover, proportion of annuals and proportion of unpalatable species were higher in heavily grazed areas than in light grazed areas [5–7]. Vegetation outcrops on a disturbed area and surroundings are a function of availability of seeds or propagules of species or species groups.

Debates have ensued on the relative importance of both the biotic and abiotic factors on range conditions. Explanations for these are based on the equilibrium and nonequilibrium models [3, 8–11]. The equilibrium model stresses the importance of biotic feedbacks between herbivores and their resource, while the nonequilibrium model sees stochastic abiotic factors as the primary drivers of vegetation and livestock dynamics [3]. However, in most arid and semiarid rangelands both equilibrium and nonequilibrium models are at play, though at different scales.

It takes a considerable time for a species composition in a disturbed area to return to its previous condition. Samuel and Hart [1] reported that after 61 years of monitoring a disturbed area, its species composition did not reach the point of that of an undisturbed area it was compared with since there were visible differences between the two areas. The differences were attributed to various factors that included increase of invasive and alien species that often dominate in disturbed sites out competing native vegetation or disrupting native plant communities and nutrient cycling. On cessation of disturbance, expectations are that vegetation development follows a definite sequence of functional groups where early stages of recovery are dominated by species of light seeds, producing seeds in great numbers, fast growing and dispersing over vast areas [12]. These are hardened, annual plants that grow in very unfavorable conditions and improve the growth conditions resulting in plant communities that are adapted to the new, improved growth conditions, and replacing the existing plant communities. Species with heavy seeds, slower growth, and long life span dominate in later stages [13]. Studies by O'Connor and Roux [14] on the Kalahari landscape have shown that vegetation is able to reestablish after grazing pressure is lessened. Seitshiro [15] and Perkins [16] also observed that areas in the Kalahari sandveld vegetation communities, denuded of grass during dry years, had some rapid return of perennial grass cover in subsequent years of average or better rainfall or cessation of grazing. Indications are that, during prime growing conditions, it can take 8–10 years for disturbed vegetation to reestablish in the Kalahari landscape [17]. The Kalahari is a substantial part of Southern Africa interior covering countries among them Botswana, Namibia, and South Africa [18]. It is extensively elevated, flat and covered by Kalahari sand soils. Kalahari sand soils typically consist of over 95% fine sand-sized, aeolian-deposited sediment and are predominantly deep, structureless, and lacking in N, P, and organic matter [18].

Within the Kalahari ecosystem in Botswana lies Central Kalahari Game Reserve, the largest game reserve in the world that covers an area of some 52 800 km^2. Some pockets of the Central Kalahari Game Reserve (CKGR) are inhabited by people. When people inhabited the area in the 1960s, their main source of food was hunting and gathering. However, with the decrease of natural resources, people started keeping domestic animals such as horses, donkey, and goats. Over time, it was realized that the area had been invaded by a noxious weed, *Cenchrus biflorus* Roxb. It is common in the savannas of sub-Sahara Africa. *Cenchrus biflorus* Roxb. is an annual grass of the Poaceae family with synonyms: *C. annularis* Andersson, *C. barbatus* Schumach, *C. catharticus* Delile, *C. leptacanthus* A.Camus, and *C. perinvolucratus* Stapf & C.E.Hubb. Its culms are 4–90 cm high. The leaf: lamina is 2–25 cm long, 2–6 mm wide and the panicle 2–15 cm long. Its spikelets are 1–3 per bur and 3.5–6 mm long. Molecular analyses suggest that the species invading the Kalahari originates from India hence the common name "Indian sandbur". The grass was first observed in Botswana in the 1940 s growing around Nata. It is currently spreading rapidly in the western and central part of the country. The grass species is regarded as a noxious weed because of its objectionable burs, which adhere to animal skin, clothes, shoes and machinery. These burs are the likely vehicle to its rapid spread. The burs are harmful to grazers and may cause ulcers in the mouths of animals. The grass has also spread to arable fields making weeding difficult. As a result, some farmers in Botswana have opted to abandon their *C. biflorus* invaded arable fields. Intensive land use increases the potential to *C. biflorus* invasion as this increases the area of disturbed soil, thus creating conditions under which the invasive grass thrives. Control of this grass species is achievable in arable fields through weeding, cultivation, and herbicides application before seed formation. However, controlling this grass species in range and pasture areas still remains a challenge since there is lack of a selective herbicide that will kill only this grass species. As such other control measures have to be explored. Environmental friendly control measures will be more appropriate to be used in Game Reserves were minimal interventions are allowed.

In 1997, Central Kalahari Game Reserve (CKGR) residents at Xade were relocated outside the reserve as their activities were no longer compatible with wildlife conservation. This abandoned Xade area has been under disturbance for four decades. The nature of the disturbance ranged from simple cumulative trampling on the herbaceous layer to large-scale clearing of trees and shrubs. Establishment of modern and traditional homesteads and institutions like the "Kgotla" (traditional gathering place headed by a Chief) contributed to land disturbance. The keeping of livestock (horses, donkeys, sheep, and goats) exerted more pressure on the soil and vegetation leading to the disappearance of nutritious grass species and the increase of annuals [19]. Concerns were then raised that this would negatively affect wildlife populations and eventually deteriorate the biodiversity of the area.

The relocation of Xade residents prompted this study as an opportunity to determine how herbaceous species composition and cover changes overtime in the absence of livestock and human disturbance. Wildlife activities that had previously been observed to be absent or minimal were left to go on as usual. Thus, this study aimed at determining whether a disturbed area invaded by an exotic invader grass species can recover if human and livestock activities were terminated.

2. Methods and Materials

2.1. Study Site. Xade is in Central Kalahari Game Reserve (CKGR) and lies at Latitude 23.01 degrees south, Longitude 22.33 degrees east. The vegetation is characterized by medium to open bush savannah with occasional isolated tress. The vegetation has mainly been kept in shape by frequent bush fires. The climatic conditions of the area can be summarized as semiarid. Generally, the CKGR lies between 350 mm and 400 mm isohyets [19]. The Xade rainy season is between November and April with long-term annual rainfall of 350 mm. There is however considerable variation in the amount and pattern of rainfall between years 1998 and 2006 (Figure 1). The area is covered mainly by deep Kalahari sands. Its topography is flat to undulating with low immobile sand dunes.

2.2. Experimental Design. The vegetation data was collected from seven (10) strategically located plots at Xade. Strategically here means that it was made sure that five of the plots were in disturbed sites while two were in undisturbed sites (reference sites). The disturbance arose from livestock

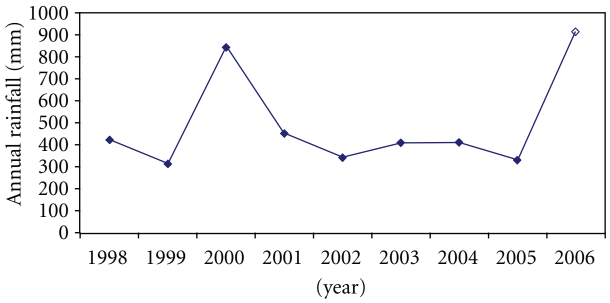

FIGURE 1: Annual rainfall amounts in Xade during the study period.

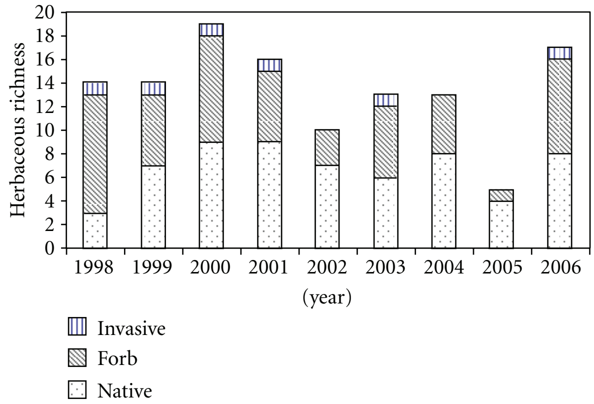

FIGURE 2: Mean species richness at disturbed sites (Xade) from 1998 to 2006. Native species refers to all indigenous species while invasive refers to *Cenchrus biflorus*.

and human activities in the area before relocation in 1997. The plots measured 30 m × 20 m in size. Sampling was done from April 1998 to April 2006. Sampling was carried out in April of each year, the peak plant growing period. During April, herbaceous species are mature and easy to identify since most are either flowering or in seed. Within each of the 30 m × 20 m plots, five transects each measuring 30 m long and being 5 m apart were sampled. The herbaceous species frequency was recorded every two (2) meters along each transect using the wheel point method [20]. Numbers of individuals of each species by life form (forb, native grass and exotic) were recorded. The data was used to calculate species richness, composition, and herbaceous cover. Grass species nomenclature is according to Field [21] and Van Wyk and Van Oudtshoor [22].

Rainfall data was obtained from Botswana Department of Meteorological Service, Ghanzi offices.

2.3. Statistical Analysis. STATISTICA program, version Kernel 5.5 A, was used to calculate species richness, composition, and herbaceous cover. Species richness here refers to the number of individual plants of each species in each life form group (forbs, native, and invasive). Composition refers to relative abundance of each group. Herbaceous cover means the cover contributed by each group excluding that covered by litter and bareground. Excel was implored to draw charts showing species richness, composition, and cover. Spearman's rank correlation coefficient (r_s) was used to calculate the correlation between herbaceous species richness and site age (time). Spearman's rank correlation was also applied to determine correlation between the native grass species, invasive species, and native forbs over time. The Spearman's rank correlation coefficient values were tested for significance using the t statistic. The student t-test was also used to test if there was some significant difference in species richness and cover and functionality composition between sites (disturbed and undisturbed). STATISTICA [23] was used to perform these calculations.

The Czekanowski coefficient [24] was used to assess the similarity or dissimilarity in herbaceous species composition between disturbed and undisturbed plots (reference sites). The coefficient values range from zero (0), complete dissimilarity, to one (1), total similarity.

3. Results

3.1. Herbaceous Species Richness. The herbaceous species richness varied during the study period (Figures 2 and 3). Mean species richness was higher in disturbed sites than in undisturbed sites. Initially an average of fourteen (14) herbaceous species was recorded in the disturbed sites and six (6) in undisturbed sites. These included forbs, native grass species, and the exotic grass species *Cenchrus biflorus*. The native grass species included *Stipagrostis uniplumis, Pogonarthria squarrosa, Schmidtia pappophoroides, Aristida meridionalis, Eragrostis lehmanniana, Aristida congesta, Melinis repens, Urochloa trichopus, Enneapogon cenchroides,* and *Schmidtia kalihariensis*. The forbs included *Tribulus terrestris, Amaranthus thunbergii, Heliotropium steudneri, Xenostegia tridentata, Harpagophytum procumbens, Hermbstaedtia odorata,* and *Cucumis myriocarpus*.

Cenchrus biflorus disappeared after four years of termination of disturbance but some reappeared during the sixth and ninth years after termination of disturbance (Figures 2 and 3). Species continued to recruit to reach a peak mean of nineteen (19) species and eighteen (18) for disturbed and undisturbed sites in 2000 and 2006, respectively (Figures 2 and 3). The lowest herbaceous species mean number of five (5) was recorded in 2005 for disturbed sites and of four (4) in 2003 for undisturbed sites. Species richness ranged from 5 to 18 (mean ± SE of 13 ± 1.26) plant species for disturbed sites and 4–18 (mean ± SE of 10 ± 1.26) for undisturbed sites. There was no significant difference in species richness between undisturbed and disturbed sites (t value = 1.71 P-value = .126).

3.2. Herb Layer Composition. The herbaceous layer composition differed substantially between sampling periods in both disturbed plots and undisturbed plots (Figure 4). The herbaceous layer in disturbed plots was composed of exotic grass species (*C. biflorus*), native grass species, and forbs and in undisturbed plots only native grass species and forbs were recorded. No exotic grass species were recorded in

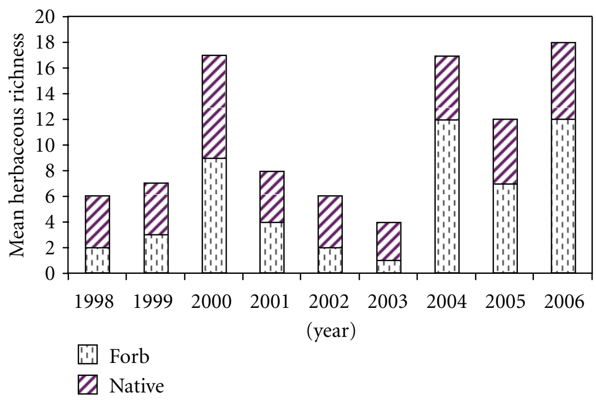

Figure 3: Mean species richness at undisturbed sites (Xade) from 1998 to 2006.

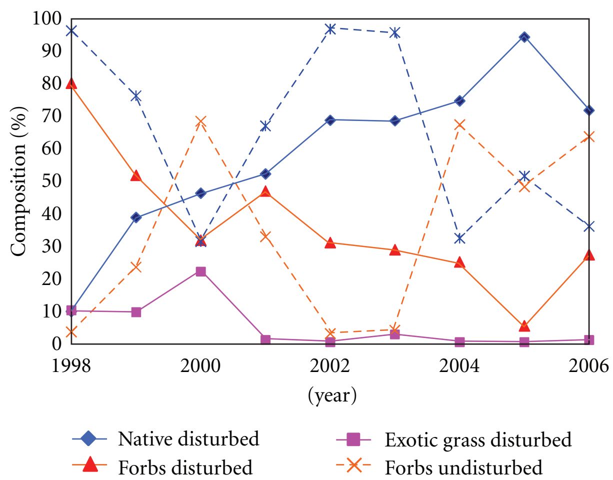

Figure 4: Herbaceous species composition at the disturbed (distbd) and undisturbed (undistbd) sites in CKGR: 1998 to 2006.

undisturbed sites. The Spearman's rank correlation coefficient indicated that there were some negative relationships between percentage of forbs and time postdisturbance for disturbed sites ($R = -0.933$, $P = .0024$). A similar pattern was also observed for *C. biflorus* ($R = -0.746$, $P = .021$). In contrast, Spearman's correlation coefficient showed a strong positive correlation between native grass species and time postdisturbance for disturbed sites ($R = 0.933$, $P = .0002$).

During the first two years of sampling, forbs dominated in disturbed plots but gradually declined with time. In the first year, forbs contributed 80.56%, C. *biflorus* 9.88%, while native grass species contributed 9.56%. *Cenchrus biflorus* gradually recruited reaching an average score of 21.94% in 2000 coinciding with the year of high rainfall (Figure 1) but disappeared in the fourth year with its traces being noted on the 6th and 9th years postdisturbance. Similarly, forbs decreased gradually reaching a minimum of 5.10% on the 8th year of study but went up to 27.23% on the subsequent 9th year.

On the contrary, native grass species recruited gradually in disturbed plots dominating in the third year of sampling.

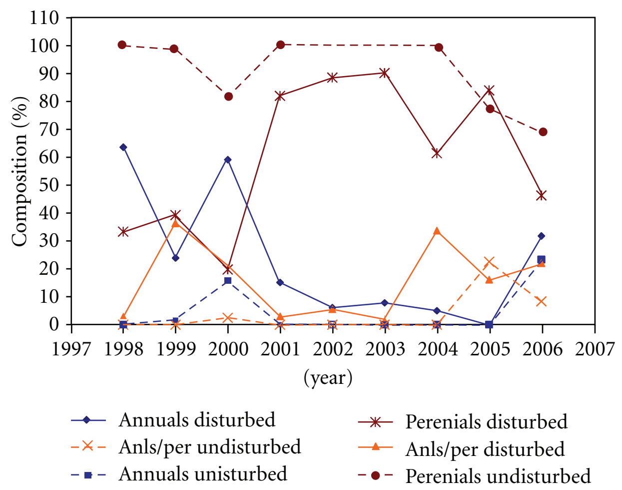

Figure 5: Composition of annuals and perennial grass species in disturbed (distbd) and undisturbed (undistbd) sites in CKGR:1998 to 2006.

The native species reached a peak average of 89% on the 7th year of sampling. In disturbed plots, both forbs and native grass species fluctuated between years but native grass species were much higher throughout the study period except in 2000, 2004, and 2006 (Figure 4). In comparison, forbs dominated in disturbed plots while native grass species dominated in undisturbed plots during the first two years of sampling. Native grass species recruited gradually in the disturbed plots, exceeding that of undisturbed plots in 2004.

3.3. Perenniality. Annual grass species were relatively high during the first three (3) years in disturbed sites but gradually declined (Figure 5). In contrast, from 2001 until 2003 perennial species recruited gradually to a species composition of about 80% exceeding annuals but subsequently declined during the last three years of sampling. Nonetheless, the decline was not significant. The fluctuations indicate that the vegetation had not yet fully recovered. In undisturbed sites, perennial species dominated throughout the study period.

3.4. Herbaceous Cover. Generally the disturbed sites showed some relatively higher percentage cover compared to undisturbed sites (Figure 6) but the difference was not significant (t value $= -0.37$, $P = .721$). The highest herbaceous cover was recorded in 2000 and the least in 2005 for both disturbed sites and undisturbed sites, respectively. The peak score was 94.46% while the least score was 41%.

3.5. Similarity. There were great dissimilarities in species composition during the first two years of sampling (Table 1). However, as the range rested following termination of disturbance, the similarity index increased gradually reaching 0.48 in 2001. Nonetheless, the similarity index continued to fluctuate indicating that the range condition had not stabilized.

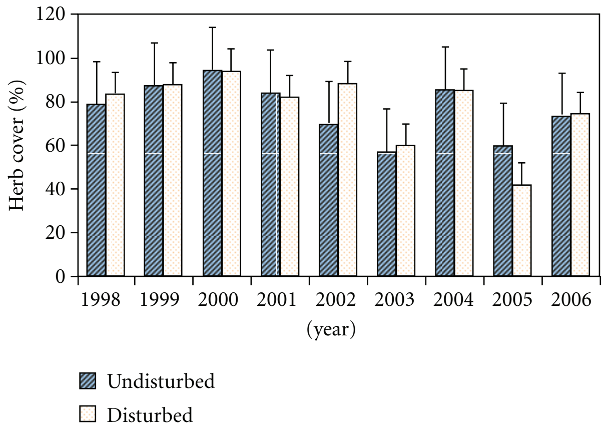

Figure 6: Herbaceous cover at disturbed and undisturbed sites in CKGR: 1998 to 2006. Error bars signify standard errors.

Table 1: Similarity Czekanowski coefficients of grass and forbs species between the disturbed and undisturbed sites.

Year	Coefficients
1998	0.07
1999	0.14
2000	0.29
2001	0.48
2002	0.33
2003	0.26
2004	0.26
2005	0.40
2006	0.32

4. Discussion

The study showed that forbs were the first to colonize the disturbed area and continued to dominate within the first two years posttermination disturbance. Dominance of forbs on disturbed area may be attributed to their hardness, ability to grow in very unfavorable conditions, adaptation to disturbed sites, and ability to grow vigorously to outcompete other plants [22].

Native grass species recruited gradually in disturbed plots dominating in the third year of sampling. Initially pioneer grass species that include *Schmidtia kalihariensis*, *Enneapogon cenchroides,* and *Melinis repens* dominated during the first five years of sampling but climax species which included *Schmidtia pappophoroides* and *Eragrostis lehmanniana* dominated during the last two years of sampling. This transition pattern of dominance by forbs and pioneer grass species in the early years of abandonment followed by an increase in climax species after some years postdisturbance are consistent with succession patterns observed by Holl [25].

Cenchrus biflorus recruited substantially as well in the first three years postdisturbance but declined significantly in the fourth year coinciding with the dominance of native grass species. This suggests that *C. biflorus* is outcompeted by native grass species if disturbance is reduced or minimized. Of significance is that *C. biflorus* did not spread to undisturbed plots suggesting that the species is not competitive, and when factors promoting range deterioration are minimized, the species may not spread in the Central Kalahari Game Reserve. Also, the removal of livestock which degraded the area might have reduced the proportion of disturbance hence limiting the spread of *C. biflorus* to undisturbed areas. These results concur with previous studies that reported that reducing intensity of use of affected land is an efficient tool to control *C. biflorus*.

Annual grass species were relatively high during the first three (3) years in disturbed sites but gradually declined. In contrast, perennial species recruited gradually exceeding annuals from 2001 until 2003 but subsequently declined during the last three years of sampling. Nonetheless, the decline was not significant as the species continued to dominate. This pattern of vegetation succession growth was observed by Seitshiro [15] and Perkins [16] who concluded that perennial grass cover return rapidly to areas denuded of grass during dry years in subsequent years of average or better rainfall or cessation of grazing in the Kalahari sandveld vegetation communities. The presence of perennial grass species is vital since it protects the soil from erosion. It also changes the morphology of the landscape which would otherwise be bare during the dry season if it was dominated by annuals.

The results of this study concur with Wiggs [17] who concluded that it takes 8–10 years for a disturbed Kalahari biome to fully recover. However, studies by Samuel and Hart [1] have shown that it takes a longer time for the disturbed areas to fully recover if the sites were severely disturbed. This could be the situation here considering that the study area was under immense pressure of disturbance from human activities that included decades of small scale cultivation, livestock production, harvesting of grass and wood, as well as general infrastructure developments.

Generally the disturbed sites showed some relatively high percentage cover compared to undisturbed sites. The high cover in disturbed sites could be attributed to invasive species ability to vigorously regenerate and recruit rapidly in abandoned disturbed sites [22]. *Cenchrus biflorus,* though classified as a weed in Botswana, has potential of being a nutritious food plant for herbivores. The National Research Council [26] quotes it has "potential to improve nutrition, boost food security, foster rural development and support sustainable landcare".

In conclusion, the results show that *Cenchrus biflorus* has some high tolerance to disturbance as it comprised the larger proportion of grasses in disturbed sites at the inception of the study. However, it decreased in abundance and was absent in the undisturbed area, suggesting that its ability to invade undisturbed sites is limited. The results indicate that resting an area invaded by *C. biflorus* might rehabilitate it, and this takes several years depending on rainfall variability. It is thus important to mitigate and prevent factors which promote range deterioration such as human activities (ploughing, trampling, developments, harvesting of grasses for thatching, and firewood collection) and overgrazing in wildlife protected areas. This action will reduce the probabilities of range deterioration and intrusion of undesirable invasive exotic species in protected areas. This will promote viable wildlife populations and its habitat, thus conserving the biodiversity in such a protected area.

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