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EFFECTS OF ARTIFICIAL WATER POINTS ON SEMI-ARID RANGELANDS IN NORTHERN NAMIBIA

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Hallo Mary,
This the 'paper that that Gufu submitted based on my Thesis
Selma.

ABSTRACT

This paper reports on effects of artificial water points on land degradation in the semi-arid rangelands of Northern Namibia. The effects of artificial water points on land degradation was better measured in terms of bare ground. We showed that greater bare ground was increased with increasing age of artificial water points. Conversely, landscape types explained changes in herbaceous species richness, cover and biomass more than radial grazing distances from water points. The results of the present study did not, therefore, verify the negative effects of radial grazing distances from water points in terms of vegetation degradation as reported by others. We suspect that absence of vegetation degradation induced by artificial water points may be due to the recent establishment of artificial water points in Northern Namibia. Although the present study did not confirm vegetation degradation, common knowledge would suggest that proper distribution and rotational use of water points will be necessary to avoid future land degradation. Moreover, understanding processes of land degradation will be improved if management of water points in Northern Namibia is integrated through systems of monitoring.

KEY WORDS: Artificial water points, bare ground, equilibrium model, herbaceous species richness, Namibia, non-equilibrium model, pioshere, rangeland degradation,

INTRODUCTION

Degradation of the arid zone grazing lands in Africa occurs in many forms that are difficult to objectively quantify and predict. Large areas of the rangelands lack permanent sources of water; making such rangelands to be under-utilized, while few areas provided with deep wells or perennial water points such as bore holes are overutilized (Hanan *et al.,* 1991). Greater annual rainfall variability also implies that plant cover and production are highly varied from season to season and from one year to another. In addition to this, spatial variability attributed to landscape heterogeneity influences rangeland productivity (Oba et al., 2000a,b).

Livestock during the dry season walk from grazing areas to watering points and back, creating a gradient of grazing pressure (Zumer-Linder, 1976). In the sub-Saharan rangelands, provision of water, therefore, promotes heavy concentration of livestock around artificial water points (Van Rooyen *et al.,* 1990; Hanan *et al.,* 1991; Thomas *et al.,* 2000), with the immediate vicinity of water points being heavily trampled and overgrazed (Lang, 1969). Continuous heavy livestock grazing and trampling around water points is suggested to create radial patterns of degradation that decrease with increasing distances (Barker *et al.,* 1989; Pickup *et al.,* 1998; Thrash *et al.,* 1995; Parker and Witkowski, 1999; James *et al.,* 1999), which in the Sahelian rangelands are associated with bare patches that vary in radius from 100 m to 10 km distance (Hanan *et al.,* 1991).

The patches called "piospheres" (Lange, 1969), provide natural experiments that ecologists could use to understand effects of grazing pressure on vegetation near water points compared to moderately used rangelands (Andrew, 1988). The cumulative effects of heavy grazing and trampling is suggested to induce changes in plant species composition (Thrash, 1999), reduce plant species richness, plant cover, and biomass as well as increasing bare ground (Pickup *et al.,* 1998; Parker and Witkowski, 1999). The dynamics of species richness, biomass and bare ground might reflect age of artificial water points (Andrew, 1988).

The effects of artificial water points in the arid zone grazing lands, may, therefore, reflect conditions described by the equilibrium grazing models (e.g. succession, carrying capacity), which characterize land degradation in relation to effects of stocking rates on fluctuating plant populations (Jeltsch *et al.,* 1997). The models used overgrazing around water-points as symptomatic of rangeland degradation in the arid zones in general and those of sub-Saharan Africa in particular (Sinclair and Fryxell, 1985). The equilibrium view suggests that population dynamics of plants and livestock are mutually dependent with predictable changes in grazing pressure causing corresponding changes in plant composition (Illius and O'Connor, 1999).

Heavy grazing impacts around water points is reported to selectively remove perennial grass species, while promoting annual grasses (Thrash *et al.,* 1993). The presumption being that any observed changes in herbaceous vegetation biomass or composition with increasing distance from water points can directly or indirectly be explained by radial grazing distances from water points (Hanan *et al.,* 1991; Thrash, 1998). It is also suggested that degradation will be implied if there are no increases in biomass or herbaceous plant cover with increasing distances from water points (Ward *et al.,* 2000).

This may be contrasted with conditions in the arid zones that are better described by non-equilibrium grazing models (Ellis and Swift, 1988) that are characterized by high spatial and temporal variability (Behnke and Scoones, 1993; Oba *et al.,* 2000a,b). The latter model emphasised the role of landscape variability in vegetation dynamics. The non-equilibrium model suggests that response of vegetation to grazing pressure is less than that of temporal and spatial rainfall variability. Thus, when analysing response of vegetation to grazing pressure one needs to separate the effects of landscape heterogeneity from those induced by grazing interacting with rainfall variability. The problem is confounded when artificial water points introduce an element of predictability (at least in water supplies) that leads to concentration of animals in landscapes within the arid zones. The problem is believed to be happening in the Kalahari ecosystem of Namibia, where artificial water points is suspected to be accelerating environmental processes that lead to desertification (NAPCOP, 1997).

The article reports on effects of artificial water points on the semi-arid rangelands of Northern Namibia. Three questions were posed. (1) What were the relationships between distances from artificial water points and, (2) age of water points and changes in herbaceous species richness, herbaceous cover, biomass, bare ground and litter compared to non-water point sites? (Hereafter called benchmarks), (3) What were the relationships between landscape types and changes of herbaceous species richness, herbaceous cover, biomass, bare ground and plant litter in relation to radial grazing distances from water points?

BACKGROUND TO THE STUDY

In the communal grazing lands of Northern Namibia livestock grazing historically involved seasonal movements between the remotely placed cattle posts and the main settlements (Thomas *et al.,* 2000). The general pattern of cattle movement was towards the cattle posts during the wet season and back to the homesteads during the dry season. Traditionally, variable rainfall and seasonal floods in the Oshana hydrologic systems regulated land use. The Oshana system, which covers approximately 10, 000 km^2 arises in the central highlands of Angola terminating in the Etosha Pan (Marsh and Seely, 1992). The system is made up of networks of low-lying, interconnecting seasonal watercourses that recharge the groundwater and hand-dug wells (*Omifima*). During the wet season the annual floods make the area saturated with water. During the dry season (i.e. after the surface water has evaporated) water scarcity is a major problem for both livestock and human use. In order to solve drinking water problems networks of pipelines and systems of canals were diverted from the Kunene River. Among the first constructed was the Oshakati - Ogongo pipelines which were serviced by 1975, while between 1993-1998 the Oshakati-Omapale pipeline was constructed. Presently a total of 2600 km pipeline lengths are developed (Marsh and Seely, 1992).

The new water points induced a system of land use different from that traditionally practiced by the Owambo agro-pastoralists (Williams, 1991). The distance livestock and humans walk to water has been shortened, with individual settlements located about 3.0 km, while grazing distances averaged 7.2 km. Individual water points on average served 44 households (Nangula, 2001). The region of North-central Namibia has an estimated cattle population of 39 000 heads (Mendelson *et al.*, 2000). The Owambo agro-pastoralists considered that the rangelands around water points are gradually being degraded (Nangula, 2001). The information on effects of artificial water points on the surrounding rangelands is, therefore, useful for refining adjustments of the density of water points as well as understanding the effects on the semi-arid rangelands of Northern Namibia.

[Figure 1 near here]

The study area

This study was conducted in Uuvudhiya constituency in the Oshana region of Northern Namibia (Fig. 1a). The constituency covers 5872 km^2 and comprises the communal grazing lands as well as part of the Etosha National Park. The Uuvudhiya constituency is among the least populated administrative regions of Namibia with only 0.6% of the total population found in the North of the country (Total population for the region is about 786,000 people). Migration into the constituency followed the development of water (Marsh and Seely, 1992).
The climate is classified as semi-arid, with 99 percent of the rain falling in the summer months (October-April). Rainfall is variable and ranged from 300 mm to 400 mm year^{-1} moving from

the south to the north (Ward *et al.,* 2000). The soils comprised the Kalahari sands and sand stones, forming gently undulating landscapes with an altitude ranging between 1100 m and 1200 m (Marsh and Seely, 1992). The dominant vegetation types are *mopane* shrubland and grasslands (hereafter called *mopane* and saline grassland landscapes, respectively). The *mopane* landscapes comprised the *Colophospermum mopane* shrub that reached 2.5 m height. The shrub grows on loamy sands, which are deeper than those of the saline grasslands. The *C. mopane* shrub is found in association with *Termilia prunioides* trees, which grow up to 6 metres in association with *Acacia* sp. and *Catophractes alexandri* shrub and *Boscia* sp., *Combrectum* sp. and the *Commiphora* sp. Grass production in the *mopane* landscapes is highly variable (Selma Nangula unpubl.). The *mopane* landscapes are grazed during the wet season and the grassland landscapes during the dry season (Mendelsen *et al.,* 2000).

FIELD SURVEYS

Six artificial water points along the Oshakati-Omapale pipelines in the Uuvudhiya constituency plus two-benchmark sites located about 5-7 km from water points were randomly selected (Fig. 1b). Given that a snapshots analysis of effects of water points was unlikely to provide understanding of land degradation created by water points (Andrew, 1988), we included in the sample, water points that were recently established (< 3 years old) in addition to the older ones (5-8 years old) (Table I and Fig. 1b). In order to separate responses of herbaceous species richness, cover, biomass, bare ground and litter to radial grazing patterns around water points from those caused by landscape types, equal numbers of water points and the benchmark sites were selected in the grassland and the *mopane* shrublands, respectively. In this article, benchmark sites refer to areas where effects of grazing pressure induced by water points was absent. Whereas the benchmark sites were seasonally grazed, the change in vegetation was attributed to environmental factors such as rainfall variability as opposed to water points. We assumed that if grazing pressure around water points contributes to reduction of herbaceous species richness, cover and biomass, then the benchmark sites would show opposite trends. Conversely, lack of differences between the water points and the benchmark sites in terms of the response variables will imply that land degradation is not a problem.

[Table I & Fig. 2 near here]

The study design was 6 water sites x 4 radial grazing distances replicated by landscape types. The radial grazing distances from water points and the benchmark sites were at 100, 300, 500 and 1000 m, respectively. For each radial distance, a series of transect were fixed, each sampled using a point sampling method technique (Floyd and Anderson, 1987). Sampling was at 1 m intervals with each sample point considered as a hit. The hit may register bare ground, plant litter or live herbaceous plants. The herbaceous plants in the study area were mostly annuals and perennial grass species. At random intervals the standing herbaceous biomass was harvested using 1 x 1 m plots. Before the harvest, all herbaceous species, herbaceous and woody cover was estimated; the latter based on canopy cover of individual trees that were intercepted by transects.

Statistical analysis

Effects of radial grazing distances from water points, age of water points and landscape types (i.e. categorical variables) on herbaceous species richness, herbaceous and woody cover, herbaceous biomass, bare ground and litter (as response variables) were compared using nested ANOVA. For individual grass species, distribution in relation to distances from water points were tested by one-way ANOVA. Herbaceous plant species frequency data was used to determine composition in response to categorical variables. Given that the present survey was a one season event, the age of water points was used to understand the temporal effects. Simple correlation was run to test effects of age of water-points on herbaceous cover, herbaceous species richness, biomass and bare ground. All analyses were done by SYSTAT (1995) and significance accepted at $p = 0.05$.

RESULTS

Response to distances from water points

Radial grazing distances from water points did not influence total herbaceous species richness ($F_{3, 88} = 1.520$, $p = 0.215$), while the herbaceous species richness varied among water point sites ($F_{4, 88} = 11.941$, $p = 0.004$). The difference in terms of species richness between water points and the benchmark sites was overall not significant (Fig. 2a). The annual and perennial grass species composition varied significantly among water point sites ($p = 0.001$) but not along radial distances from water points ($p>0.05$). Generally, the water points and the benchmark sites had greater dominance of annuals than perennial grass species (Fig. 2b). The composition of the annual grass *Aristida effusa* ($p = 0.049$) and the perennial grass *Eragrostis rotifer* ($p = 0.034$) were influenced by radial grazing distances from water points (Table II). The other grass species: *Eragrostis viscosa, E. tricophora, E. porosa, Eragrostis spp, Anthephora pubescens, Anthephora schinzii, Chloris virgata* and *Wilkommia sarmentosa* did not disclose sensitivity to water points ($p>0.05$).

[Fig. 3a,b near here]

Our data did not confirm that distances from water points had an influence on distribution of herbaceous cover ($F_{3, 88} = 1.395$, $p = 0.250$), although herbaceous cover showed high spatial variability among water point sites ($F_{4, 88} = 4.536$, $p = 0.002$). Similarly, distances from water points did not influence herbaceous biomass ($F_{3, 88} = 0.958$, $p = 0.417$). The pattern of herbaceous biomass among water point sites was comparable with those of the benchmark sites (Fig. 3a). The most sensitive indicator of impacts of grazing and trampling around water points was bare ground that showed significant difference along radial distances from water points ($F_{3, 88} = 10.249$, $p < 0.0001$) and among water point sites ($p = 0.009$). Distribution of bare ground was more pronounced around artificial water points compared to the benchmark sites (Fig. 3 b). Bare ground was negatively correlated with herbaceous biomass ($r = -0.410$, $p = 0.001$) and herbaceous species richness ($r = -0.186$, $p = 0.141$). Litter cover was unaffected by radial grazing distances from water points ($p >0.1$).

[Fig. 3a,b near here]

Effects of age of water points

The water point sites included in the current survey did not adequately explain variations in herbaceous species richness ($p = 0.116$) and herbaceous cover ($r = -0.176$, $p = 0.104$) but did so in terms of herbaceous biomass ($F_{1, 87} = 8.244$, $p = 0.005$), which seemed to decline with an increase with the age of water points ($r = -0.269$, $p = 0.012$). But given that there was no interaction between the age of water points and effects of radial grazing distances on herbaceous biomass ($p = 0.145$), we might suggest that herbaceous biomass was influenced more by environmental factors (e.g. landscape types) than grazing gradients alone. Generally, the age of water points had significant effects on bare ground ($F_{1, 87} = 4.478$, $p = 0.037$), which showed strong interactions with landscape types ($F_{1, 87} = 5.350$, $p = 0.023$).

Effects of landscape types

Overall, total herbaceous species richness did not vary between landscape types ($F_{1, 88} = 0.38$, $p = 0.540$) (Fig. 4a). The herbaceous species, which showed significant variations among landscape types, were: *Schmidtia Kalahariensis* ($p = 0.009$), *Pogonarthria fleckii* ($p = 0.017$), *Odyssea paucinervis* ($p = 0.002$), *Microchloa caffra* ($p = 0.011$), *A. effusa* ($p < 0.001$) and *E. rotifer* ($p = 0.004$). The greater majority of the grass species did not show any difference among the landscape types [(*Eragrostis viscosa, E. tricophora, E. porosa, Eragrostis spp, Anthephora pubescens, Anthephora schinzii, Chloris virgata, A. effusa, E. porosa, O. paucinervis, P. fleckii,* and *S. Kalahariensis* and *Wilkommia sarmentosa* ($p > 0.1$)] (Table II).

[Fig. 4a,b near here]

By comparison, herbaceous vegetation cover was greater ($F_{1, 88} = 16.221$, $p < 0.001$) in the grassland landscapes (61.44±4.80 percent) relative to the *mopane* shrub landscapes (39.48±4.88 percent). The woody canopy cover showed significant differences between the landscape types ($p < 0.001$) being greater in the *mopane* landscape types (39.94±4.66 percent) than the grassland landscape types (3.31±4.66 percent). By contrast, herbaceous biomass ($F_{1, 88} = 19.950$, $p < 0.001$) was greater in the grassland landscapes (78.77±11.6 g m^{-2}) compared to the *mopane* shrub landscapes (14.81±2.51 g m^{-2}) (Fig. 4b). Furthermore, landscape types showed significant differences in terms of bare ground ($p = 0.055$) this being more pronounced in the *mopane* landscape compared to the grassland landscape types (Fig. 4c). Our results showed that the two landscape types did not differ in terms of patterns of plant litter ($p = 0.105$).

DISCUSSION

Responses to distance from water points

The research concerned with effects of artificial water points in the arid zone rangelands in general report a reduction in plant species richness in the immediate area of water points (e.g. Thrash, 1999) but the results have not been widely supported. On one the hand, some studies reported a decline in grazing intolerant perennial grass species followed by an increase by pioneer annual grass species. The view is consistent with the equilibrium model, which often rationalizes the composition of perennial grass species as a standard against which rangeland degradation is measured (Illius and O'Connor, 1999). On the other hand, herbaceous species have been reported to change along radial grazing distances, reflecting gradients of grazing and trampling tolerance (Van Rooyen *et al.*, 1990, Greatz and Ludwig, 1978). The present study did not confirm these earlier findings. Rather, among the grass species that were identified only about 12.5 percent showed changes in composition in relation to radial distances from water points (Table II). The majority showed no direct responses. Much of the differences observed in terms of herbaceous species richness, cover and biomass was attributed to landscape types.

Yet, the lack of response by the herbaceous species to radial grazing distances might suggest that species distribution was influenced more by environmental factors such as soil water and nutrients than by distances from water points alone. From the present survey, therefore, it was impossible to predict if the lack of response suggested a greater resilience of the landscapes in the Oshana systems in Northern Namibia or due to the fact that the water points used were relatively new. In contrast to our study, investigations of older water points in the Kalahari (e.g. Skarpe, 2000) showed variations in radial patterns in plant species associated with grazing pressure. Furthermore in Northern Namibia, establishment of artificial water points resulted in heavy grazing that is associated with poor range conditions in the communal rangelands (Zeidler, 1999). Similarly, in Botswana (e.g. Tolsma *et al.,* 1987) and South Africa (e.g. Thrash, 1998, Thrash, 1999) a decline in herbaceous vegetation production near water points have been reported. The decline is interpreted in terms of gradual land degradation (Ward and Ngairrorue, 1999).

Other studies have disputed that grazing contributed to range degradation (e.g. Sullivan, 1999). There are also disagreements that water points influenced changes in plant species composition. In the Kalahari ecosystems of Botswana, Thomas *et al.* (2000) reported that long-term investigations are needed to make any objective statements about land degradation around water points that separate effects of environmental heterogeneity and climatic variability. In these rangelands distances from artificial water points do not directly influence the composition of herbaceous plant species, implying that grazing pressure was not necessarily associated with radial grazing distances from water sources. Rather, differences in herbaceous species richness were linked to landscapes (Van Rooyen *et al.,* 1994).

In the current study by comparison, the result of herbaceous species richness, cover and biomass was inadequate to generalize radial effects of grazing pressure around artificial water points. Moreover, direct relationships between distances from water points and distribution of herbaceous species richness, cover and biomass was not established (*cf.* Thrash, 1999). Similarly, in Northern Namibia, Muvungua (1998) did not find statistically significant variations in plant cover within 1 km of water points. In the current study, we also did not establish evidence to show that total herbaceous species richness and biomass declined in relation to distances from water. A probable explanation for the different results in this and the earlier reported studies is that effects of landscape types were not incorporated into the analyses. The exception was Van Rooyen *et al.* (1994) who reported that variability in plant species richness was explained more by environmental factors as opposed to radial grazing distances from water points. In the Sahelian rangelands as much as 80% of the variability in plant species was explained by environmental variables such as rainfall and soils as opposed to distances from water points (Hanan *et al.*, 1991). Similarly, in the current study, landscape types were influential on patterns of herbaceous species richness, cover and biomass, suggesting that the effects of artificial water points will be better understood within the domain of landscape types (see below). However, in agreement with other studies (e.g. Thomas *et al.*, 2000), we found closer relationships between radial grazing distances from water points and bare ground, although we shall suggest that the response of bare ground to radial grazing pressure around water points is expected to be dynamic in response to rainfall variability. Thus, additional bio-indicators that are sensitive to the underlying environmental effects will be required to understand response of vegetation to radial distances on one hand and age of water points and grazing management on the other.

Effects of age of water points

The impact of water points on the surrounding rangelands is related to the frequency and duration of use. The literature seems to imply that the impacts on the arid zone rangelands are more pronounced around the older than a more recent water points (James *et al.*, 1999). In Sahelian Africa, for example, the older boreholes reflected the processes of desertification (Zumer-Linder, 1976; Rapp, 1976). In the Kalahari rangelands of Namibia by comparison, age of water points did not affect total vegetation biomass (Ward *et al.*, 2000), while Skarpe (2000) in the Kalahari region of Botswana reported greater bare ground around the older boreholes. In the current study, given that the establishment of water points are relatively recent, negative impacts on herbaceous species richness, cover and biomass was not found as opposed to the findings of others (e.g. Thrash, 1998). Yet, regarding the herbaceous biomass, although age of water points seemed influential, the lack of interactions between age of water points and radial grazing distances implied that other environmental factors might be playing a more effective role. The most significant changes were those attributed to bare ground. Generally, high percentage bare ground was reported in the vicinity of the older than the more recent water points (Lange, 1969; Graetz and Ludwig, 1978, Thrash, 1999). Indeed, an improved picture will emerge when assessing the dynamics of bare ground if researchers will make distinctions between causes due to livestock trampling from the general fluctuations of herbaceous vegetation cover in response to erratic rainfall. In the latter, increased bare ground during dry years may not represent degradation, since rapid recovery is possible when rainfall returns (Oba et al., 2000a,b).

Effects of landscape types

The effect of landscape types on herbaceous species richness, herbaceous cover, woody cover, herbaceous biomass and percentage bare ground was superimposed on those of water points (Fig. 4a,b, c). Further, the current study as opposed to the findings of Mendelsen *et al.* (2000) found dominance of annual grasses in the two landscape types. Elsewhere in the rangelands of Southern African, introduction of water points promoted bush encroachment (Jeltsch *et al.*, 1997; Sullivan, 1999; Skarpe, 2000) which is a widespread problem in Namibia but less so in the Oshana systems. We suggest that the different potentials disclosed by landscape types implied that they posed different levels of risks of degradation. The *mopane* landscape type showed greater risks of land degradation induced by water points (in terms of bare ground) than the grasslands (Fig. 4c). The evidence suggests that landscape types may confound the effects of radial grazing distances from water points. We suggest that response of vegetation to water points should take into consideration the use of soil types and rainfall variability.

Based on the present results, however, we cannot be more categorical regarding vegetation degradation in Northern Namibia. This conclusion should not ignore the risks of water induced land degradation in the future. Rather, because development of artificial water points altered grazing patterns of livestock, one would expect that unless resource managers build into their plans precautionary measures, degradation might occur in the future. The management should include rotational use of water points by simply turning off the taps at sites where land degradation was becoming a threat and forcing livestock to move on to the next water points. The assumption being that the water points in Northern Namibia will be integrated through systems of monitoring.

CONCLUSIONS

The study, despite being preliminary has shown that artificial water points in the semi-arid rangelands of Northern Namibia promoted bare ground, which was highly correlated with radial distances and age of water points. The results, however, did not show land degradation in terms of herbaceous species richness, herbaceous and woody cover and herbaceous biomass. The study suggests that the vegetation variables were a product of landscape types as opposed to radial grazing distances. Moreover, the presumed differences in herbaceous species richness, species composition, cover and biomass from water points reported by others might be explained by differences among landscape types. Thus, if effects of landscape types are not accounted for, the effects of water points on land degradation might be inconclusive. Further, although the spacing of water points was not considered in the current study, common knowledge would suggest that proper distribution of water points are necessary to reduce the impact of grazing. The most practical measure is to regulate the use of water points by turning off the taps where land degradation seems a threat. In addition, using fixed transects radiating from the water points; indicators such as soil organic matter and soil seed banks should be added into monitoring. Nutrient concentration (e.g. phosphorus and nitrogen) along radial grazing distances from water in addition to showing the positive role livestock play provides an environmental dimension to the radial effects of water points, which might improve understanding of the effects of artificial water points on rangelands of Northern Namibia.

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Table I: Water points and non-water point sites in the Uuvudhiya constitueny covered by the study

Sites	Location	Used since	Description
Site 1	Uuvudhiya	BM	This site was 5 km away from Site 2. The site was situated in the grasslands and was lightly grazed.
Site 2	Omapale	1996	This was a water point on Oshakati-Omapale pipeline situated in the grasslands used as cattle posts.
Site3	Eengombe	1996	The site was a water point on the Oshakati-Omapale pipeline, located in the grasslands. It is used both for domestic and livestock from the cattle posts as well as nearby homesteads.
Site 4	Omapopo	1993	The site was a water point on an older pipeline in the constituency that supplied water for domestic use. The site was located in the grasslands, although a high number of bushes were detected.
Site 5	Onkani	BM	The site was not a water point, but located about 5 - 7 km away from the Onkani centre. The site occurred in the *Mopane* shrubland.
Site 6	Onkani-centre	1998	The site was a water point on the Oshakati-Omapale pipeline mainly used by domestic livestock. In addition, it is situated very close to the main centres of the village. It is situated in the *Mopane* shrubland.
Site 7	Omapale	1996	The site was a water point on the Oshakati-Omapale pipeline, and is used for livestock only from the far south of the constituency. *C. mopane* trees dominated the landscapes.
Site 8	Onaushe	1993	The site was a water point situated on older pipeline. The area was situated close to the canal that supplied livestock water. Main vegetation was dominated by *C. mopane* Shrubs

BM represents the benchmark sites located at 5-7 km from the water points. (Source: current survey)

Table II. Response of herbaceous plant species composition in relation to radial distances from water points and at the benchmark sites in the grassland and the *mopane* shrubland landscapes.

	Radial distances from water points				Benchmark sites	
Herbaceous species	100 m	300 m	500 m	1000 m	Grassland	*mopane* shrubl
Anthephora pubesscens	0	0	0	0.13±0.4	0.1±0.04	0
Anthephora schnzii	1.0±2.8	1.1±3.2	1.3±3.5	0	0	1.7±0.7
Aristida effusa	8.5±15.4	13.8±14.5	18.5±22.6	21.6±22.2	28.7±3.2	2.5±3.2
Chloris virgata	1.9±3.5	0.3±0.5	0	0	1.1±0.4	0
Eragrostis tricophora	11.4±11.4	7.1±5.8	5.8±4.2	6.8±7.13	6.6±5.1	8.8±9.5
Eragrostis viscosa	7.0±7.4	6.4±6.2	4.9±5.4	2.0±3.02	6.6±1.9	8.9±1.9
Eragrostis rotifer	0	0	0.3±0.5	0.25±0.46	2.4±1.23	7.8±1.2
Eragrostis porosa	3.6±4.4	3.0±4.3	2.6±4.4	6.4±13.5	1.4±1.8	6.4±1.8
Eragrostic sp.	0.5±1.4	1.1±1.9	0.6±1.8	0.4±1.1	0.6±0.4	0.8±0.04
Microchloa caffra	2.4±6.7	2.1±4.6	4.1±7.6	1.9±5.3	0	5.3±1.4
Pogonarthria fleckii	8.1±9.0	18.0±15.2	16.7±14.1	12.3±12.6	8.4±3.0	19.2±3.01
Scmidtia kalaharensis	22.5±19.5	22.9±10.5	28.4±18.9	17.4±16.1	30.1±3.7	15.4±3.7
Odyssea paucinervis	8.9±10.3	7.6±6.8	7.8±9.9	2.3±3.9	10.7±1.7	2.6±1.7
Wilkommia sarmentosa	1.5±3.9	5.8±14.4	5.1±9.2	0.9±1.6	1.9±2.2	4.8±2.2

Source: Current survey

Captions for the figures

Figure 1a. Map showing the local of the study area in Northern Namibia (Source: Desert Research Foundation of Namibia).

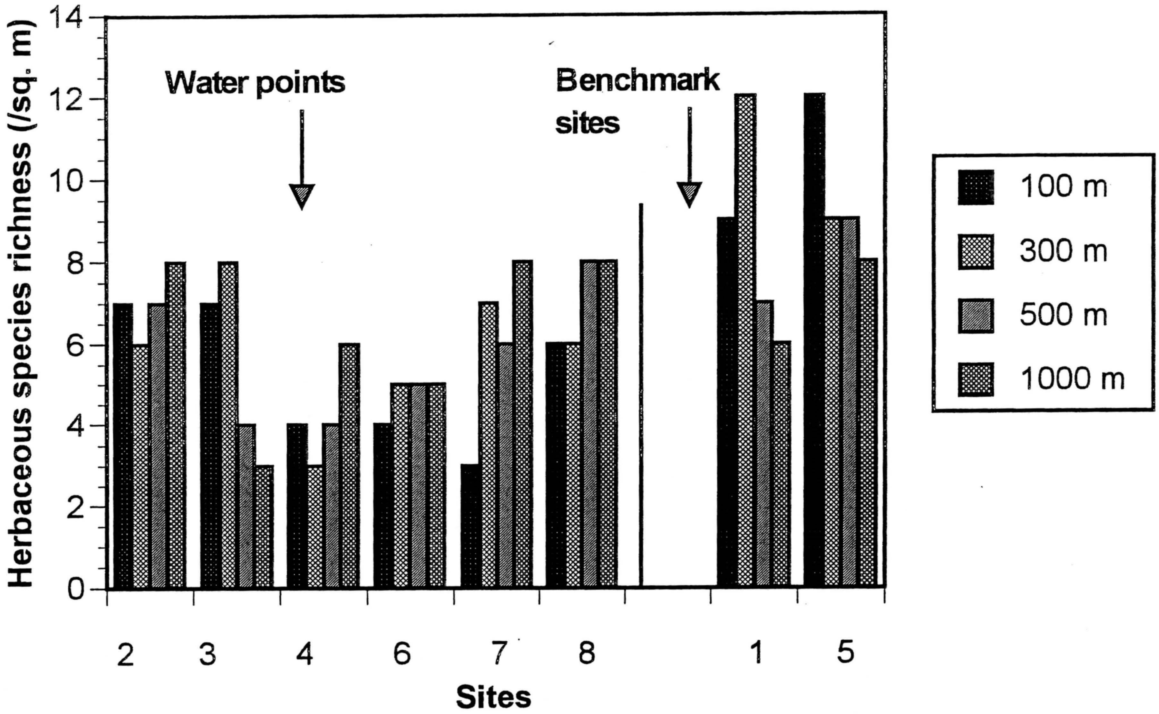
Figure 1b. Location of artificial water points and benchmark sites in Northern Namibia (Source: NIPEP, 1999).

Figure 2. Effects of radial grazing distances from water points on (a) herbaceous species richness and (b) number of annuals and perennial grass species recorded at the water points and the benchmark sites in Northern Namibia (Source: current survey).

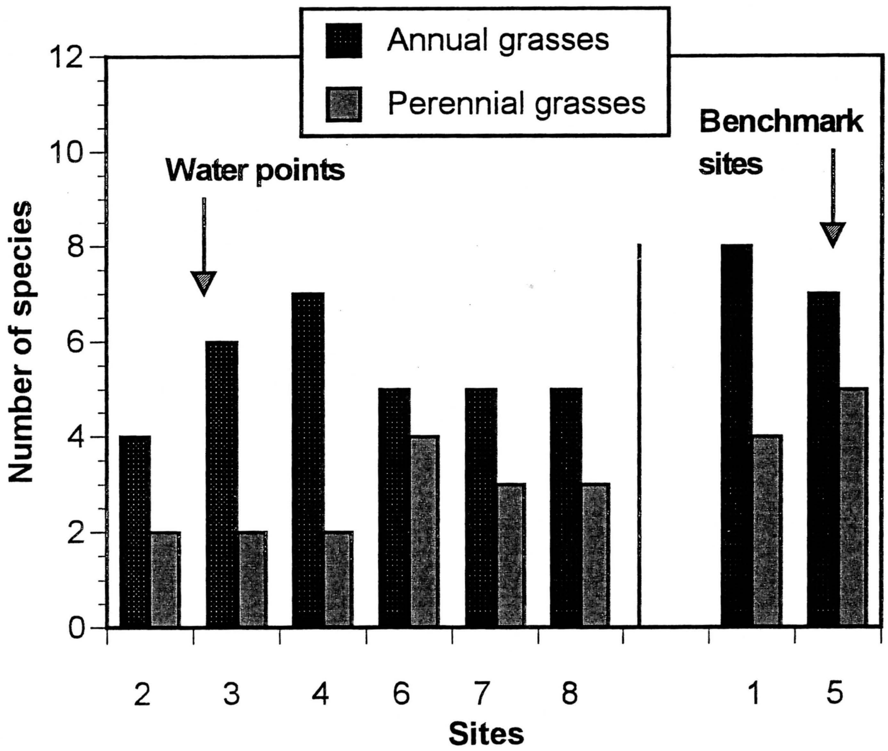
Figures 3. Effects of radial grazing distances from water points on (a) herbaceous biomass and (b) bare ground in Northern Namibia (Source: current survey).

Figure 4. Effects of radial grazing distances from water points on (a) herbaceous species richness, (b) herbaceous biomass and (c) bare ground by landscape types in Northern Namibia (source: current survey).

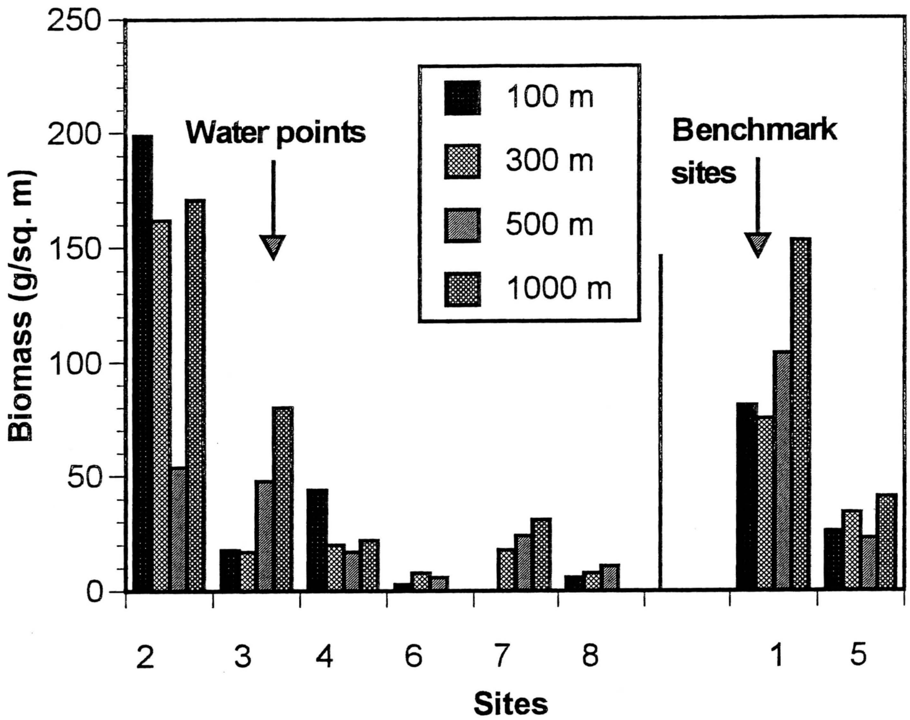
a


Herbaceous species richness (/sq. m)
14
12
10
8
6
4
2
0
Water points
Benchmark sites
100 m
300 m
500 m
1000 m
2 3 4 6 7 8 1 5
Sites

b

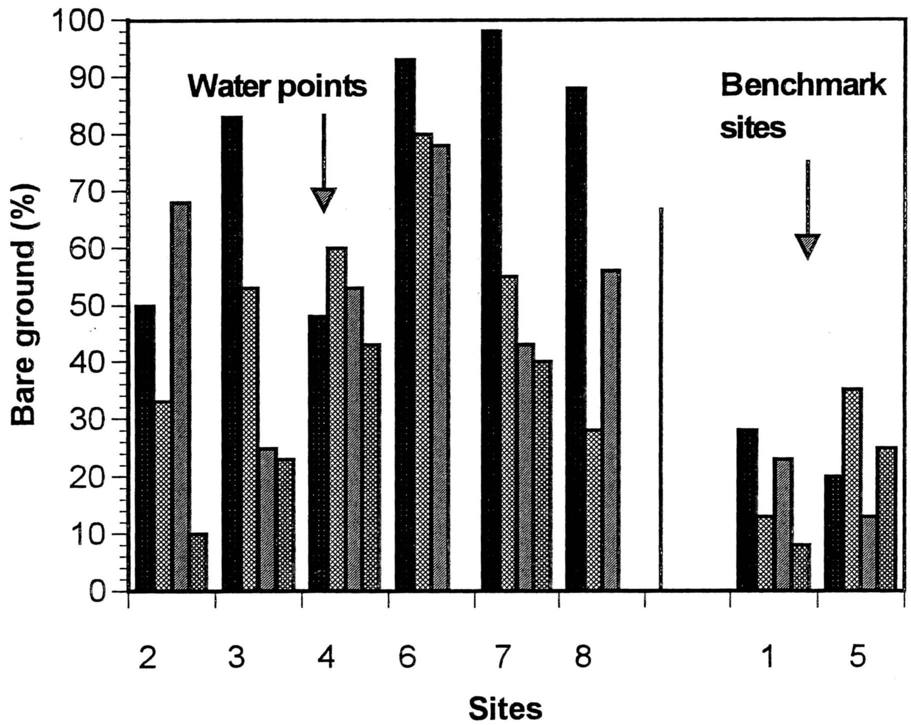

Number of species
12
10
8
6
4
2
0
Annual grasses
Perennial grasses
Water points
Benchmark sites
2 3 4 6 7 8 1 5
Sites

a



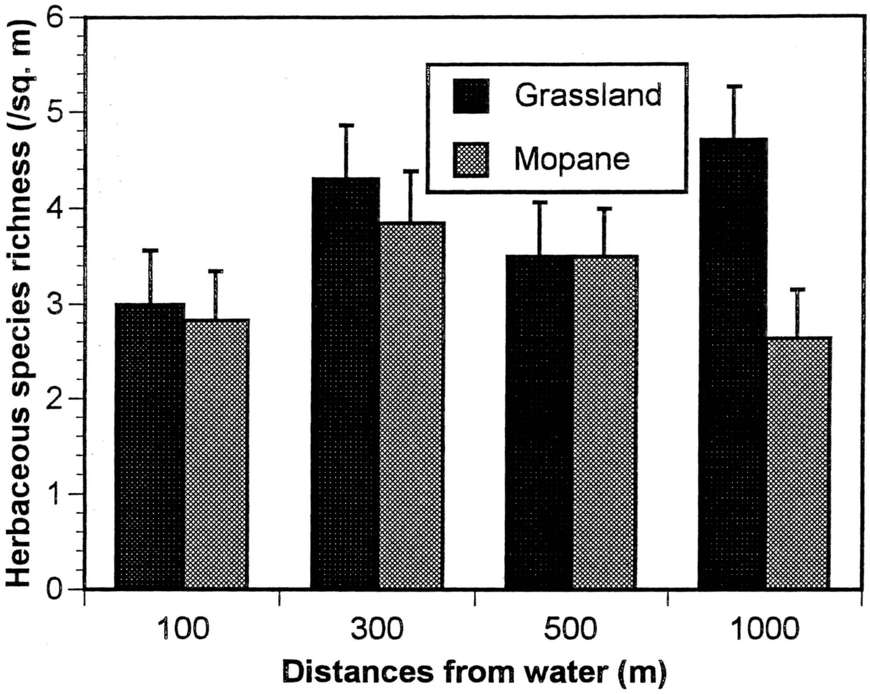
250
200
150
100
50
0
Biomass (g/sq. m)
Water points
100 m
300 m
500 m
1000 m
Benchmark sites
2
3
4
6
7
8
1
5
Sites

b

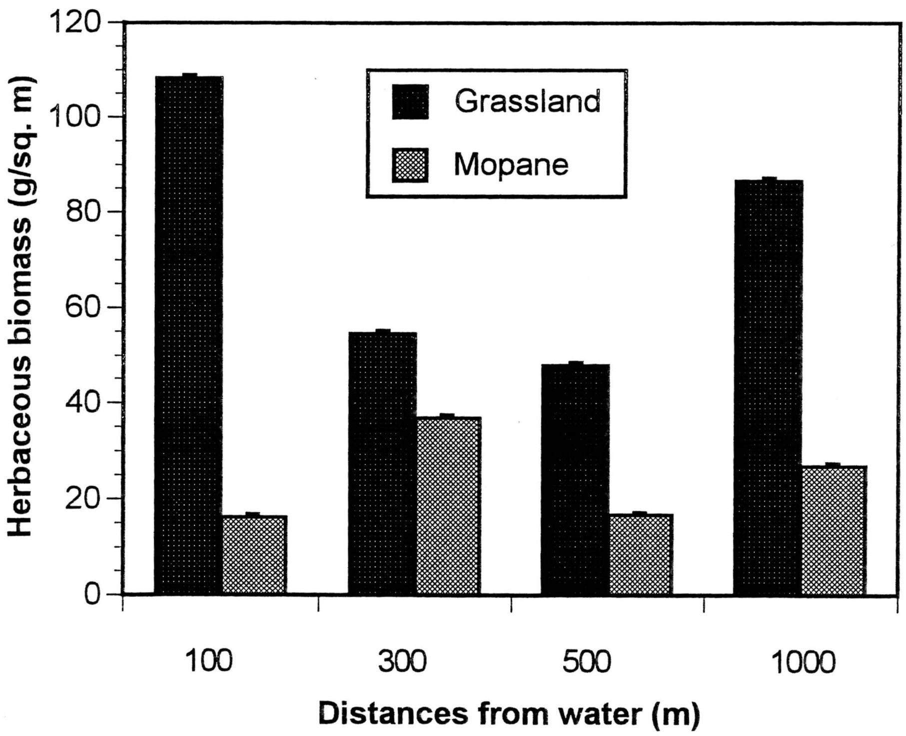


100
90
80
70
60
50
40
30
20
10
0
Bare ground (%)
Water points
Benchmark sites
2
3
4
6
7
8
1
5
Sites

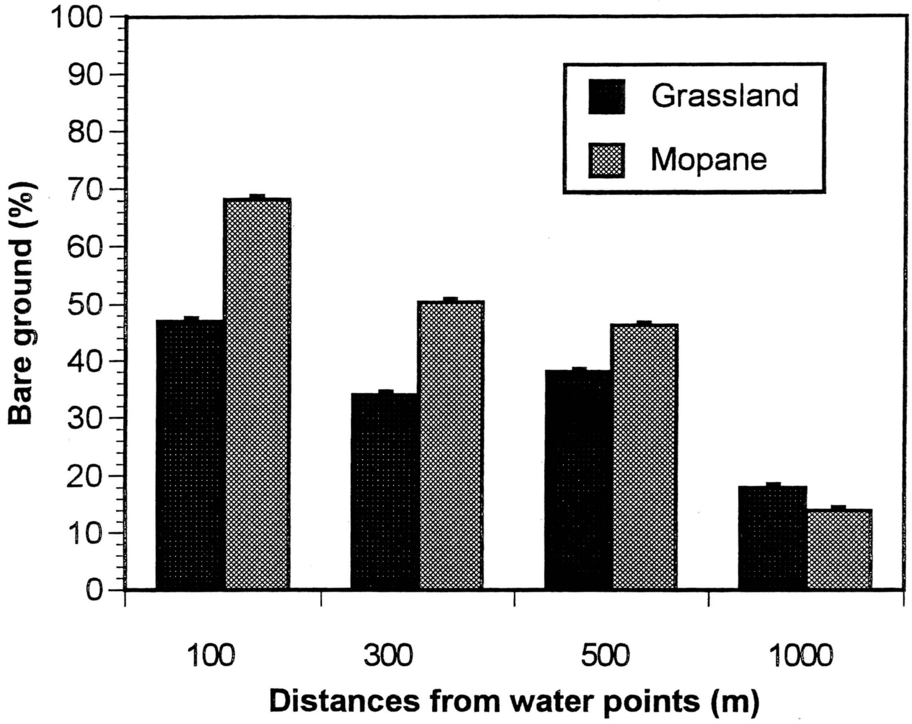
a


Herbaceous species richness (/sq. m)
6
5
4
3
2
1
0
Grassland
Mopane
100
300
500
1000
Distances from water (m)

b


Herbaceous biomass (g/sq. m)
120
100
80
60
40
20
0
Grassland
Mopane
100
300
500
1000
Distances from water (m)

c


Grassland
Mopane
Bare ground (%)
0
10
20
30
40
50
60
70
80
90
100
100
300
500
1000
Distances from water points (m)