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Drought as an analogue climate change scenario for prediction of potential impacts on Malawi's wildlife habitats

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ABSTRACT: This study compares precipitation and temperature from recent drought episodes with general circulation model outputs to examine the likely effects of climate change on herbaceous layer productivity, ground cover, and forage utilization in Malawi's Lengwe National Park. There are no differences in precipitation distribution and temperature during the drought episodes and climate change scenarios. The implication is that deteriorating habitat conditions such as those observed during the drought incidents might occur under climate change. Herbacious layer productivity was 2 to 6 times lower than in a normal year; ground cover was reduced to 22–32%; and the number of intensely browsed plants increased significantly (chi-square = 10.5, p = 0.01) as the drought progressed. Consequently, it is unlikely that the degraded habitat would support large mammal populations in Lengwe specifically, or in Malawi in general.

KEY WORDS: Precipitation · Temperature · Productivity · Ground cover · Browse utilisation

1. INTRODUCTION

Severe drought incidents have afflicted wildlife in southern Africa, including Malawi. Their impacts have been variable, but certainly harmful. Kamvazina (1981) reported that the drought of 1980 resulted in poor regeneration of vegetation and nyala *Tragelaphus angasi* Gray mortality in Lengwe National Park, Malawi. Similar effects of the drought occurred in wildlife conservation areas in Botswana and South Africa (Walker et al. 1987) and in Zimbabwe (Magadza 1994).

The temperatures predicted by general circulation models (GCMs) under climate change are higher than those found during the droughts (Magadza 1994). However, Magadza (1994) reported that recent comparisons of GCM control runs and observed climate have shown that models (GFDL, GISS, UK) tend to underestimate current temperatures in some regions of southern Africa while overestimating precipitation. An assessment of the impacts of global climate change on Malawi wildlife was done by Mkanda (1996) using climate change scenarios and the habitat suitability model developed by the US Fish and Wildlife Service in 1981. The study suggested that ungulates in Lengwe National Park would be susceptible to climate-induced changes in habitat and food supply. The problem with modelling habitat suitability using climate change scenarios, however, is that the model outputs cannot be validated, as suitable methods are not yet available. A second problem is that models may not necessarily reflect the actual magnitude of future ecosystem change (Carter et al. 1994, Hulme 1996). Previous drought episodes, on the other hand, can act as analogue climate change scenarios because the observed effects can be used to project the likely impacts of climate change.

The uncertainty surrounding predictions of global climate change by models, and hence the inability to deduce from the models what the impacts of climate change on wildlife habitats are likely to be, leads to the following question: Will the impacts be worse than those observed during the recent drought episodes? To address this question, this study examined some

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climate and wildlife habitat variables during drought events in Lengwe National Park.

1.1. Study site

Lengwe National Park, which lies at 34° 35' E, 16° 15' S in the Lower Shire Valley in southern Malawi, was selected as the study site. There are 2 advantages to using Lengwe as a study site. The first one is the availability of some records of drought episodes and their consequences. Second, the area is apparently vulnerable to drought; hence, using it as a case study gives an insight into the potential effects of climate change on wildlife habitats in Malawi.

The park has a semi-arid type of climate (Anonymous 1975). The minimum temperature is 14.3°C in June, while the maximum is 35.8°C in November. Monthly mean precipitation ranges from 5 mm in September to 167 mm in December, while the annual rainfall is 751 mm. The rainy season lasts from November to April, but small amounts of precipitation called Chiperoni are brought by high-pressure southeasterly winds from May to July (Mkanda 1996).

Acacia thicket clump savannah is the dominant vegetation in Lengwe. The common ungulates include buffalo *Syncerus caffer*, kudu *Tragelaphus strepsiceros*, warthog *Phachoecorus aethiopicus*, impala *Aepyceros melampus*. Reptiles, small mammals, and birds are common. The nyala is the keystone species in the park, numbering about 2000 in 1992.

2. MATERIALS AND METHODS

To assess the likely impacts of global climate change on wildlife habitat, the study compared precipitation and temperature from the drought of 1979/80 (Drought 1) and 1991/92 (Drought 2) with GCM scenarios. Herbaceous layer productivity, ground cover, and forage utilisation by browsers during Drought 2 were measured, and inferences were made as to the likely response of these habitat variables to climate change.

2.1. Climate scenarios. Mean monthly precipitation and ambient temperature data came from the Meteorological Department (hereafter as 'MwMet') database for the period 1961–1990. Data from 3 sites close to Lengwe National Park—namely, Makhanga, Mangochi, and Salima at 35° 10' E, 16° 30' S; 35° 16' E, 14° 29' S; and 34° 35' E, 13° 45' S, respectively—were averaged and considered as the baseline (existing climate) scenario for the study area.

As part of technical support, the US Country Studies Program supplied the following 4 GCM outputs: Canadian Climate Centre (CCC) model (Boer et al. 1992); GFD3 model from the Geophysical Fluid Dynamic Laboratory (Manabe & Wetherald 1987); and United Kingdom Meteorological Office UK89 model (Mitchell et al. 1989).

Baseline climate scenarios were developed from these outputs following Unganai (1996). As done with the MwMet data, precipitation and temperature outputs from 3 grid points (Table 1) close to the study area were averaged for each model. The averages served as baseline scenarios. The mean model outputs and the spatially averaged MwMet precipitation and temperature data were compared to facilitate selection of GCMs that closely simulated the seasonal patterns of the current climate in Malawi. Three GCMs—GFD3, UK89, and CCC—appeared useful in simulating the current climate in the study area (Figs. 1 & 2).

To develop climate change scenarios, changes in ambient temperature patterns were analysed in comparison with the existing climate patterns as described by Unganai (1996). The ambient temperature changes were computed from the difference of the baseline and climate change scenarios from the GCM outputs. Precipitation pattern changes were computed as the ratio of the baseline to climate change outputs.

2.2. Comparisons of drought with climate scenarios. Temperature and precipitation were recorded by the park research unit during the drought events, while evaporation was only recorded during Drought 2. Magadza (1994) showed that during the 1991/92 drought in Zimbabwe, evaporation exceeded precipitation throughout the cropping season from December to March while during normal seasons precipitation exceeds evaporation. To determine if this trend applied to the study area, the precipitation and evaporation data were plotted (Fig. 3). Besides the annual totals, precipitation distribution in terms of amount (mm d^{-1}) was considered (Fig. 4). Experience has shown that, in Lengwe, precipitation that is distributed over the seasons is more crucial in sustaining forage production than large quantities received only at the beginning of the rainy season.

Mean precipitation and temperature for the current climate (MwMet), drought episodes, and GCM baseline scenarios were calculated. To test if there were significant differences between the different data sets,

Table 1. Selected grid points for generation of climate scenarios, Lengwe National Park

GCM	Grid points		
CCC	30.00° E, 16.70° S;	33.75° E, 16.70° S;	37.75° E, 16.70° S
GFD3	30.00° E, 16.77° S;	33.75° E, 16.77° S;	37.50° E, 16.77° S
UK89	31.88° E, 16.25° S;	35.63° E, 16.25° S;	39.38° E, 16.25° S

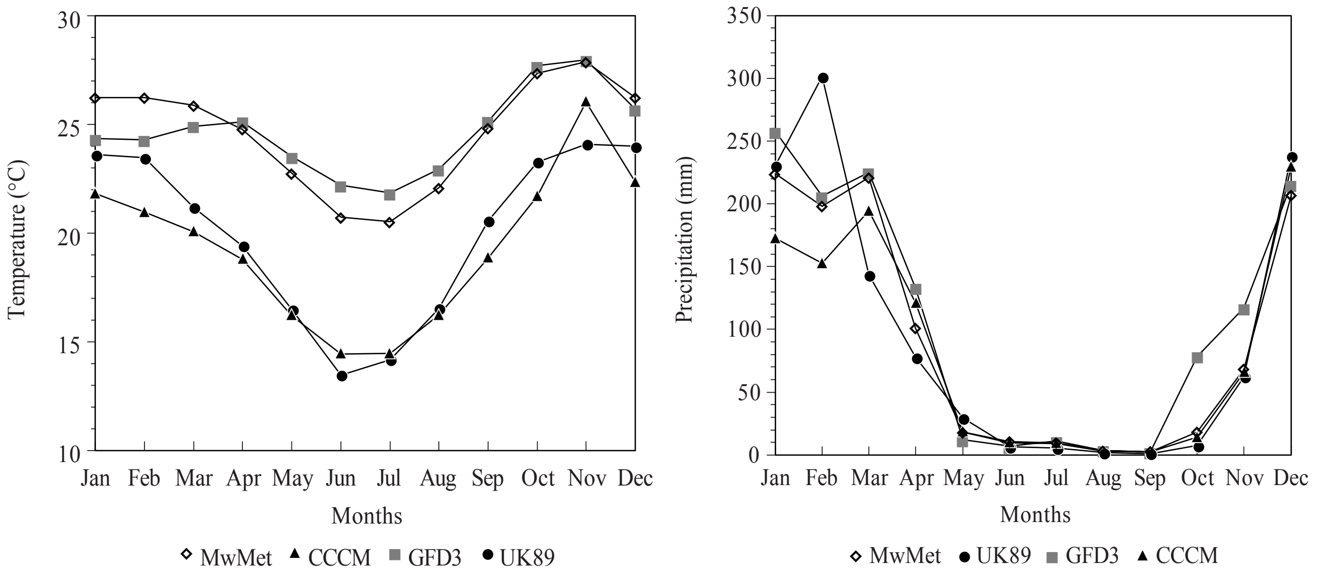

Fig. 1. Ambient temperature and precipitation pattern, MwMet and GCM baseline scenarios, Lengwe National Park, Malawi (baseline scenario)

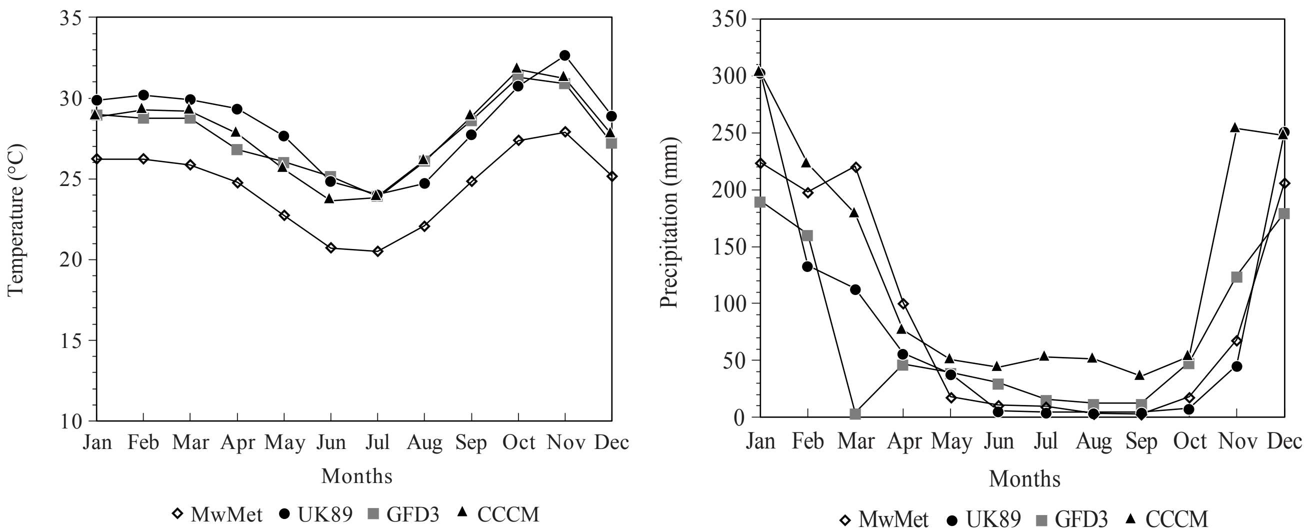

Fig. 2. Ambient temperature and precipitation pattern, MwMet and GCM climate change scenarios, Lengwe National Park (climate change scenario)

Dunnett's method of means comparison with a control (Sall & Lehman 1996) was employed. The tests were as follows: (1) MwMet versus the drought episodes and baseline scenarios, the MwMet data acting as the control because the assumption is that the current climate is optimally suitable (Mkanda 1996); (2) MwMet compared with climate change scenarios; and (3) Drought 2 against Drought 1 and climate change scenarios, using Drought 2 as the control because it was described as the worst in living memory (Magadza 1994).

2.3. Herbaceous layer productivity and off-take. Walker et al. (1987) reported that grass productivity, which is part of the herb layer productivity, was drastically reduced in the Tuli block (Botswana) during the drought of 1980/81. Therefore this study found it imperative to measure herbaceous layer productivity and off-take by mammals and harvester termites *Hodotermes mossambicus* Hagen.

The rainy season for Drought 2 (November 1991 to April 1992) was subdivided according to Mkanda & Munthali (1991)—that is, early rains (November to January), and late rains (February to April). Productivity and off-take were assessed in two 5 × 5 m exclosures that the Lengwe Research Unit established in 1986 in

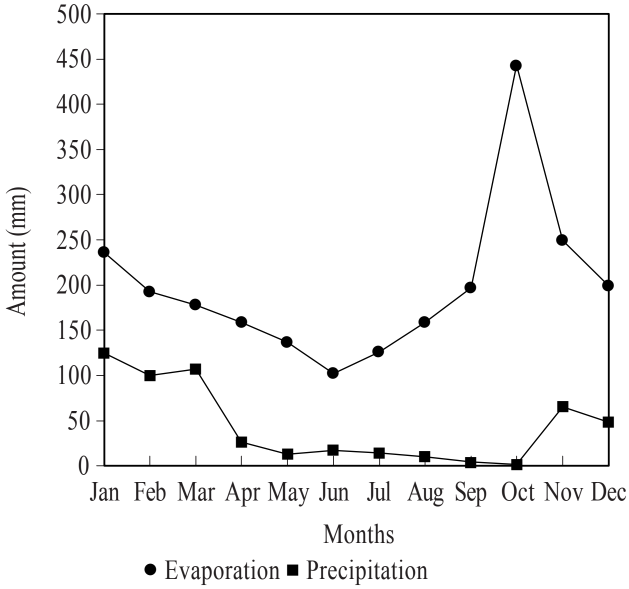

Fig. 3. Precipitation and evaporation during Drought 2 (1991/92), Lengwe National Park

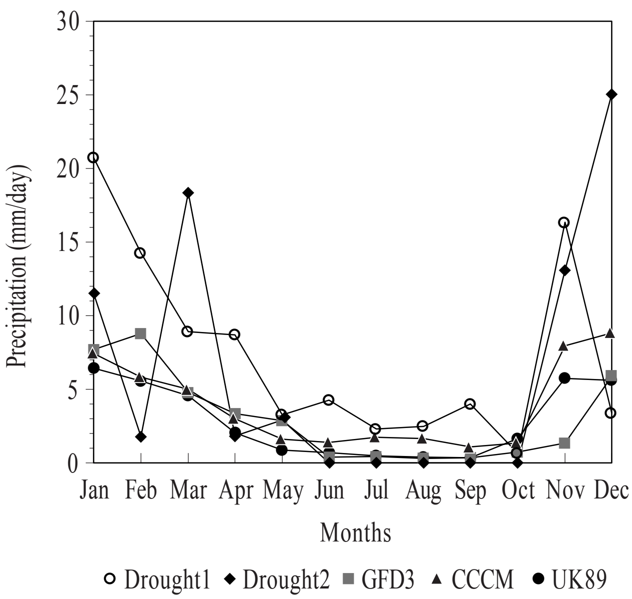

Fig. 4. Precipitation distribution for drought episodes and GCM climate change scenarios, Lengwe National Park. Drought 1: 1979/80; Drought 2: 1991/92

Acacia nigrescens and *Albizia harveyi/Ziziphus mucronata* vegetation communities. These vegetation communities generally support high animal biomass and are some of the favourite nyala (keystone species) habitats (Munthali 1991). Samples were clipped inside and outside the exclosures in the late rainy season when productivity was at its peak. Productivity was calculated as kg of dry matter per hectare. The difference between the inside and outside of the exclosures reflected the off-take by harvester termites, as well as grazing and trampling by ungulates. The results were compared with those obtained during normal seasons, for example, 1989 and 1990.

2.4. Ground cover. In contrast with herb layer productivity monitoring, the park did not have a ground cover monitoring program. Therefore, data were collected during Drought 2 only.

To determine if there was a trend in ground cover as the drought progressed, sampling took place in the late rainy season and early dry season (May to July). Poor accessibility precluded sampling during early rains, while funding constraints hindered sampling during the late dry season (August to October).

Forty-four clearly marked sampling stations were established at 1 km intervals along the road network (61 km long) during the late rains in 1992. Because of poor accessibility, the stations covered only 9 of the 20 vegetation types described by Hall-Martin (1972). The vegetation included the preferred habitats of nyala—that is, *Pterocarpus lucens* shrub thickets, *Acacia nigrescens* thicket clump savannah, and *Acacia harveyi/Ziziphus mucronata* thicket clump. The herbaceous vegetation cover was assessed using the line-intercept technique (Mueller-Dombois & Ellenberg 1974). At each station, a 10 m line was set, and the basal length of the herbaceous stratum beneath the line was recorded. The basal cover was calculated as the percentage of the line intercepted by the basal portions of herbaceous plants. A basal cover of <40% was arbitrarily considered as low since there were no previous data for comparison. The relative frequency of occurrence of the intercepts and bare ground in each vegetation community was determined and averaged for all the vegetation communities. An unpaired *t*-test was applied to detect any differences in basal cover between the late rains and early dry season.

2.5. Browse utilisation. Since the park has browsers such as kudu, bushbuck *Tragelaphus scriptus*, and nyala, it was essential to elucidate their impact, through browsing, on woody plant growth. The main factor considered was the intensity of browsing.

Sampling took place in the same vegetation communities where ground cover was assessed. For the reasons given above, the assessment was also confined to the late rainy and early dry seasons. Sampling was done at 500 m intervals using the Point Centred Quarter method (Mueller-Dombois & Ellenberg 1974). Each sampling station was positioned 100 m away from the road as it was assumed that animal activity increased with distance from the road. The number and height of woody plants that were nearest to the sampling point were recorded and categorised according to browsing impact by modifying the method used by Vesey-

FitzGerald (1973) as follows: (1) *b*0 = zero browsing; no sign of browsing; (2) *b*1 = light browsing; evidence of browsing apparent, but the impact is replaceable by the season's growth; the leaves are browsed but branches or twigs are intact; (3) *b*2 = intense browsing; leaves browsed, branches or twigs are broken; and (4) *b*3 = severe and damaging browsing; stems broken, individual plants may be disfigured so that their chances of survival are reduced.

The number of plants in each browse category was grouped by season to determine the trend in browsing impact. To detect any differences in browsing impact, Dunnett's method was used, *b*0 acting as the control. To detect if the changes in browsing impact between the seasons were significant, Pearson's chi-square test (Sall & Lehman 1996) was used.

3. RESULTS

3.1. Current climate simulation by climate scenarios

Overall, the GCMs predict seasonal trends of annual precipitation and ambient temperature that are similar to the existing climatic conditions (Figs. 1 & 2). As reported by Mkanda (1996), the general trend is frequent precipitation at the onset of the rainy season in November, continuing until January. The Chiperoni rains take over in winter (May to July). Ambient temperatures are usually above 25°C during most of the year except between May and August, when they decline below 20°C. Although the UK89 and CCC models also simulate the seasonality of the temperature, they predict lower ambient temperatures than the existing temperatures and those predicted by the GFD3 model (Fig. 1).

Table 2. Changes (differences between baseline and climate change) in precipitation and ambient temperature under 3 climate change scenarios, Lengwe National Park

GCM	Δ temperature (°C)	Δ precipitation (%)
UK89	3.8	2.11
GFD3	3.1	17.23
CCC	3.2	–8.26

3.2. Comparison of current climate with drought and baseline climate scenarios

The mean annual precipitation was lower during Drought 1 and Drought 2 than found for MwMet. The GFD3 and UK89 models predict an increase over the current precipitation (MwMet) (Tables 2 & 3). Only the CCC model implies a decline (–8%) in annual precipitation under climate change, while the GFD3 model shows a higher expected increase in precipitation than the UK89 model. However, the differences in mean annual precipitation between MwMet and the Drought 1, Drought 2, and the baseline climate change scenarios are not significant (Table 4).

All GCM scenarios suggest that ambient temperatures will rise within the study area; the temperature increases range from 3.1 to 3.8°C (Table 2). The UK89 and CCC models predict significant increases in mean temperatures under the climate change scenario relative to the current mean temperatures (Table 5).

Mean temperatures under current (MwMet) climate conditions are significantly higher than predicted by the UK89 and CCC models (Tables 3 & 5), almost the same as suggested by the GFD3 model, but lower than found during the drought events. The differences in mean temperatures recorded during the 2 drought incidents are not significant (Table 5).

3.3. Comparison of drought with climate change scenarios

The mean annual precipitation under the 2 drought episodes was lower than projected by the GCM scenarios, Drought 2 having the lowest amount (Table 3). However, the differences are not significant (Table 4).

Table 3. Annual means of precipitation and ambient temperature under MwMet, drought, and climate change scenarios, Lengwe National Park

Scenario	Baseline scenario		Climate change scenario		
	Precipitation (mm)	Temperature (°C)	Precipitation (mm)	Precipitation (mm d^{-1})	Temperature (°C)
CCC	131.0	19.3	82.7	3.9	27.8
UK89	80.8	20.0	92.0	2.9	28.4
GFD3	72.1	24.6	105.7	3.1	27.7
Drought 1	44.2	25.7	–	–	–
Drought 2	29.9	26.3	–	–	–
MwMet	90.1	24.6	–	–	–

Table 4. Dunnett's values from precipitation mean comparisons at the 99% level, Lengwe National Park. Negative values: pairs are not significant

Scenario	Baseline scenario control	Climate change scenario control	
	MwMet	Drought 2	MwMet
CCC	–63.4	–55.9	–115.2
UK89	–94.8	–46.6	–120.7
GFD3	–86.2	–33.0	–107.1
Drought 1	–58.3	–94.5	–
Drought 2	–44.0	–	–
MwMet	–	–48.5	–

Table 5. Dunnett's values from ambient temperature mean comparisons at the 99% level, Lengwe National Park. Negative values: pairs are not significant

Scenario	Baseline scenario control	Climate change scenario control	
	MwMet	Drought 2	MwMet
CCC	1.3	–2.1	0.04
UK89	0.5	–1.5	0.6
GFD3	–4.1	–2.2	–0.1
Drought 1	–2.9	–3.1	–
Drought 2	–2.4	–	–
MwMet	–	–1.9	–

Precipitation distribution (mm d^{-1}) under Drought 2 was lower than under Drought 1, but was higher than those obtained by the 3 climate scenarios (Fig. 4). The differences in precipitation distribution are not significant at the 99% level between the different data sets—that is, Drought 2 versus Drought 1 and the climate change scenarios. The distribution pattern throughout the year, however, was worst during Drought 2. There was no precipitation from June to October in Drought 2, while there was some during Drought 1; the climate change scenarios predict that there will be some precipitation during this period (Fig. 4). Monthly precipitation was lower throughout Drought 2 than the amount of evaporation (Fig. 3).

The mean annual temperatures were lower under the drought events than those predicted by the GCMs (Table 3). The differences in temperature rise among Drought 2, Drought 1, and the climate change scenarios might not be so large (Table 5).

3.4. Herbaceous layer productivity, ground cover, and browse utilisation

Drought 2 reduced herbaceous layer productivity drastically (Table 6). Independent of any off-take, the productivity was 2 and 6 times lower in 1992 than during the normal rainy seasons, i.e. 1989 and 1990 respectively. The off-take was also correspondingly lower in 1992 than in the seasons preceding the drought.

The drought reduced the ground cover drastically as evidenced by the high relative frequency of bare ground in both seasons (Fig. 5). The mean basal cover was 32 ± 23.3 and 22.9 ± 21.1 in the late rains and early dry season, respectively. However, a decline was significant over the seasons.

More plants were intact and lightly browsed than intensely or severely browsed during the late rains (Table 7). A similar pattern is apparent during the early dry season. During the early dry season, more plants were browsed than in the late rains. However, there were more plants in the *b*0 and *b*1 categories than in *b*2 and *b*3.

4. DISCUSSION

Temperature, precipitation, and soil moisture are important in the primary production of natural ecosystems. As these would change because of global warming, to assess the likely impacts of climate change inferred from the GCM models and observed climate and drought is sensible.

The increases in temperature and precipitation in southern Africa as a result of doubling carbon dioxide in the atmosphere have been reported in the studies of Magadza (1994), Hulme (1996), and Unganai (1996), to mention just a few. This study and the previous one for the same site (Mkanda 1996) concur with the findings of the other investigators. It should be expected that the study area will become wetter (albeit not significantly) than it is under the current climate, if the climate change conditions occur as the UK89 and GFD3 models predicted (Tables 2 & 3). However, the high temperatures will possibly diminish the effects of increased precipitation. Since there are no significant differences between temperature and precipitation between Drought 2 and all 3 GCM climate change scenarios (Tables 4 & 5), it can be contended that evapo-

Table 6. Herbaceous layer productivity and off-take (kg ha^{-1}) in *Acacia nigrescens and Albizia harveyi/Ziziphus mucronata* in the late rains, Lengwe National Park

Year	Productivity	Off-take
1989	480	11.6
1990	170.0	17.0
1992	75.7	5.6

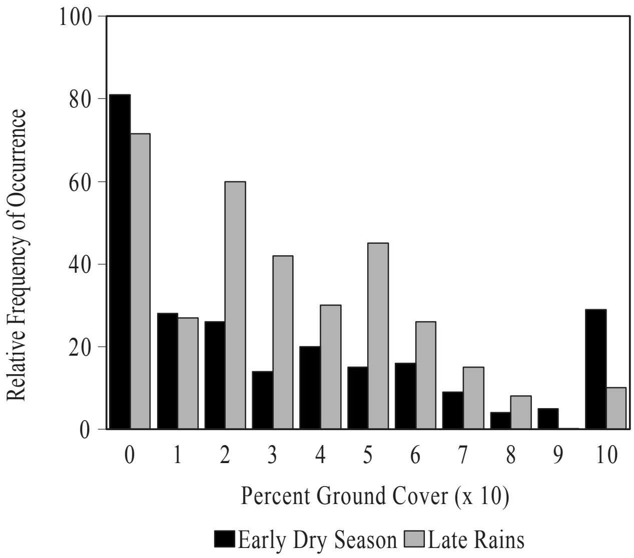

Fig. 5. Ground cover relative frequency of occurrence during Drought 2, Lengwe National Park

ration rates that are higher than precipitation as recorded during Drought 2 (Fig. 3) will prevail under climate change. Under such conditions, soil moisture would be deficient. The study therefore agrees with Hulme et al. (1994), who postulated that the significant increases in ambient temperatures would probably increase evapotranspiration rates, reduce water availability, and reduce vegetation productivity. Walker et al. (1987) also observed that precipitation influenced vegetation productivity and ground cover in various wildlife reserves in southern Africa.

Being the primary food resource and habitat for animals, vegetation is essential for conservation of wildlife in the park. The high evaporation rates observed under Drought 2 are liable to occur or become permanent under climate change. Such a situation would not only limit vegetation productivity, but also affect animal biomass negatively. Coe et al. (1976) and Western (1991) have shown that there is a positive correlation between animal biomass, vegetation productivity, and precipitation. The reduction in herbaceous layer productivity and low off-take observed under Drought 2 in Lengwe illustrate that, indeed, low precipitation would not support high animal biomass in the park.

The reduction in ground cover during the 1991/92 drought has adverse consequences for habitat suitability. Bare ground is subject to high surface runoff and resultant soil erosion. Erosion adversely affects soil quality and productivity by reducing infiltration rates, water-holding capacity, nutrients, organic matter, soil biota, and soil depth (El-Swaify et al. 1985, Troeh et al. 1991). In the tropics, Lal (1976) reported that erosion may reduce infiltration by up to 93%. Low productivity because of low precipitation, high temperature, and high evaporation would lead to poor ground cover and soil degradation. In turn, soil degradation would lead to low productivity, hence low habitat suitability. It would appear then that such a vicious cycle is probable under climate change conditions. Magadza (1994) used a drought analogue scenario to question the continued capability of the savannahs, particularly those of east and southern Africa, to support huge populations of large mammals. This study concurs with this concern.

There was speedy regrowth as more woody plants were lightly browsed or untouched during both the late rains and early dry season. Vesey-FitzGerald (1973) indicated that a *b*1 plant is not greatly harmed and any damage is speedily replaced by growth. A *b*2 plant is also replaceable by growth, although the stature and shape of the plant may be reduced or modified by continued browsing. It was also indicated that *b*2 impact is the most important category to monitor in assessing the supply and use of browsable vegetation. The increase in the number of plants in the *b*2 category insinuates that the impact progressed from the late

Table 7. Number of species, plants sampled, and browse impact in vegetation communities, Lengwe National Park, 1992. Vegetation community codes: *A h* = *Albizia harveyi*, *A n*1 = *Acacia nigrescens* thicket clump savannah, *A n*2 = *Acacia nigrescens*/*Dalbergia melanoxylon* tree savannah, *A n*3 = *Acacia nigrescens*/*Ziziphus mucronata* tree savannah, *A n*4 = *Acacia nigrescens* tall tree savannah, *A n*5 = *Acacia nigrescens* savannah woodland, *D m* = *Dalbergia melanoxylon* tree savannah, *I b* = *Ischaemm brachyatherum* grassland dambo, *P l* = *Pterocarpus lucens*. *b*0–*b*3: levels of browse impact (see Section 2.5)

Season	Vegetation community	No. of plants *b*0	*b*1	*b*2	*b*3
Late rains	*A h*	17	7	40	0
	*A n*1	48	14	45	0
	*A n*2	44	5	36	0
	*A n*3	31	5	10	0
	*A n*4	7	2	6	0
	*A n*5	6	5	5	0
	D m	4	1	3	0
	I b	7	0	1	0
	P l	4	0	3	0
Total		**168**	**39**	**149**	**0**
Early dry	*A h*	31	39	25	0
	*A n*1	123	121	119	29
	*A n*2	60	38	59	10
	*A n*3	32	12	19	1
	*A n*4	29	21	14	0
	*A n*5	25	7	8	0
	D m	1	6	12	5
	I b	12	0	4	0
	P l	23	20	16	4
Total		**336**	**264**	**276**	**49**

rains to the early dry season. Most likely, it continued increasing in the late dry season.

Unlike in Drought 1 when nyala mortality occurred, there was no mortality during Drought 2. Since there is no significant difference in precipitation and temperature between Drought 1 and Drought 2, the absence of animal mortality during Drought 2 was due to the fact that the nyala population had been reduced through culling (Mkanda & Munthali 1991).

Variations in large mammal populations have occurred because of gradual aridification of the Chobe wetlands (Magadza 1994). During the Quaternary period, climate change resulted in geological redistribution of micro-mammalian fauna of southern Africa, as ecologically preferred zones for various assemblages changed their geographical ranges (Thackeray 1987). Franklin (1980) stated that a species that is vulnerable to capricious events is likely to be so because it has, in the past, adapted less well than its competitors to a changing environment. The nyala and other species in Lengwe have been subjected to harsh climate, hence they are likely to be adapted less well than those not subjected to similar conditions. Since drought episodes, as analogue climate scenarios, illustrate that vegetation productivity declines, the variations in large mammal populations and redistribution of micro-fauna observed elsewhere might act as a lesson specifically for Lengwe, but possibly in other wildlife conservation areas in Malawi as well.

5. CONCLUSIONS

Ambient temperature and precipitation in Lengwe National Park will probably increase under climate change. It appears that the conditions will be similar to those observed during the 1991/92 drought—namely, high temperature and evaporation rates. The consequences will be low vegetation productivity that would likely lead to habitat degradation. Consequently, the habitat would be unable to sustain a high population of large mammals.

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