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Full Length Research Paper

Grass Biomass and Hippopotamus Distribution: A Study of Population Density Along Zambia's Luangwa River

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Hippopotamus is a selective nocturnal grazer consuming 50 kg of grass. Due to its large body size, it requires large areas of grass often exceeding 5 hectares within 2 to 5 km of the water body to maintain good body condition. In this study, hippo population size and density, grass biomass and grazing capacity were assessed in March 2008 along a 165 km stretch of the Luangwa River. The study area was subdivided into study blocks, A, B, C, D, E and F. Methods used were: river bank total counts, quadrat sampling and identification of all grass species, clipping of grass in a quadrat, drying of clipped grass at constant temperature of 70°C and weighing to obtain dry weight. Grazing capacity of the hippo was estimated based on grass biomass values obtained during the study. Hippo population density was then matched with grass biomass distribution along the study blocks A-H. Total primary production was 62, 800 kg with mean biomass per study block of 7, 850 kg /ha^{-1} (in 2008). Grazing capacity was 1 hippo/6 ha^{-1}. Grass biomass varied significantly between river segments being higher in study blocks A, B and E and lower in study blocks C, D, F and G. Mean hippo density was 33 individuals/km stretch of the river. Hippo density was found to be above 33/km in study blocks A, B and E which had higher biomass and lower than 33/km in study blocks C, D, F and G. Hippo population density distribution was found to be influenced by grass species diversity and amount of biomass produced which also determined grazing capacity. In light of global climate change and changing rainfall patterns, more studies are required to determine the influence of rainfall on primary production and how this would affect the increase or decrease in hippo density and grazing capacity in the long-term.

Key words: Hippo, density, grazing capacity, grass biomass.

INTRODUCTION

Hippopotamus *(Hippopotamus amphibius)* is a selective nocturnal grazer consuming 50 kg of grass or about 2.5% body weight daily (Tembo, 1987; Stuart and Stuart, 2001). In dry years, it occasionally scavenges meat from dead animals found in their range (Kingdon, 2008). Types of grasses utilized depend on grass availability, though Scotcher et al. (1978) showed that in Ndumu Game Reserve, South Africa, *Panicum maximum, Urochloa mosambicensis, Cynodon dactylon, Hermathria altissima* and *Echinocloa pyramidalis* occurred predominantly in their diet. Around St Lucia, South Africa *Ischaemum arcuatum* was the most preferred species (Scotcher et al.,1978). Dorst and Dandelot (1970) recorded *Themeda*,

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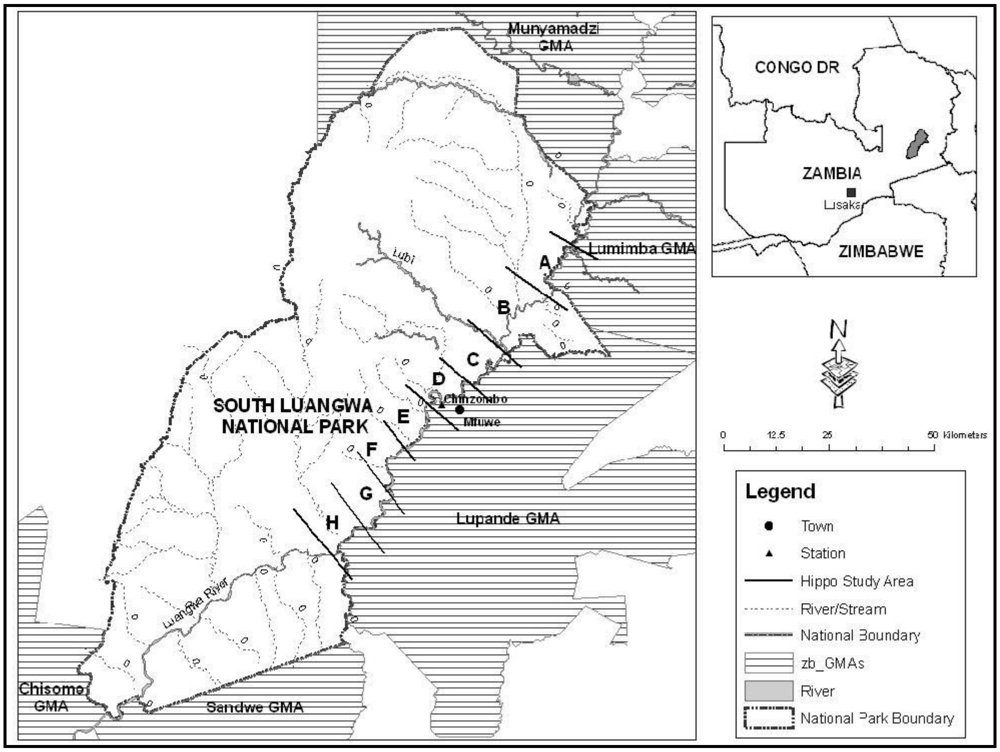

Figure 1. Location of the study area in Luangwa Valley, Zambia.

Panicum, Heteropogon, *Pistia stratiotes* and fruits of *Kigelia pinnata*. Hippos are very close croppers and will graze on stands of grass such as *C. dactylon* until they are of lawn-like appearance. This is accomplished with the horny edges of the lips where grass is plucked with an upward movement of the head. Grazing is usually confined to 2 to 5 km of the water body and grazing patches usually connected by pathways. Where populations are high such as in the Luangwa valley where density may exceed 42/km stretch of the river (Tembo, 1987), hippos would require large tracts of land to meet their daily food requirements (Owen-Smith, 2002). Grass biomass and grazing capacity are therefore, considered as one of the major environmental factors limiting hippo population size and density (Encyclopedia Britannica, 2010).

In the Luangwa Valley, no studies have been done to determine grass biomass production and grazing capa-city of the hippo, yet this area holds the largest global hippo population (Lewison, 2007). Absence of empirical evidence on grass biomass and grazing capacity and how this would relate to other large herbivores sharing the range with hippo has exacerbated range deterioration.

This study was aimed at estimating the amount of grass produced and grazing capacity of the hippo in the Luangwa Valley. Estimating grass biomass was found to be important in preventing over stocking of the range which would destroy it and cause loss of habitat for hippo and other large herbivores utilizing the same range. The main objectives of the research were to determine; hippo population size and density, grass biomass and grazing capacity and to establish the relationship between grass biomass produced and hippo density distribution.

MATERIALS AND METHODS

Study area location and description

The location of the study area was the Luangwa Valley in eastern Zambia (Figure 1) which has the largest global hippo population (Lewison, 2007). The study was conducted between March and October 2008 and covered a 165 km stretch of the Luangwa River and the associated riverine habitat within 2 km of the river banks from the Chibembe pontoon (12^o 48' S, 32^o 03'E) to the Lusangazi – Luangwa confluence (13^o 24' S, 31^o 33' E). Eight study blocks A-H were used.

Climate and drainage

The study area lies on the Central African plateau whose rainfall pattern is controlled by the movements of the Inter-Tropical Convergence Zone (ITCZ) and increases form south to north. Climate has three distinct seasons namely; hot rainy season from late November to April; a cool-dry season from mid May to August; and a hot dry season from September to early November. The Luangwa Valley generally experiences a hot climate with the mean daily maximum temperatures in the range of 32 to 36°C. The minimum and maximum temperatures are 15°C (June-July) and 36°C (October), respectively. The mean annual rainfall is in the range of 400-800 mm although records above 1,000 mm have been documented (Sichingabula, 2008).

Estimating grass biomass production

To ensure equitable sampling of all study blocks, line transects, 2 km long each were used as sample grasses and herbs in the study blocks A-H. A total of 100 transects were located in each study block A – H, in order to determine biomass and match it with hippo density distribution along the 165 km stretch (Table 1). The river bank was used as base line from which each line transects was randomly located. Transects were consistently placed in an east to west orientation and aligned perpendicular to the baseline. Adherence to the orientation of transects was determined using a Geographical Positioning System (GPS) by the pacer. This prevented transects from overlapping or crisscrossing. On each transect, 200 quadrats with dimensions of 1 m × 1 m were located at 10 m intervals. Dimension of quadrats were measured using a measuring tape and the four corners of the quadrat were marked with wooden pegs.

In each quadrat, grass species and herbs were identified using a field guide developed by Vernon (1983) and Van Oudtshoorn (2006) and plants' names were recorded on a data sheet. Uniden-tified species were collected and taken to Chinzombo Research Centre herbarium for identification. Plants were then clipped to ground level in each quadrat using a sharp pair of shears or sickle (Walker, 1976). Cut grass was weighed using a digital solar scale with readings calibrated to the nearest 0.5 of a gramme to obtain wet weight in kilogrammes. Clipped grass samples were taken to the Chinzombo Research Centre, where they were dried in an oven at a controlled temperature of 70°C for a minimum of two days. They were weighed again to obtain dry weight (Smit, 2005). Grass biomass obtained was allocated to respective study blocks A-H to show the amount of grass biomass produced in each study block.

Frequency of grass species encountered in the quadrats

Names of grass species and not numbers of individuals encoun-tered in each quadrat were recorded and used for calculating relative frequency (Walker, 1976). All grass and herb species with more that 5% relative frequency occurrence were recorded on the final data sheet. Photographs of areas heavily grazed by hippo were taken using a Digital Camera and down loaded in the data base for future monitoring of the same sites.

Grazing capacity estimation

Grazing capacity which is the number of hectares needed per hippo in each study block was determined as follows: (i) first by clipping and drying grass to obtain grass biomass; (ii) the grass biomass obtained was converted to primary production per hectare based on the formula developed by Smit (2005) as follows:

$$y = \frac{dr}{DM \times f}$$

Where;

y = grazing capacity (ha/GU); GU being the Grazer Unit which is the metabolic equivalent of an average weight of hippo; in this case 1,500 kg, the average weight of hippopotamus was obtained in the present study.

d = number of days in a year (365)

DM = total grass dry material production per hectare.

f = utilization factor, expressed as a decimal (not all produced material can be used by the animal, therefore, f = 0.3) which is the mean factor used where different grass species are pooled together, thus obtaining a mean between palatable species (0.4) and unpalatable (0.2).

r = daily grass DM needed/GU (2.5% body mass = 50 kg/day; (Skinner and Smithers, 1990).

Daily food consumption in kilogrammes per hippo was 50 kg (Skinner and Smithers, 1990; Tembo, 1987; Scotcher et al. 1978). Mean body weight for hippo obtained from weight measurements taken during the culled hippo specimens in 2008 was 1,500 kg. Consumption rate per year was then obtained by multiplying 2.5% body weight for each species by 365 days. The number of hectares required to support one hippo per year (grazing capacity) was calculated based on the daily food intake (2.5% body weight) and primary production per hectare.

Estimating population size and density of the hippo

A total river bank count method was used. It involved six members of the research team walking along the bank of the river. Of the six, two were recorders, one recording on data sheets and the other on the map. Two were observers using a pair of binoculars each and the other two carried firearms to protect the team from dangerous animals. Up to 30 min were spent observing a spotted hippo school, which provided sufficient time to count every individual in a school. Global Positioning Set (GPS) coordinates were taken for each hippo school in every study block A – H. Such GPS locations facilitated the plotting of density distribution in each study block.

Rainfall figures

Rainfall figures for a five year period 2003 – 2008 were collected from the weather station at Chinzombo Research Centre in Mfuwe. Collecting data on the amount of rainfall in the study area was found to be important as it was assumed that rainfall influenced primary production (Owen –Smith, 2002).

Data analysis

Population density

Population density was calculated based on the formula by Onyango and Plews, (2005) and Ramos-Onsis and Rozas (2002):

$$D = \frac{N}{L}$$

Where; *D* is density; *N* is the number of hippopotami and *L* is the river length.

Chi-square non parametric statistical test was applied to determine whether there was a significant difference in the amount of grass biomass produced per study block.

Relative frequency for each species of grass was determined by the formula provided by Shukla and Chandel (2008) and Kothari (2009), as follows:

$$\text{Frequency} = \frac{\text{Total number of quadrats in which the species occur}}{\text{Total number of quadrats sampled}} \times 100$$

Chi-square non parametric statistical test was used to test for any difference in the number of grass species per study block.

Table 1. Geographic coordinates of area sampled for grass biomass, Luangwa Valley, Zambia, 2008.

Block code name	Description	Distance (km^2)	Area sampled (ha)		Total	GPS Location of study block
			East bank	West bank		
A	Chibembe River side river Lodge to Tafika Safari camp	16.1	1	1	2	E 12°46' 42'' S 032°02' 55''
B	Tafika Safari camp to Tena Tena Safari camp	45.3	1	1	2	E 12°50' 48'' S 032°00' 09''
C	Tena Tena Safari camp to Kamana Mchenja Stream	14.2	1	1	2	E 12°59' 40'' S 031°54' 14''
D	Kamana Mchenja stream to Luangwa main Gate	15.6	1	1	2	E 13°03' 14'' S 031°52' 29''
E	Luangwa main gate to Nkwali Pontoon	20.2	1	1	2	E 13°05' 53'' S 031°47' 10''
F	Nkwali pontoon to Tundwe Safari camp	16.4	1	1	2	E 13°05' 45'' S 031°44' 09''
G	Tundwe Safari camp to Nyamaluma pontoon	24.6	1	1	2	E 13°14' 39'' S 031°38' 54''
H	Nyamaluma pontoon to Lusangazi Luangwa confluence	12.6	1	1	2	E 13°22' 35'' S 031°36' 41''
Total			8	8	16	

RESULTS

Grazing capacity

The total number of quadrats sampled was 1,600 or 16 hectares. The total area was 660 km^2 or 66,000 hectares in extent. The mean primary production (dry weight kg) for the study area was 7, 850 kg /ha^{-1} in 2008 and grazing capacity was 1 hippo/6 ha.

Influence of primary production on hippo density distribution

The hippo population size was 6, 318 individuals and mean density was 33/km of river bank. The amount of grass biomass per study block A – H along the 165 km river stretch varied significantly, being higher in study blocks, A, B and E and lower in C, D, F, G, and H ($P < 0.05$). Study blocks with grass biomass >7, 850 kg /ha^{-1} had higher hippo population density > 33/km and vice versa (Table 2). Hippo population density followed the pattern of amount of grass biomass produced per study block A-H (Figure 2).

The amount of rainfall received in 2008 was the highest in the previous five years (2003-2008). A total of 1,186 mm was recorded compared with 1,144 mm in 2007, 963 mm in 2006, 940 mm in 2005, 788 mm in 2004 and 827mm in 2003. This amount of rainfall was also higher than the areas' mean annual rainfall of 800 mm by 511 mm (Sichingabula, 2008).

Plant species diversity and hippopotamus density distribution

Twenty six species of grasses with more than 5% relative frequency were assessed for signs of grazing. Of the 26 species, 14 were in short grasslands out of which 12 (86%) were grazed. In tall grasslands, there were 12 species recorded and only 8% were grazed. The most grazed species in order of importance were: *Cynodon dactylon, Echinocloa pyramidalis, Cenchrus ciliaris and Chloris spp.* (Table 3).

Species diversity and frequency of palatable species (species recorded as grazed) varied significantly between study blocks ($P < 0.05$) being higher in study blocks A, B, E and H and lower in study blocks C, D, F and G (Figure 3). Study blocks with high primary production, high species diversity of palatable grasses had high hippo density (Table 4). A plot of hippopotamus density, total number of grass species and the frequency of palatable

Table 2. Comparison of hippopotamus population density and primary production (food) between study blocks A-H, Luangwa Valley, Zambia, 2008.

Study block	Hippopotamus population density/km	Primary production kg/ha^{-1}	Total relative percentage
A	53.8	12,744	21
B	54.04	16,336	25.0
C	22.46	5,392	8.59
D	11.92	2,864	4.56
E	38.42	7,976	12.70
F	29.27	6,408	10.20
G	19.92	4,784	7.62
H	31.43	6,296	10.03
Total		62,800	
Mean	33	7,850	99.7

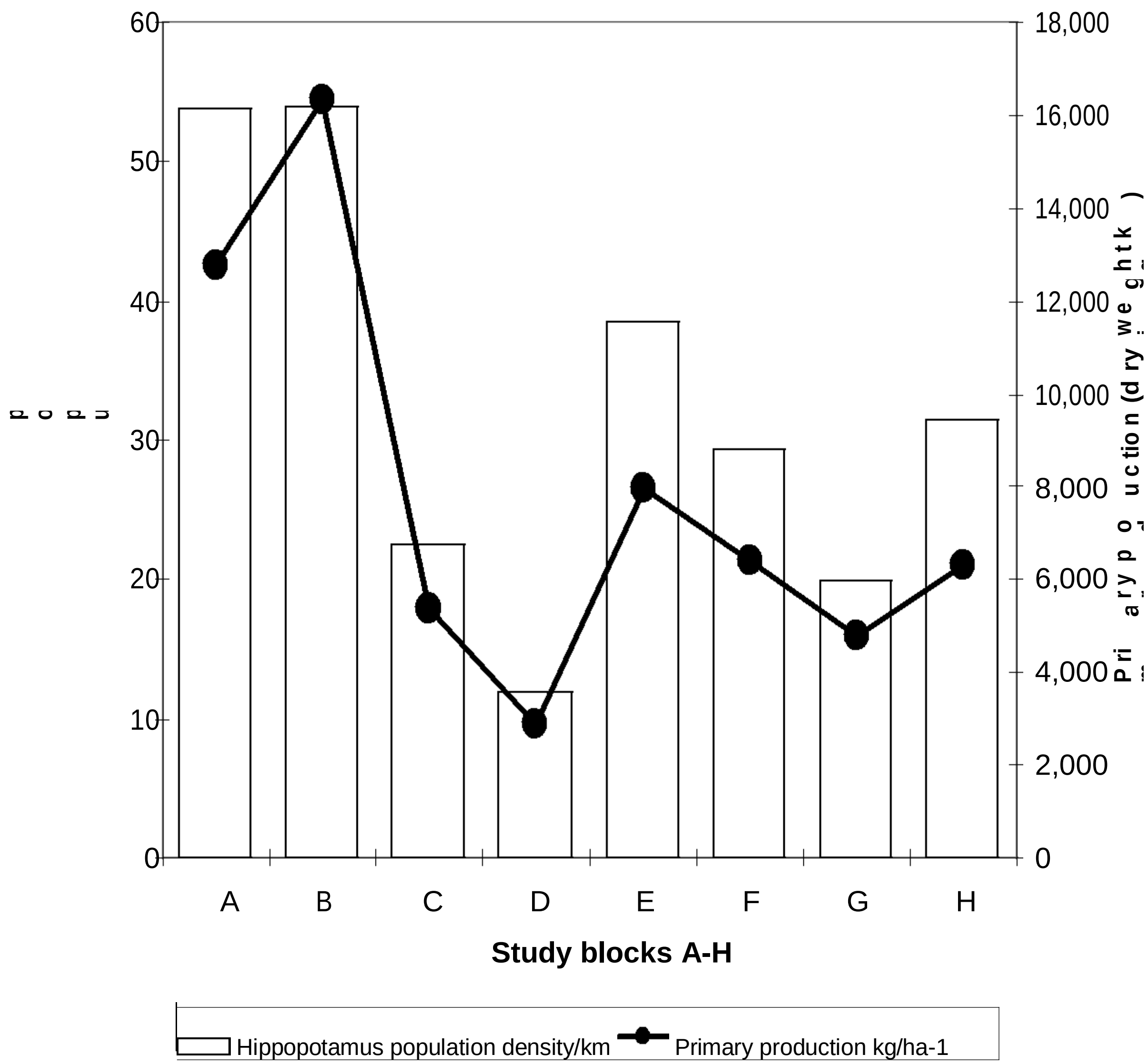

Figure 2. Hippopotamus population density /km between study blocks A-H based on amount of grass biomass, Luangwa Valley, Zambia, 2008.

Table 3. Grass species grazed by hippos in the study blocks A - H, Luangwa Valley**,** Zambia, 2008.

Species name	Species sighting frequency		Signs of grazing
	Short grassland	Tall grassland	
Andropogon spp		15	Not grazed
Aristida adscensionis	5	5	Not grazed
Brachiaria spp	5		Grazed
Chloris spp	10		Grazed
Cenchrus ciliaris	12	8	Grazed
Cynodon dactylon	25		Grazed
Cymbopogon spp		33	Not grazed
Cyperus rotundus	5		Grazed
Dactyloctenium spp	5		Grazed
Digitaria spp	8		Grazed
Echinocloa pyramidalis	20		Grazed
Diheteropogon spp		6	Not grazed
Commelina spp	6		Grazed
Eragrostis superba	5		Grazed
Heteropogon spp		10	Not grazed
Heteropogon contortus		10	Not grazed
Hyparrhenia spp		9	Not grazed
Hyperthelia spp		4	Not grazed
Panicum spp	8		Grazed
Phragmites australis		7	Not grazed
Setaria spp	5	7	Not grazed
Sporobolus spp	3		Grazed
Themeda triandra		9	Not grazed
Total number of species	14	12	
Number not grazed of total	2	11	
	(14 %)	(92 %)	

species showed that hippo density declined with decline in the number of palatable grass species (Figure 3).

DISCUSSION

The amount of grass biomass produced determined hippo density distribution along the 165 km stretch of the Luangwa River. Study blocks with high grass biomass had more food available to support high hippopotamus density. Food availability enabled hippo to obtain adequate daily food requirements which was converted into protein thus explaining why areas of high biomass such as study blocks A, B and E with biomass > 7,000 kg/ha, had hippopotamus density exceeding 35/km. Such study blocks provided enough food for each individual. Since each hippo is estimated to take 50 kg of grass per day, in areas or years of low primary production, hippo would require vast areas of land to obtain their daily food requirement. Scotcher et al. (1978) demonstrated that the maintenance of grazing lawns by hippo was a mode of grazing caused by the structure of broad mouth, which makes the hippopotamus ill adapted for selecting leafy material from a tuft of grass although it may select a leafy grass in preference to one with a high stem to leaf ratio (Boisserie, 2005). On that basis, it may also be assumed that the closely cropped grasses of the hippo lawns produce more leaves than adjacent lesser-used areas. In such areas, each hippo may require a smaller area such as in the Luangwa Valley to meet its daily food requirement. In areas where primary production is lower than 7, 850 kg/ha^{-1} hippos would require more than 6 hectares per individual.

Field (1970) concluded that selective digestion was probably most important in the hippo, which appears to have a digestive system that copes mainly with leaf blades and whose feaces contain a much higher proportion of culms than the ingested material. Presence of certain grass species which are of good quality would therefore, provide adequate nutrition and promote population growth and vice versa. Therefore, areas with high primary production and high frequency of palatable

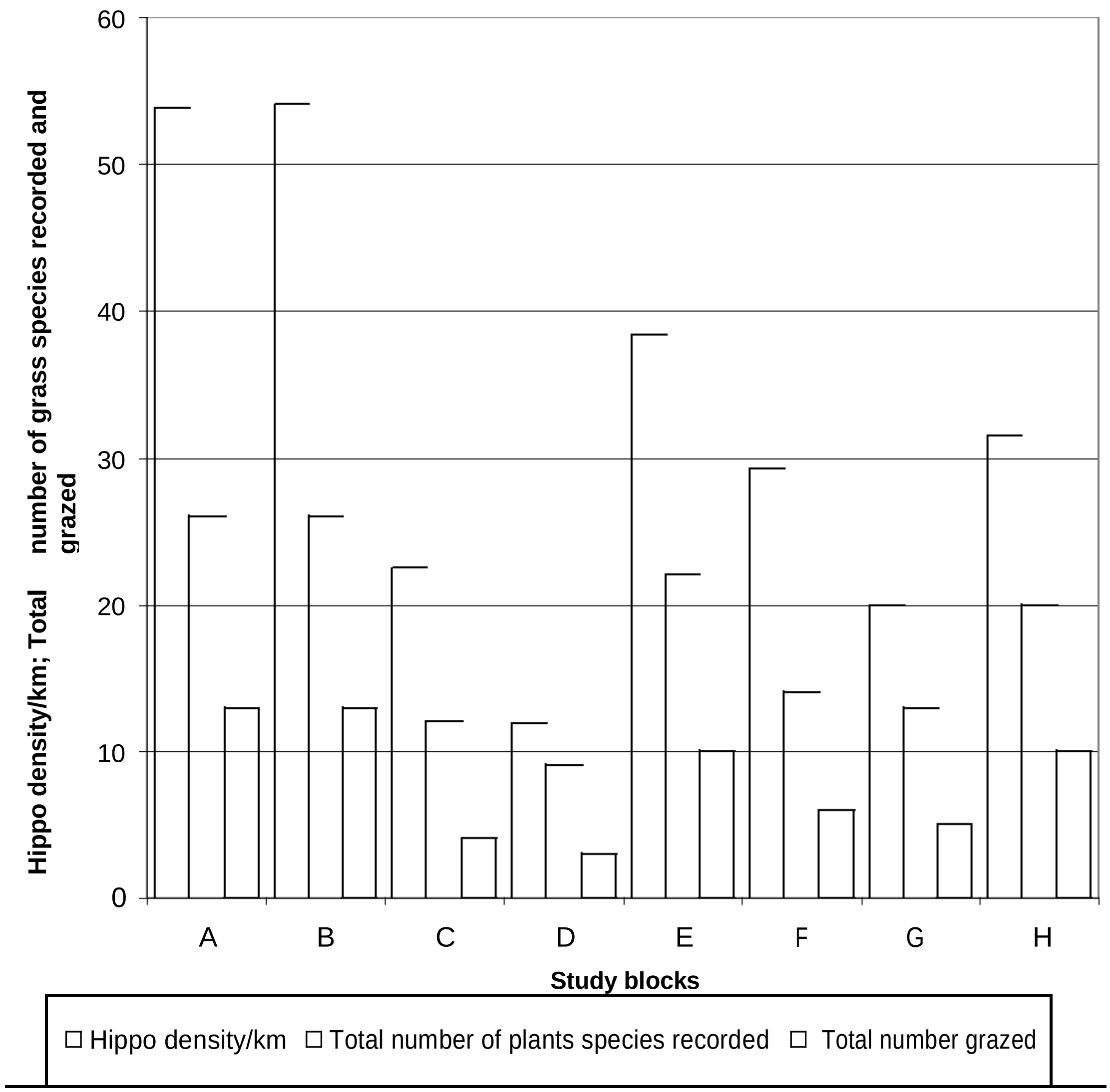

Figure 3. Hippopotamus density and number of grass species per study block, A-H. Luangwa Valley, Zambia 2008.

species of grass would have high hippo density. In this study *C. dactylon, E. pyramidalis, C. ciliaris and Chloris spp.* (Table 3) were the most preferred species and these are also among the species classified as palatable by Owen-Smith (2002).

Attwell (1963) also made a comparative analysis of grazing capacity between Uganda and Congo Democratic Republic (DRC) where there was higher primary production due to the bimodal rainfall regime and concluded that a conservative population estimate of 14,000 hippos utilized only 400 square miles of pasture. This indicated that the range was carrying one hippo per eighteen acres (7.28 hectares). Sinclair (1979) and Sinclair and Grimsdell (1982) also noted that in the Serengeti ecosystem, it appeared that dry season rainfall was particularly important in explaining the increase in herbivore carrying capacity. He concluded that the increasing dry season rainfall over the years in the Serengeti was an important factor in increasing the carrying capacity. By contrast, and based on Chapman and Reiss (2000) interpretation of the role of food in reproduction, absence of rainfall in some months of the year in the Luangwa Valley, reduces quality food available to hippos and was assumed to be the main cause of reduced birth rates and population decline of the Luangwa hippo reported by Sayer and Rhaka (1974).

In the present study, no direct influence of rainfall on primary production was established. However, it was assumed that influence of rainfall on hippopotamus population size and density was indirect through promotion of plant growth. It was assumed that higher rainfall would imply higher primary production and a higher hippo density.

It was assumed that, the high grazing capacity of 1 hippo/6 ha obtained during this study, could be attributed to the above mean rainfall experienced during the 2008

Table 4. Hippopotamus density/km and diversity of palatable species of grass, Luangwa Valley, Zambia 2008.

Study block	Total number of grass species recorded	Number of grass species grazed	Hippopotamus density/km
A	26	13	53.80
B	26	13	54.04
C	12	4	22.46
D	9	3	11.92
E	22	10	38.42
F	14	6	29.27
G	13	5	19.92
H	20	10	31.43

which was 71% higher than the areas' mean annual rainfall. Thus it is suggested that during years of normal rainfall, a grazing capacity >1 hippo/6 ha would be required.

In years of drought, primary production would decline due to inadequate moisture to support plant growth. Deficiency of water in the soil would affect the transportation of nutrients from the soil to plant roots. Plants in turn, absorb water from the soil through their roots which is used in metabolic processes, mainly photosynthesis, maintaining cell turgidity and regulating plant tempera-ture. Limited water in the soil therefore, would limit plant growth and hence less grass biomass for hippo and other herbivores. Availability of water in the soil would also influence activities of soil organisms which are involved in organic matter decomposition and the transformation of nutrients from unavailable to available forms, hence supporting plant growth. In years of drought when soil moisture is deficient, plant growth would be negatively affected and the amount of food available to hippo would be reduced. Low rainfall or during the dry season, water flow would be reduced and many pools and lagoons would dry up. Reduced number of pools would increase school size as individuals compete for limited space which often leads to crowding, aggressive behaviour and increased stress. Coupled with reduced food base in dry years or dry season, animals would lose body condition since there would be no excess food to convert to fat deposits and subsequently animals lose physiologic condition and are unable to breed and give birth. This subsequently leads to population decline which reduces density. The amount of grass biomass therefore, was the main factor responsible for hippopotamus population density distribution along the 165 km stretch of the Luangwa River.

Conclusion

The results obtained during the present study suggest that the amount of food produced was the main factor responsible for hippopotamus population density distribution between study blocks A-H, while rainfall was assumed to have an influence on the amount of grass biomass produced.

In assessing the influence of the amount of grass biomass on hippopotamus population size in future, it is suggested that consideration should be given to the population size and density of other grazing herbivores particularly those of ≥100 kg body weight and how biomass would be distributed between hippo and other herbivores. Therefore, in estimating carrying capacity for the hippo, it would be advisable to consider population size of other herbivores.

Considering that the amount of food produced may vary from year to year based on the amount of rainfall received, competition with other bulk grazers such as buffalo, coupled with the unimodal rainfall regime in the Luangwa Valley, grazing capacity ≥ 1 hippo /6ha would be the most appropriate for the Luangwa Valley.

In light of the global climate change and expected changing rainfall patterns (Holmgren et al., 2003; Gassey, 2000), it would also be important to collect rainfall data annually and to estimate primary production as these are likely to impact on the hippo population density. Such data would enable the Zambia Wildlife Authority to manage the Luangwa hippo population within the food available and in a manner that would maintain a balance between the hippo population, other large herbivores and the range.

It is also important for Zambia Wildlife Authority management to consider conducting further research on the status and distribution of *C. dactylon, E. pyramidalis, C. ciliaris and Chloris spp.,* as these were found to be most preferred species by hippo.

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