Herbage Yield and Grazing Capacity Estimation in a Tropical Coastal Savanna Rangeland Using Spatial Statistics

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Abstract

Herbage production is known to vary spatially. However, herbage yield (dry matter basis) in the savanna rangelands of Ghana is always generalized leading to inappropriate interventions for herbage improvement. The study sought to employ field survey and geostatistics to determine the spatial variability in herbage yield and grazing capacity in the south-eastern part of the coastal savanna rangelands of Ghana. It was hypothesized that there is spatial heterogeneity in herbage yield and grazing capacity in the coastal savanna rangelands of Ghana. This study employed field survey to estimate point herbage yield and grazing capacity at 109 randomly selected sites. The herbage yield and grazing capacity point estimates were integrated into geostatistics. Estimates of herbage yield and grazing capacity were made for the entire area using ordinary kriging interpolation. The heterogeneity in herbage yield and grazing capacity were evident from the results with herbage yield ranging between 0.58 and 7.21 tha^{-1} and grazing capacity between 0.4 and 4.94 tropical livestock unit (TLU) ha^{-1}. The root mean square errors (RMSE) of prediction were close to the average standard errors (0.98 and 1.06 for herbage yield; 0.79 and 0.71 for grazing capacity) indicating a high precision in prediction. Herbage yield and grazing capacity declined from the western to the eastern parts indicating the need for more functional intervention toward the eastern parts of the study area. Results of the study could be used to facilitate site-specific range management decisions to improve livestock production.

Introduction

Regular monitoring and evaluation of range resources is very essential for planning their sustainable use (Timpong-Jones, 2010). Conventionally, evaluation methods rely greatly on field sampling, which has been found to be laborious and expensive (Flynn, 2006). By using traditional, field-based sampling methods, herbage production in the coastal savanna rangelands of Ghana has been determined at various locations, and generalized for the entire coastal savanna region. However, herbage yield is known to have spatial variability. Although mean biomass yield value in a given rangeland is useful in describing the general productivity

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of the ecosystem, information about the spatial distribution of biomass is more important (Correll *et al*., 2003). This helps to identify chronically poor areas of herbage growth and leads the way for the introduction of more functional site-specific grazing management decisions (Hill *et al*., 1999). There is the need for an improved approach in monitoring and evaluating rangeland resources to complement the field sampling methods. Geomatics – the science and technology of gathering, analysing, interpreting, distributing and use of geographical information (Duncan, 2004) has, in recent times, been employed by researchers and range managers in range monitoring and evaluation. This modern approach to range research complements field-based data with spatial information.

In spatial variability studies, one vital aspect is to move from point observations towards making decisions involving larger spatial areas. Geostatistics, which is based on the theory of regionalized variables, is capable of using spatial correlation between neighbouring observations to predict attribute variables at unvisited locations (Phillips *et al*., 1992). The study sought to employ field survey complemented with Geostatistics to estimate herbage yield (dry matter basis) and grazing capacity, highlighting their spatial variability in the south-eastern part of the coastal savanna rangeland of Ghana. This was to enhance the imposition of area specific interventions in rangeland improvement in the area. It was hypothesized that there is spatial heterogeneity in herbage yield and grazing capacity in the coastal savanna rangeland of Ghana.

Materials and methods

Study area

The study was carried out in the coastal savanna zone of Ghana, West Africa. The coastal savanna lies between latitude 4^0 55' N and 6^0 05' N, and longitude 1^0 45' W and 0^0 30' E of the meridian. It covers an area of 456,901 ha and divided into two broad sections; the south-eastern plains, east of the capital Accra, and the south-western plains, west of Accra (Alhassan *et al*., 1999). The rainfall regime of this area is the dry equatorial type with the mean annual rainfall ranging between 600 and 1000 mm (Alhassan *et al*., 1999).

Preparation for field work and data collection

Analogue vegetation and district maps of the study area were digitized. Using the study area vegetation map as a reference layer, 109 sample points were generated randomly using the Hawth's Analysis extension tool for ArcGIS, version 3.27. The coordinates of the randomly selected sample points were then extracted from the point map. The point map was overlaid on the district map and a hard copy produced for field work. Relevee sheets were prepared to record field data. Using a Garmin handheld Global Positioning System (GPS) and the district map with sample points, the 109 sample points were located in the field. At each sample point, a sampling site measuring 30 m × 30 m was demarcated. Within each site, the Ranked Set Sampling method (RSS) was used to randomly select three plots, each measuring 3 m × 1 m (McIntyre, 1987).

The RSS was used because it is very efficient in forage yield estimations (Hall & Dell, 1966) and very efficient in obtaining a very representative plot for sampling (McIntyre, 1987). Each of the three plots was sub-divided into three sub-plots measuring 1 m × 1 m. Sub-plots within each plot were ranked in order of magnitude with respect to the percentage basal herbaceous cover into low, medium and high. This was followed by a second phase observation where the above-ground herbaceous biomass measurements were taken by clipping herbage at 1–2 cm from the ground from the high, medium and low ranked sub-plots from the first, second and third plots, respectively. There were 327 biomass samples since sampling per plot was done in triplicate.

Herbage yield and grazing capacity estimations

Fresh herbage samples, weighing between 250–500 g, were dried in a forced draught oven at 65 ^{0}C for 48 h (Tarawali *et al.*, 1995). The dried samples were then weighed at room temperature and expressed as herbage yield in tha^{-1} for the 109 sample sites. These herbage yield values were added to the attributes table of the study area map in ArcGIS.

Grazing capacity, which is defined as the maximum possible stocking of herbivore that a rangeland can support sustainably (FAO, 1988), was calculated using the formula of Thalen (1979) as follows:

$$G = (F/_R) \times g$$

where G is the grazing capacity in Tropical livestock units (TLU) per unit area for a specified grazing season in TLU ha^{-1}. This was estimated for the critical months in the dry season when forage was scarce. The length of the dry season was taken to be 105 days (from mid-November to end of February) (MSD, 2010) and one Tropical livestock unit was taken to be 250 kg (FAO, 1988; LEAD, 2010).

F is the weight of herbage production per unit area during the grazing season in kg ha^{-1}. R is the herbage dry matter requirement per TLU in the dry season in kg TLU^{-1}. A daily herbage dry matter intake of 2.5% of live weight was used in line with the findings of de Leeuw & Tothill (1990). g is the grazing efficiency, which is the proportion of forage material that is ingested by the grazing animal. A grazing efficiency of 45% was used as suggested by Wijngaarden (1985). It was proposed that 45% of total dry matter be used for the dry season because a higher percentage would cause a decline in perennial grass cover in the subsequent growing season. The grazing capacity values for the 109 sample sites were added to the attributes table of the study area map in ArcGIS.

Test for data normality

The Shapiro-Wilk numerical test for data normality was used. This is the ratio of the best estimator of the variance to the usual corrected sum of squares estimator of the variance (Shapiro & Wilk, 1965). In most cases, the interpolation methods used to generate surfaces gave best results when data were normally distributed (ESRI, 2001).

Geostatistics

Kriging interpolator was used in this study because it is a very flexible and moderately quick interpolator that allows one to investigate graphs of spatial autocorrelation (ESRI, 2001). The specific kriging interpolator used was the ordinary kriging interpolation technique (Table 2). In using ordinary kriging, variograms (function of a separation vector that includes distance and direction) were used to quantify autocorrelation and to plot semivariance (γ)

as a function of the distance between samples, known as lag distance *h*. The semivariogram calculated *n* pairs of data locations with the algorithm below:

$$\gamma(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} \{ z(x_i) - z(x_i + h) \}^2$$

where $\gamma(h)$ is the estimated or experimental semivariance value for all pairs at lag distance; *n* is the number of pairs of observations separated by *h*; $z(x_i)$ is the value at location x_i; $z(x_i+h)$ is the value of other points separated from x_i by a discrete lag h (Hudak *et al*., 2002). The semivariogram calculated was half the variance of the increment in the random function.

Attribute values at unsampled locations were estimated using ordinary kriging algorithm with the equation:

$$U^*(x) = \sum_{\alpha=1}^{n} \lambda_\alpha(x) U(x_\alpha)$$

where U(*x*) is the optimal unbiased estimated value at location x; $U(x_a)$ is the sampled value at location $x_{a,}$ and λ_a is the optimal weight selected to minimize the estimation variance (Isaaks & Srivastava, 1989). Variograms for this analysis were simulated by spherical models following evaluations of the goodness of fit. A nugget component was fitted to the variograms. The modelled variogram was then used to map herbage yie
ld using ordinary kriging interpolator. The standard searching neighbourhood function was used with a maximum of five (5) and a minimum of four neighbours (Table 2). The one sector neighbourhood search was used. This was to limit the measured points to be used in order for the predictions to be accurate. Points too far away may be in areas much different from the prediction location and, thus, contribute very little to the measured point (ESRI, 2001).

Accuracy test

The calculated herbage yield and grazing capacity point maps were used as input layers and randomly divided into training and test datasets using the ¾ training and ¼ test sample criterion, respectively. This made the training samples 81 and the test samples 28. This proportion is recommended since it gives more weight to data for model building (McGarigal *et al*., 2000). The training and test datasets were then added to the "table of contents" in ArcGIS. Using the training dataset, a model was created using the ordinary kriging interpolation technique. The validation tool was then activated and the test dataset was used to evaluate how good the predictions are relative to the known values in the test dataset. The split sample validation criterion was used since the sample size was large enough to compute variograms and also because this technique is very much used in the study of vegetation cover (Schmidt & Skidmore, 2003; Mutanga & Rugege, 2006).

The predictive capability of this method was assessed using the root mean square error (RMSE) value between the predicted and the measured test data as follows:

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} \varepsilon_i^2}$$

where ε_i is the prediction standard error for location 'i' and n is the number of observations. With this method of validation, when the RMSE and average standard error values are close and when the root mean squared standardized error value is close to 1, predicted surface is said to be accurately predicted (ESRI, 2001).

Results

The Shapiro Wilk's test for normal data indicated that both datasets were normally distributed as their p-values were less than the W-statistics (Table 1). The standard deviation, Kurtosis and Skewness for the herbage yield dataset were 1.48 tha^{-1}, 3.06 and 0.79, respectively, while that of the grazing capacity dataset were 1.01, 3.06 and 0.78 TLU ha^{-1}, respectively.

TABLE 1

Shapiro-Wilk's test for normality for herbage yield and grazing capacity datasets

Variable	*W*	*p-value*
Herbage yield (tha^{-1})	0.94	1.6×10^{-4}
Grazing capacity (TLU ha^{-1})	0.94	1.8×10^{-4}

Herbage yield and grazing capacity estimations

The herbage yield in the south-eastern coastal savanna rangeland of Ghana ranged from 0.58 to 7.21 tha^{-1} (Fig. 1), with a mean herbage yield of 3.15 tha^{-1} during peak vegetation cover. The grazing capacity ranged from 0.4 to 4.94 TLU ha^{-1} (Fig. 2), with a mean value of 2.16 TLU ha^{-1}. It was assumed that herbage yield at peak vegetation cover is what is made available to livestock in the dry season.

Discussion

The result of the study indicated that the herbage yield of the south-eastern coastal savanna rangeland of Ghana ranges between 0.58 and 7.21 tha^{-1}, with a mean value of 3.15 tha^{-1}. This is a clear indication of spatial variability in herbage yield in the region with higher values in the south-western parts and lower values in the south-eastern parts. Fleischer *et al*. (1996) reported that herbage yield on the clayey and sandy soils of the coastal plains were 4.67 and 5.03 tha^{-1}, respectively. Alhassan *et al*. (1999) reported a total annual herbage yield of 1.97 tha^{-1} in the coastal savanna rangeland of Ghana.

Table 2

Parameters used for predicting dry matter yield and grazing capacity

Decision	*Dry matter yield*	*Grazing capacity*
Method	Kriging	Kriging
Type	Ordinary	Ordinary
Searching neighbourhood	Standard	Standard
Neighbours to include	5	5
Include at least	4	4
Sector type	Full	Full
Variogram	Semivariogram	Semivariogram
Number of lags	12	12
Lag size	8077.4	8077.4
Nugget	0.7499	0.3519
Model type	Spherical	Spherical
Range	95743.8 m	95743.8 m
Anisotropy	No	No
Partial sill	3.06	1.44

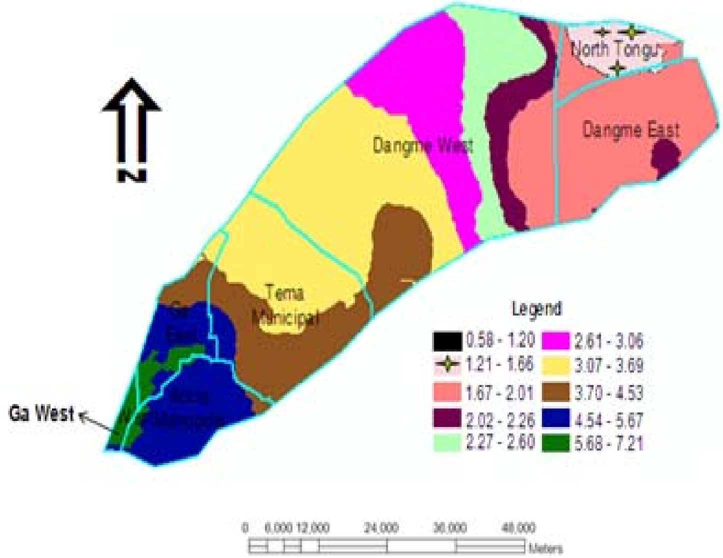

Fig. 1. Herbage yield map of the coastal savanna of Ghana (tha[-1])

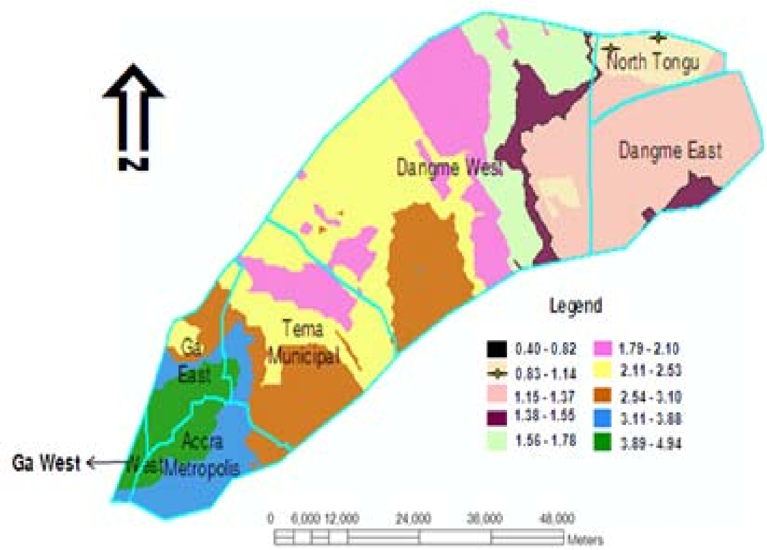

Fig. 2. Grazing capacity map of the coastal savanna of Ghana (TLU ha[-1])

Oppong-Anane (2001) also estimated the herbage yield in the coastal savanna to be about 2.0 tha^{-1}.

The different herbage yield values reported by these researchers fell within the 0.58 – 7.21 tha^{-1} range obtained in this study. These researchers might have conducted their studies at different locations within the coastal savanna region and also at different times. This highlights the spatial heterogeneity of herbage yield in the region and confirms the importance of this research that has inherently catered for these differences by providing herbage yield values that are area specific. Scoones (1999) reported that the heterogeneity of rangelands is often forgotten with simplistic categorizations made to describe situations over wide areas.

Furthermore, the study has also shown that the grazing capacity of the coastal savanna rangeland ranges between 0.4 and 4.94 TLU ha^{-1}, with a mean value of 2.16 TLU ha^{-1}. Rose Innes (1977) reported a grazing capacity of unfertilized *Vetiveria* grassland on the black clays of the south-western coastal savanna to be 2.5 ha per beast of 300 kg live weight. This is equivalent to a grazing capacity of 0.48 TLU ha^{-1}. While some work has been done in herbage yield estimations in coastal savanna of Ghana (Fianu *et al.*, 1972; Rose- Innes, 1977; Fleischer *et al.*, 1996), it is evident that much work has not been done in the estimation of grazing capacity. The results of this study, therefore, will be useful to researchers and policy makers in taking appropriate interventions to improve livestock production in the coastal savanna rangeland of Ghana.

The observed trend of a reduction in herbage yield and grazing capacity from the south-western part to the south-eastern end of the study area is attributable mainly to the reduction in rainfall in the same pattern (Dickson & Benneh, 1988; Alhassan *et al.*, 1999) making the south-eastern parts drier, thus, leading to low vegetation growth and a reduction in herbage yield (Rose Innes, 1977) and grazing capacity.

Conclusion

The study has shown that the use of Geostatistics to complement field data is a dependable approach to estimating herbage yield and grazing capacity of rangelands. The study has also highlighted the spatial variability of herbage yield and grazing capacity in the coastal savanna rangeland of Ghana, with higher values in the south-western parts and lower values in the south-eastern parts. The decline in herbage yield and grazing capacity from the south-western parts to the south-eastern parts indicates the need for more functional intervention toward the eastern parts of the study area.

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