INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 18, No. 4, p. 82-92, 2021
http://www.innspub.net

RESEARCH PAPER OPEN ACCESS

Spatial-temporal variation of biomass production by shrubs in the succulent karoo, South Africa

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Article published on April 30, 2021

Key words: Forage, Landscape heterogeneity, Rangeland, Richtersveld

Abstract

Forage production in arid and semi-arid rangelands is not uniform but varies with seasons and in various landscapes. The aim of this study was to investigate the spatial and temporal variation in forage production in RNP. Plants sampling was carried out in 225 plots distributed in each of the five vegetation types. In each vegetation strata, sampling points was based on proximity to an occupied stock post, a rain gauge, a foothill and flat plains. A total of were measured in the 5 study sites. Line Intercept Method in combination with harvest method were used in ground measurement of biomass production. To assess biomass production using remote sensing technique, par values were obtained from Moderate Resolution Imaging Spectroradiometer (MODIS) imageries which consisted of 8 days composite images at spatial resolution of 1km² pixel size. There was positive correlation between line intercepts and biomass production Biomass production was higher in succulent Karoo biome than in desert biome. There was a strong relationship between biomass production with rainfall and with fpar values. Since leaf and stem succulents' plants were found to contribute the highest amount of forage production in RNP, they should be given conservation priority.

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Introduction

Forage production and distribution in arid and semi-arid rangelands is not uniform but varies with seasons and in various landscapes (Easdale and Aguiar, 2012). In arid ecosystems, precipitation influences forage production and availability to a large extent and tends to be highly variable inter and intra-annually. Not only are rangelands highly variable in their provision of fodder for livestock production, they are also extremely unpredictable systems (Jakoby *et al.,* 2014). Therefore, for effective utilization of forage in these ecosystems by herbivores as well as development of proper management policies there is need to understand spatial and temporal forage production and factors that influence forage productivity in arid and semi-arid rangelands. Information on spatial and temporal forage production and variability is crucial to farmers, rangeland managers and policy makers in making decisions on issues related to conservation and management of arid and semi-arid rangeland ecosystems (Jakoby *et al.,* 2015). The forage production capacity of any rangeland is the principal variable that limits stocking rates while range conditions are determined by their forage production capacities (Fynn, 2012). Risks associated with over-grazing have been associated with lack of detailed information on temporal and spatial variation in primary productivity in arid rangelands (Rasch *et al.,* 2016).

Primary productivity in rangelands can be estimated by the use of remote sensing techniques, whereby primary production is determined by the amount of photosynthetically active radiation (PAR) absorbed by the plant canopy (Palmer and Yunusa, 2011). The advantage of using satellite remote sensing to estimate Net Primary Productivity (NPP) is that a large area can be measured directly. According to Diouf and Lambin (2001), harvest method has been widely used in the past but was found to be laborious, expensive and destructive, and cannot be repeated over time in exactly the same location. The alternative, less intensive methods that have been widely used include remote sensing data and allometric relationships between readily obtained plants measured parameters with biomass (Anderson *et al.,* 2010). Due to variability in forage production in arid and semi-arid rangelands, the challenge has been standardization of variations in primary productivity at a smaller (landscape) scale. Therefore, use of Spatial Resolution Satellite Data which can be collected at high frequency, make it possible to track productivity changes and habitat quality at a smaller scale with possibilities of going back in time and covering a large area within a short period of time (Tsalyuk *et al.,* 2015). Use of line-intercept method in estimating above-ground biomass production has also been found used and found to be non-destructive, less labour intensive and allows continuous re-sampling of the same area subsequently (Flombaun and Sala, 2007).

Arid and semi-arid environments are characterised by high climatic variability and large fluctuations in forage production (Easdale and Aguiar, 2012). Rainfall variability between years cause high levels of variability in forage availability to the herbivores and the result is a temporally uncertain and spatial heterogeneous fodder resource. Flexible and opportunistic strategies such as migratory movement are a response of both wild and domestic animal populations to spatial and temporal variability in fodder availability (Rasch *et al.,* 2016). To cope with fluctuations in forage yields caused by climatic variability, pastoralists adopt survival strategies. They may opt for opportunistic movement of herds to track resources in areas that receive sporadic rainfall such as movements between different landscapes (Samuels *et al.,* 2007). Forage yield in arid and semi-arid rangelands are highly influenced by climatic variability from year to year; for example annuals respond very quickly to water availability and disappear faster in the dry season leading to fluctuations in forage availability (Easdale and Aguiar 2012). Therefore, understanding the spatial and temporal heterogeneity of forage production in various landscapes in arid and semi-arid ecosystems is critical in the design of rangeland utilization and conservation management plans (Rasch *et al.,* 2016). In RNP there are distinct wet season resources (plains and mountains) and dry season resources (Orange

River riparian zone) that animals utilize at different seasons. The understanding and utilization of spatial variability in forage production has helped the farmers in RNP to manage their livelihood in a better way than the surrounding farmers in the wide Richtersveld area (Hendricks *et al.,* 2004) who do not have access to a large key resource area such as Orange River Riparian zone.

Considering the landscape heterogeneity and climatic variability that characterise arid and semi-arid ecosystems, the ecological study of spatial and temporal forage production in Richtersveld National Park is crucial in the formulation of management plans, conservation priorities and land use practices that are suitable for the arid and semi-arid rangelands in South Africa. This study will investigate the effects of land use practices and rainfall patterns on forage production and distribution in RNP. Studies on spatial and temporal variation in forage production as well as the effects of land use practices on forage availability in RNP are appropriate for testing effects of current and future climate change scenarios in the Succulent Karoo Biome. The aim of this study was to estimate spatial and temporal variation in biomass production by shrubs in RNP; specifically to, determine variation in production of biomass by shrubs in various vegetation types and to assess the effect of rainfall on perennials biomass production in RNP. Studies on spatial and temporal variation in forage production as well as the effects of land use practices on forage availability in RNP are appropriate for testing effects of current and future climate change scenarios in the Succulent Karoo Biome.

Materials and methods

Study area

Richtersveld National Park (RNP) is located in the semi-arid region of the Namaqualand magisterial district (28º 15'S, 17°10'E) in the north-western part of South Africa (Fig. 1). The park is located immediately south of the Orange River which marks the international border with Namibia. Topographically, RNP is regarded as a remote, inhospitable and the only true mountain desert in South Africa (Cowling *et al.,* 1999). The study area consist mainly of extremely mountainous terrain with large altitudinal changes over very short distance (Mucina *et al.,* 2006). The geology of the park and immediate surroundings is underlain by rocks belonging to formations that vary in age from some of the oldest known to the youngest in South Africa (Cowling *et al.,* 1999). Soils in Richtersveld are shallow due to presence of hardpans at superficial depths in the valley (Mucina and Rutherfold, 2006).

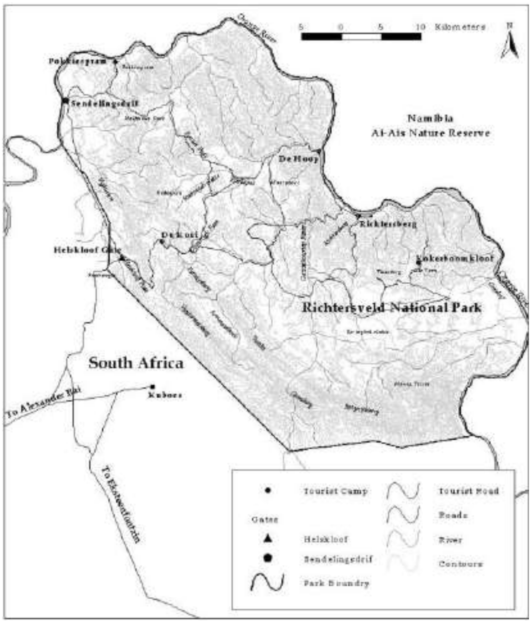


Fig. 1. Map of the study area (Source Hendricks *et al.*, 2005).

RNP is a contractual park that is managed jointly by South African National Parks (SANP) and the Richtersveld pastoralists' community. Semi-nomadic pastoralism has been practised in the Richtersveld for about 2000 years (Mucina and Rutherfold, 2006). There is resource use partitioning in the RNP with different landforms being utilized at different times of the year. During the wet seasons (May-August) animals utilize forage in the mountains and plains while in the dry summer period (September - April) they move to the riparian zone of the Orange River due to availability of browse forage and water (Hendricks *et al.,* 2004). The flocks of livestock consist primarily of Boer-goats and some sheep that graze in RNP. Pastoralists graze their animals (goats and sheep) in the park, and they move between stock posts at varying intervals in response to availability of forage and water. The pastoralists within RNP have entered into an agreement with park managers (South Africa National Parks) to limit the total number of livestock grazing within the confines of the park with an aim to conserve the biotic diversity and for proper management of the grazing resources (Hendricks *et al.,* 2004).

RNP is a winter rainfall area, with high inter-annual rainfall variability. The area has a mean annual rainfall of 72mm (Mucina and Rutherfold, 2006). The climate of RNP is arid. The average temperatures varies between 25°C in January and 14°C in June. Temperatures can rise above 50°C in the summer and plunge to freezing point on winter nights. There are five rain gauges in the park, distributed in each vegetation types. Rainfall data is usually recorded daily during the rainy seasons and forwarded to South Africa Weather Service offices located in Pretoria. Availability of water in soil is the major driving force in plant growth and development in this area with extreme climatic variation. In addition, Succulent Karoo soils are well suited to favour diverse plant species due to nutrients supply from the continuous weathering and mineralization process (Mucina and Rutherfold, 2006). The vegetation of the RNP is characterised by a variety of succulents, woody shrubs, diverse annuals and geophytes, with dwarf succulent shrubs of the family Aizoaceae being the most distinctive family in the Succulent Karoo.

Trees occur mainly along the Orange River riparian zone. Five vegetation types occur in the RNP. These are Central Richtersveld Mountain and Northern Richtersveld Scorpionstailveld in the Succulent Karoo biome and Noms Mountain Desert, Richtersberg Mountain Desert and Richtersveld Sheet Wash Desert found in the desert biome (Mucina and Rutherfold, 2006). Vegetation types in Succulent karoo biome experience winter-rainfall climate. Monthly Annual Precipitation in the Succulent karoo varies from 60–200mm, but most of the area record less than 90mm per annum. At higher altitudes, especially on south-western slopes, there is frequent occurrence of fog or cloud resulting into a significant improvement in water supply for plants. On the other hand, vegetation types found in the Desert biome experience high aridity and relatively higher temperatures compared to the western mountains of Succulent Karoo which are more often exposed to cooling air from the Atlantic Ocean. Desert biome on the eastern part of the park receive less winter rainfall compared to the Succulent karoo. Sometimes erratic summer rainfall also occurs in the Desert biome. The rockiness and very harsh spectrum of habitat conditions limits plant growth in most parts. Sparse dwarf shrubs are common in the vegetation types found in the Desert Biome.

Vegetation Sampling

Vegetation sampling was done in five vegetation types found in NRP namely Central Richtersveld Mountain and Northern Richtersveld Scorpionstailveld in the Succulent Karoo biome and Noms Mountain Desert, Richtersberg Mountain Desert and Richtersveld Sheet Wash Desert found in the desert biome. Forty five transects of 1 km in length were laid in each of the 5 vegetation types in each of the 3 landscapes (on the plain, foothills and on the mountains). In total of 225 plots were therefore measured in the 5 study sites. In each of the 1km² plots, twenty lines (20m long) were laid at a distance of 10m apart parallel to each other. The Line Intercept Method was used to measure the canopy cover of the shrubs. This was done by recording the horizontal distances covered by live crown along the 20m line as described by Flombaun and Sala (2007). The length of the line intercept of plant species along the 20m lines were recorded and the intercepted plants harvested, separated and packed on basis of their growth forms (grass, stem succulent, leaf succulents, and non-succulents).

In addition 20m lines in each 1 km² plots, ten 20m² plots were measured and within the 20m² plots, 5 sub-plots of 5m² were measured. Inside the 5m² plots, two parallel lines were laid at 20cm from the edge of the plot and all the intercepted plants (shrubs) within the 5m² were harvested after measuring their canopy intercept along the 2 parallel lines (Flombaun and Sala, 2007).

In the 5 sub-plots of $5m^2$, all the current season green biomass of the intercepted plants were harvested and packed per plant growth form (stem succulents, leaf succulents, and non-succulents). Only the current season green leaves and twigs were harvested. The harvested plant materials were oven-dried and weighed later in the laboratory. The regression equation that was obtained between the measured length of the intercepted canopy cover and dry mass of the harvested plants were used to calculate (correlate) the biomass production of all the other intercepted canopy cover of the plant species that were encountered and measured along the 20 m lines. All harvested plants were packed separately depending on their growth forms (stem succulents, leaf succulents, and non-succulents).

Measurement of biomass production using remote sensing data

The fraction of photosynthetic active radiation (fpar) values were extracted from pixels that matched the ground co-ordinates and dates when the ground measurements of biomass production were collected. In addition Moderate Resolution Imaging Spectroradiometer (MODIS) imageries were downloaded and fraction of photosynthetic active radiation (fpar) values extracted for the selected pixels in 4 vegetation types. Remote sensing fpar values were obtained from MODIS imageries which consisted of 8 days composite images at spatial resolution of 1 km^2 pixel size. The fpar values were extracted from pixels that matched the ground co-ordinates and dates when the ground measurements of biomass production were collected.

Rainfall data

There was a rain gauge in each of the 5 strata of vegetation types in RNP. Rainfall data is usually recorded in RNP and forwarded to South Africa Weather Service. The monthly rainfall data for the 5 rain gauges that had been recorded for 6 years (2002 and 2008) in the 5 vegetation types were obtained from South Africa Weather Service in Pretoria.

Data analysis

To determine relationships between canopy cover and above ground biomass production for different growth forms linear regression analyses was performed with biomass production as dependent variable and line intercept cover as the independent variable. General Linear Model (GLM) was used to compare variation in biomass production between the growth forms in the 4 vegetation types. To determine the variation in biomass production in different vegetation types and landscapes, 2-Way ANOVA was used. The relationship between above ground dry biomass and remote sensing data (par) was determined using linear regression analyses.

GLM was also used to determine the variation of above ground biomass in the 3 landscapes (plains, foothills and mountains) with biomass as dependent variable and vegetation types and landscape as categorical variables. The correlations between rainfall with biomass production and fpar values was determined by use of linear regression with rainfall as independent variable while biomass production and fpar values were considered as the dependent variables.

Results

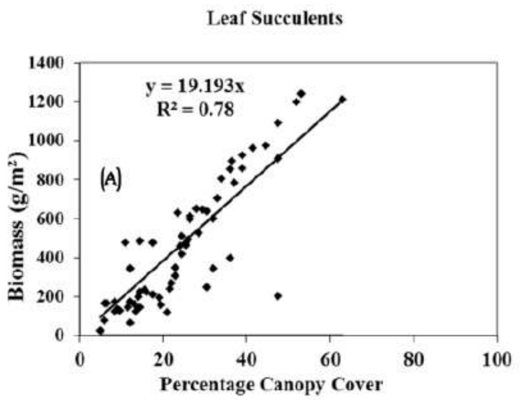
The relationships between above ground biomass production and line-intercept canopy cover were significant (at P value ≤ 0.05) as shown in Table 1 and in Fig. 2a-c. Stem succulents had the highest coefficient of determination ($R^2 = 0.67$, P-value 0.001, n = 68) followed by leaf-succulents coefficient of determination ($R^2 = 0.78$, P-value 0.0001, n= 62) and non-succulents had (R^2 of 0.72, P-value of 0.05, n = 69 as shown in Fig. 2a-c. The regression equation between the harvested above ground biomass and the line intercept cover in each plants category (stem succulents, leaf succulents and non-succulents) were later used to convert the measured intercept vegetation cover to biomass production in the 5 vegetation types.

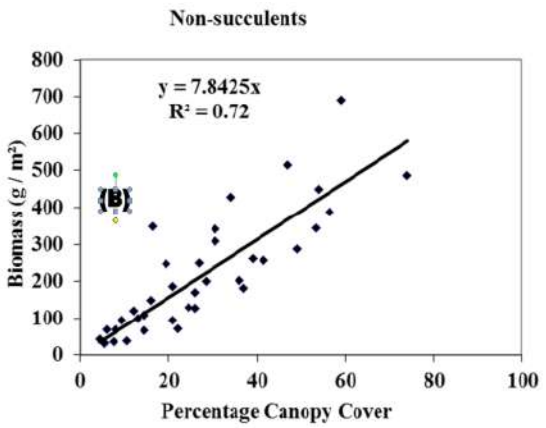
Comparison of biomass production in the three landscapes shows that in CRM vegetation type, flat plains produced significantly more biomass followed by mountains and foothills while in NRS vegetation type, foothills and mountains had more biomass production than plains. On the other hand, in the Desert biome, there was no significant difference in biomass production between the landscapes (Fig. 3).

In total biomass production was significantly higher in vegetation types in Succulent Karoo biome than in Desert biome (Fig. 3).

Table 1. Variation in biomass production in different vegetation types and Landscapes.

Growth forms	Interactions	DF	F-value	P-value
Stem succulents	Vegetation types	14	17.86	0.0001*
	Landscape	28	6.07	0.005
	R-Square	Coeff Var	Root MSE	Mean
	0.74	75.16	230.19	306.28
Leaf Succulents	Vegetation types	14	12.56	0.0001*
	Landscape	28	6.8	0.001*
	R-Square	Coeff Var	Root MSE	Mean
	0.86	46.06	111.03	241.04
Non-succulents	Vegetation types	14	0.8	0.0001*
	Landscape	28	0.39	0.005
	R-Square	Coeff Var	Root MSE	Mean
	0.59	213.12	58.41	27.41
Total Biomass	Vegetation types	4	20.7	0.0001*
	Landscape	2	5.77	0.0008*
	R-Square	Coeff Var	Root MSE	Mean
	0.76	57.02	346.27	607.28





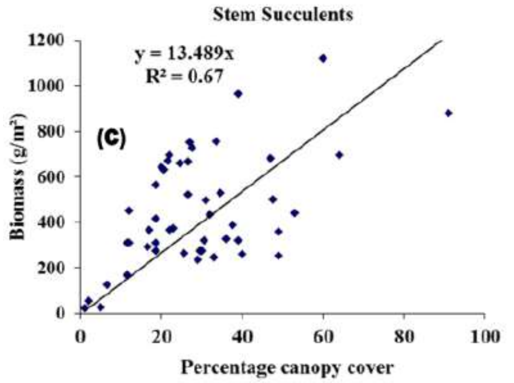


Fig. 2a-c. Relationships between percentage canopy cover and biomass production for different growth forms.

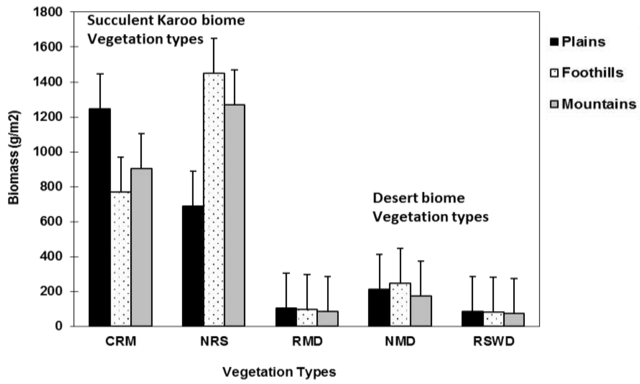


Fig. 3. Biomass production in the 3 landscapes (plains, foothills and mountains) in different vegetation types. NRS- Northern Richtersveld Scorpionstailveld, CRM-Central Richtersveld Mountain, RMD- Richterberg Mountain Desert and NMD- Noms Mountain Desert, RSWD-Richtersveld Sheet Wash Desert.

Biomass production of the stem succulents, leaf succulents, non-succulents plants and total biomass differed significantly between the five vegetation types. They also had significant difference between the two landscapes (flat plains and sloppy foothills) with P-value less than 0.05 as shown in Table 1. Biomass production by stem and leaf succulents plants were significantly different in the Succulent Karoo biome in vegetation types CRM and NRS but were not significantly different in vegetation types NMD, RMD and RSWD in the desert biome (Table 2). Total biomass was significantly higher in vegetation types CRM and NRS in succulent Karoo biome than vegetation types in desert biome as shown in Table 2

Table 2. Variation in biomass production in different vegetation types for each growth forms. (Fig.s with different letters within the same column are significant different while Fig.s with similar letters within the same column are not significant different. Mean biomass inkg/ha).

Biomes	Veg. types	Growth forms			
		Stem Suc	Leaf Suc	Non-Suc	Total Biomass
Succulent Karoo	CRM	726.3[a]	350.9[b]	63.3[a]	1162.8[a]
	NRS	317.8[b]	560.3[a]	20.5[b]	934.7[b]
Desert Karoo	NMD	84.8[d]	65.1[c]	12.4[c]	209.5[c]
	RMD	27.6[d]	22.4[c]	7.5[c]	98.5[c]
	RSWD	21.4[d]	26.2[c]	5.7[c]	81.6[c]

There was a strong relationship between above ground biomass production and fpar values (y = 195.05x, R^2 = 0.89, P<0.01) as shown in Fig. 4. Also, there was a strong relationship between amount of rainfall received and above ground biomass production (R^2 = 0.73, y = 16.391x-302 and P< 0.01) as shown in Fig. 5. In addition, there was a strong correlation between the amount of rainfall and fpar values (P<0.01, R^2 = 0.79, y = 12.794x-307.18) as shown in Fig. 6. Both fpar values and above ground biomass production increased with increase in rainfall in this arid ecosystem.

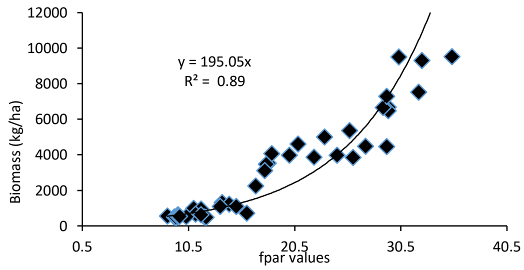


Fig. 4. Relationship between above ground biomass production and fpar.

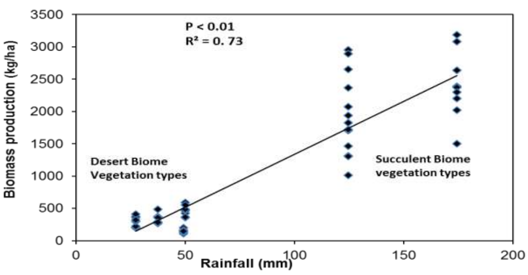


Fig. 5. Relationship between above ground biomass production and rainfall in the 5 vegetation type's in RNP.

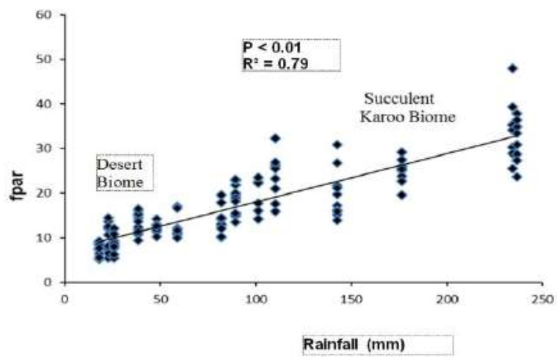


Fig. 6. Relationship between fpar values (of plots where harvesting of biomass took place) and rainfall.

Discussion

Spatial and temporal variations in forage production

The variability in biomass production in different landscapes and vegetation types reflected heterogeneity of plant growth as a result of variations in climatic and ecological attributes in the study area. In RNP herbivores utilize different landscapes at different seasons in a year. Pastoralists settle on the plains and foothill landscapes during the wet season and then move to Orange River riparian zone during the dry season. Therefore the study of temporal, seasonal and spatial variations in biomass production and distribution would be of great importance to land users in RNP in order to understand when and where forage is available at different times of the year. According to Saayman *et al.,* (2016), alternating landscape and seasonal resource use impose a cycle of plant growth resulting into forage availability at different times of the year. Separation of landscapes accessibility during the wet and dry seasons is therefore regarded as having important implication for resource use in RNP. Spatial variability of forage resources buffer seasonal variability of animal populations by allowing a dry-season refuge to herbivores (Fynn, 2012). Flat plains landscapes were found to be very productive in western part of RNP (in CRM vegetation type) compared to sloppy hills and mountainous landscapes on the northern and eastern part of the park (in desert biome).

Herbivores spent most of the time in flat plains of the Succulent Karoo biome region during the rainy season. As forage got depleted in the plains with time, herbivores would later graze in the foothills and mountains (pers observation). The plant species in this Succulent Karoo vegetation types need to be protected from effects associated with overgrazing especially near the stock posts. In NRS vegetation type, foothills and mountains produced more forage biomass than the flat plains. Although there was more biomass production in the mountainous landscapes not all forage are accessible to the herbivores (Hendricks *et al.,* 2005b). Pastoralists were found to prefer to graze their animals on the flats plains and this was evidenced by high concentration of stock posts on the flat plains compared to the steep mountainous landscapes. Mountainous landscape in Succulent Karoo are steep and rocky and thus not easily accessible by herbivores (Anderson and Hoffman 2007). This therefore means that there should be a more concentrated effort geared towards conservation of plant species found on flats plains landscapes in RNP which have been subjected to continuous grazing every year. This supported the findings by Hendricks *et al.,* (2005a) who found that species richness and diversity increased with distances away from stock posts, which was a clear indication that flat plain landscapes are more at risks of overgrazing than the rocky mountainous landscapes.

Rainfall was one of the environmental factors that was found to influence vegetation productivity in this arid ecosystem. The observed increase in biomass production with rainfall concurred with Saayman *et al.,* (2016) and Palmer and Yunusa (2011) who also found strong correlation between biomass production and rainfall in Succulent Karoo. Plant growth in Succulent Karoo occurred in winter period when there was precipitation. This may also explain why biomass production was higher in vegetation types found in Succulent Karoo biome compared to Desert biome that recorded low biomass production. Another cause of difference in biomass production in the two vegetation biomes was presence of fog from the Atlantic Ocean which was another source of precipitation in the western side of RNP (Succulent Karoo Biome). According to (Mucina *et al.,* 2006), fog from Atlantic Ocean play a great role in sustaining vegetation.

Arid and semi-arid rangelands such as RNP are usually characterised by low and erratic rainfall which in turn leads to unpredictable forage production within and among years.

Due to high rainfall variability, the primary productivity fluctuates widely whereby high forage production is witnessed in years of high rainfall and low productivity in dry years. From the recorded rainfall data for eight years (2002-2007), the years of study 2006 and 2007 recorded the highest rainfall. Consequently from the remote sensing data, the extracted fpar values of the 8 years showed the highest values were recorded in 2006 and 2007. High fpar values were interpreted to mean high primary productivity in 2006 and 2007 and therefore, precipitation was found to regulate forage productivity in RNP. The findings of a strong relationship between rainfall and biomass production concurred with studies by Hempson *et al.,* (2015) suggesting that rainfall was one of the key determinant of forage production in arid and semi-arid rangelands which consecutively regulated the herbivores productivity in RNP. Information on temporal and spatial variations in primary productivity with rainfall patterns will therefore contribute to the understanding of the effects of climate change to plant communities in this arid area which is predicted to be one of the most severely affected (Young *et al.,* 2016). The predicted decrease in winter rainfall and increase in temperatures in Succulent Karoo due to global climate change (MacKellar, *et al.,* 2007) will adversely affect biomass production in the vast winter rainfall areas such as RNP. The predicted loss of succulent plants in this winter rainfall biome due to the effect of climate change (Young *et al.,* 2016) will eventually have a negative impact on primary productivity, livestock farming, livelihoods and the entire biodiversity of the Succulent Karoo. The study show that leaf and stem succulents' plants contributed the highest amount of available forage production in most parts of this arid and semi-arid ecosystem and therefore such landscapes should be given conservation priority.

Remote Sensing data and line-intercept method were found to be suitable tools in measurement of variation in forage yield and vegetation productivity in RNP. This was attributed to the strong relationships obtained between remote sensing data (fpar values) with biomass production as well as with rainfall. In addition, MODIS data were widely available in finer spectral resolutions and in combination with *in-situ* (harvested) biomass data confirmed that they can be used in frequent assessment of spatial and temporal variation in forage productivity in heterogeneous rangelands such as RNP as well as in identification of forage hotspot areas for the herbivores. Remote sensing fpar values proved to be effective in monitoring and predicting spatial and temporal variation in biomass production in this arid ecosystem because measure of fraction of photosynthetic active radiation (fpar) was interpreted as a reflection of the amount of biomass productivity of vegetation. Remote sensing data (fpar values) were also very useful in estimating and extrapolating biomass production for a long period over time.

It was therefore possible to estimate and extrapolate biomass production over a period of 6 years (2002-2007) in the 4 main vegetation types in RNP using fpar values. Strong relationships between biomass and vegetation productivity index NDVI and MODIS have been reported in other studies in Succulent Karoo (Palmer and Yunusa 2011; Rutherfold and Powrie 2010). However, the study show that relationship between fpar values and biomass was stronger than with rainfall. This could be attributed to the application of larger and variable remote sensing data compared to few points' rainfall data collected in few numbers of rain gauges available in the study areas. In arid rangelands such as RNP, remote sensing data were available even during the dry periods and are therefore more suitable in predicting temporal primary productivity compared to the rainfall data that are only available during the rainy seasons. Also Satellite imageries such as MODIS are good predictor of forage productivity because fpar is sensitive to the greenness of plant canopies at a finer temporal and spatial resolution.

Measurement of temporal and spatial variability in primary productivity in African rangelands has ecological as well as economic implications. In livestock farming, information on rangeland productivity would help farmers to make informed decision in tracking the availability of forage resources for their herbivores (Fynn, 2012). The study shows that biomass production of this arid and semi-arid ecosystem is heterogeneous in space and variable over time and therefore flexible movement to track forage and water is very critical. Information on spatial and temporal forage production will be very important in RNP due to existence of less predictable patterns of productivity caused by patchy rainfall patterns. According to Jakoby *et al.,* 2015, forage tracking strategies based on distribution of forage production are environmentally friendly and wastes less feed, while high spatial and temporal heterogeneity in resources within an ecosystem buffer the risks associated with forage shortages as a result of climatic fluctuations. Information on spatial and temporal variation of forage production from this study will be useful in rangeland management and in regulation of land use practices such as pastoralists' nomadic movement patterns as well as resource utilization by herbivores. Since pastoralists are nomadic in nature, and they move from one place to another tracking forage, information on spatial and temporal variation in forage productivity is a guide to the rangelands managers on the maximum carrying capacity as well as to the nomadic farmers on forage hotspot areas in different seasons.

Conclusion

Information on spatial and temporal variation of forage production obtained is useful in rangeland management and in regulation of land use practices such as pastoralists' nomadic movement patterns as well as resource utilization by herbivores. RNP is a contractual park managed by the South Africa National Parks and the Richtersveld community.

Since pastoralists graze their animals in the park, and they move from one place to another tracking forage, information on spatial and temporal variation in forage productivity in this ecosystem will act as a guide to the park managers on landscapes that should be given conservation priority as well as to the nomadic farmers on forage hotspot areas in different seasons. Adjusting herds' movement patterns to rainfall patterns and primary productivity will be an appropriate management strategy in RNP to avoid environmental degradation. Use of Spatial Resolution Satellite Data such as MODIS imageries collected at high frequency made it possible to track productivity changes and habitat quality at a smaller scale in RNP with possibilities of going back in time and covering a large area within a short period of time. This technique was useful in this study in measurement of primary productivity in areas of the park that were difficult to access such as the mountains and steep valleys. The study has demonstrated that remote sensing data and rainfall patterns can be used to estimate and predict forage production in arid and semi-arid rangelands as well as in identification of forage hotspots for the herbivores. Use of remote sensing technique by use of fpar values to measure primary productivity in RNP proved to be reliable and efficient and can be applied in arid and semi-arid rangelands worldwide.

Acknowledgement

The work was financially supported by South Africa National Research Fund (2006-2009 NRF Competitive Programme for Unrated Researchers through Rhodes University). We are grateful to the management and staff of Richterveld National Park for allowing us to collect data in this biodiversity rich ecosystem and to all those who assisted in data collection. We would also like to acknowledge South Africa Weather Service for assisting us with rainfall data. Thanks to Dr. Norbert Ngowi for the review and useful comments on the manuscript.

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