Spatial and Temporal Variation of Stocking Rate in a Rotational Grazing System on a Namibian Cattle and Sheep Farm from 2006 to 2017

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Key words: rangeland management; holistic management; grazing planning; rainfall variability

Abstract
The debate on appropriate stocking rates (SR) increasingly recognizes the importance of variable, targeted and adaptive stocking in response to a temporally variable and spatially heterogeneous resource distribution, particularly in challenging environments such as the Namibian savannah. In common extensive ranching systems, a farmer's scope of action is often limited to flexibly adjusting the number and concentration of livestock to the available forage in space and time. SRs are commonly set according to carrying capacity recommendations which usually have a low spatio-temporal resolution. This may lead to punctual under- and overutilization. The Namibian Rangeland Management Strategy advocates adjusting SR in response to the fodder reserve at the end of the rainy season in May. Based on records of the 9,500 ha commercial cattle and sheep farm Springbockvley (avg. annual rainfall 272 mm, Jun-May) in central Namibia we calculated effectively applied annual (Jun-May) SRs from 2006 to 2017 for 50 paddocks. We then looked at spatial and temporal variation indicated by the coefficient of variation (CV in %). Overall average SR was 35 kg ha^{-1} with an average annual spatial CV of 35 % and an average temporal CV of 37 % within a paddock. The mean farm SR increased following a linear trendline to above the regional average but not all paddocks supported this increase alike. Until 2013 the farm was grazed with four mixed herds of cattle and sheep, each rotating in a separate farm section. Three farm sections showed linearly increasing SR trendlines, while one section's SR remained static with some paddocks showing falling trendlines. Since 2014, three large herds (cows, sheep, mixed) grazed all farm paddocks in a predefined sequence (each herd grazed each paddock once per year). We discuss environmental and management influences on SR variation at different scales.

Introduction
Under semi-arid savannah conditions, average biomass production is rather low and the high spatiotemporal variation of resource availability is limiting the farmer's room for manoeuvre (Ash & McIvor 2005). Several publications have suggested overcoming the debate about certain grazing systems (e.g. conservative stocking with continuous grazing vs. higher stocking in rotational systems) and to focus instead on the development of targeted, adaptive decision-making frameworks responding to complex, variable rangeland conditions (e.g. Briske et al. 2011; Steffens et al. 2013; Teague et al. 2013; Hawkins 2017). Rangeland models by Jakoby et al. (2015) predicted the best management strategy to be rotational, adaptive grazing in response to spatio-temporal differences in forage availability. The Namibian Rangeland Management Strategy (NMAWF 2012) advocates adjusting SR in response to the fodder reserve at the end of the rainy season in May rather than adopting suggestions based on low-resolution carrying capacity maps. The debate opens the field for research that monitors and evaluates adaptive, successful farm managers in order to understand their individual, effective approaches. Briske et al. (2011) asks: "Can we understand how people develop site-specific management strategies that are responsive to spatial and temporal variability, [and] incorporate both experiential and experimental knowledge …?"

As a step in this direction, we present in this observational study the stocking rate data (SR) at paddock level on Farm Springbockvley, and follow its spatial heterogeneity and temporal variability over the course of 11 years. The paper also addresses the question at what resolution one might need to consider variable resource distribution, a topic that has been emphasized by other authors (e.g. Burke 2004, Teague and Barnes 2017, Augustine et al. 2020). The observations should provide a starting point for future research examining the extent to which adaptation on Springbockvley is successful and what system characteristics contribute.

Methods and Study Site
Ecological Conditions: Farm Springbockvley is located in south-eastern central Namibia. Soils are predominantly sandy, heterogeneously interspersed with limestone areas with a few loamy patches. The vegetation is a typical Kalahari xeric savanna with *Acacia* trees. Main fodder grasses are *Stipagrostis uniplumis* (perennial), *Aristida* spp. and *Schmidtia kalahariensis* (annual), all of variable, low to medium fodder value. Various (forage) shrubs are present, especially in the more calcareous areas. The peak rainy and growing

season is January-March, followed by lower precipitation until the end of May. We choose a 'season' from June 1st to May 31st as the period of comparison. For example, 2006/07 starts with the dry season 2006 and the grazing of 'standing hay', the amount of which is influenced by grazing and rain in early 2006, followed by grazing during the rain and growing season from late 2006 to May 2007.

The long-term average seasonal rainfall is 272 mm (1 station, CV 48 %) based on rain gauge measurements from 1960-2017. Within our observation period from June 2006 to May 2017 the overall average was 327 ± 172 mm (9 stations, 11 seasons, temporal-CV 53 %). The period (Figure 1) included both the rainiest year (2010/11, 703 mm) and the year with the second lowest precipitation (2006/07, 67 mm) since data recording began. The period showed the usual high temporal variability that was characteristic across the nine stations (temporal-CV 51-58 %). The spatial heterogeneity between the different stations within one season averaged over the period was 11 %. However, the range was from 5 to 25 % (2006/07), showing that in some years the spatial heterogeneity was more distinct.

Management: About 900 Nguni cattle and 3,500 Damara sheep (May 2017 data) are raised in a year-round grazing, low external input system. The area of 9,500 ha area is subdivided into 60 paddocks. Until 2013, the farm was grazed with four mixed herds of cattle and sheep, each rotating in a separate farm section (Haus, Sand, Achab, Kalk, each with 9-16 paddocks. Since 2014, three large herds (cows, sheep, mixed) grazed all farm paddocks in a predefined sequence (so that each herd grazes each paddock approx. once per year). At the end of May, the farm manager draws up a dry season plan based on the standing forage according to Holistic Grazing Planning guidelines (Butterfield et al. 2006), indicating when and for how long which herd will graze in which paddock. During the short growing season, grazing duration is determined more flexibly and in response to herbage growth (approx. 4-8 days per paddock).

Analysis: Based on handwritten records of herd movements between paddocks, we analysed the effective annual SRs applied from 2006 to 2017 for 50 paddocks (mean: 162 ha, range: 53-338 ha). 10 paddocks were omitted because they were not constantly part of the usual routine for different farm management reasons. The records provided information about when, how long, and how many head of cattle and sheep grazed the paddock. We estimated the average weight of one head of cattle at 290 kg LW based on test weighings in the 2014-2016 rainy seasons. A sheep was estimated at 35 kg LW by the farm manager. We calculated the SR of a grazing event: number of livestock × average LW [kg]/paddock size [ha] × grazing days. We then summed all grazing events per paddock and season and divided that sum by 365 days to obtain the cumulative annual stocking rate [kg ha^{-1} d^{-1}]. For the preliminary and explorative analysis in this paper we use the coefficient of variation (CV %) to investigate the variation of SR at different resolutions. The spatial-CV displays the spatial heterogeneity of SR within one year (n = 50 paddocks), i.e. the dispersion of individual paddock values around the farm mean SR of all paddocks in the respective year. The temporal-CV displays the temporal variability of SR of one paddock within the observation period (n = 11 years), i.e. the dispersion of the individual annual values around the mean value of the paddock within the study period.

Results

At farm scale: The overall mean annual SR averaged over 50 paddocks and 11 seasons (equal to the means of means) was 35 kg ha^{-1} d^{-1}. This equals 1 sheep per hectare or 1 head of cattle per 8 ha (cf. above). The development of the annual farm average SR (n = 50 paddocks) over the study period is shown in Figure 1. The farm average increased gradually and followed a linear trendline. The error bars (std. dev.) show the spatial heterogeneity within the farm area, i.e. the dispersion of the paddock values around the season's farm average. The average seasonal spatial-CV was 35% and the average temporal-CV of all paddocks was 37%.

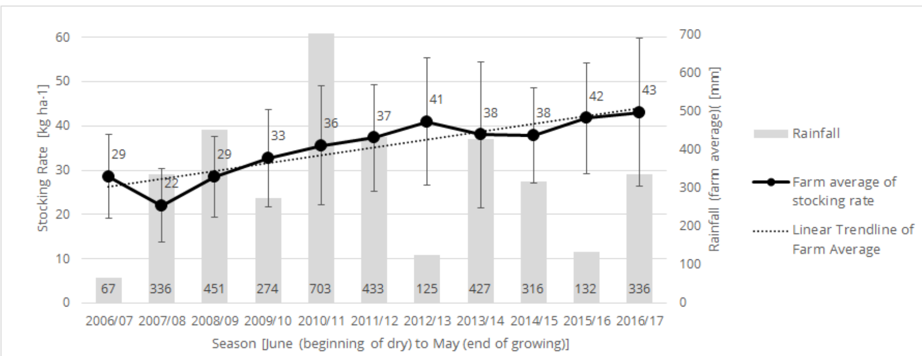

Figure 1: Development of Springbockvley's average annual (Jun-May) stocking rate (n = 50 paddocks) and its standard deviation (spatial heterogeneity) from 2006 to 2017.

At farm section scale: Until February 2013 the farm was grazed with four mixed herds of cattle and sheep, each rotating in a separate farm section. Over the whole study period, the sections Haus, Sand, and Achab showed linearly increasing SR trend lines somewhat analogous to the overall seasonal mean, except that Haus showed a severely lower mean SR in 2012/13 and 2013/14. Kalk's average SR development was static with some paddocks showing falling trend lines (e.g. K06, K10). Figure 2 shows average SRs, spatial- and temporal-CVs of the sections. Haus had the smallest average overall SR and on average, the differences between paddocks within a season were the smallest (spatial-CVs), while at the same time, the differences between years were comparatively higher (temporal-CV). The highest spatial heterogeneity among paddocks was found in Kalk. The lowest inter-annual variation was observed in Achab.

At paddock scale: The farm map (Figure 2) shows for each paddock the effectively applied SR averaged over the period (written number). It illustrates the spatial heterogeneity and patchiness of SR levels (left) or of the SR's temporal variability (right) within the period. It appears that under the given management, paddocks with higher variation in SR had a lower overall average SR across the study period.

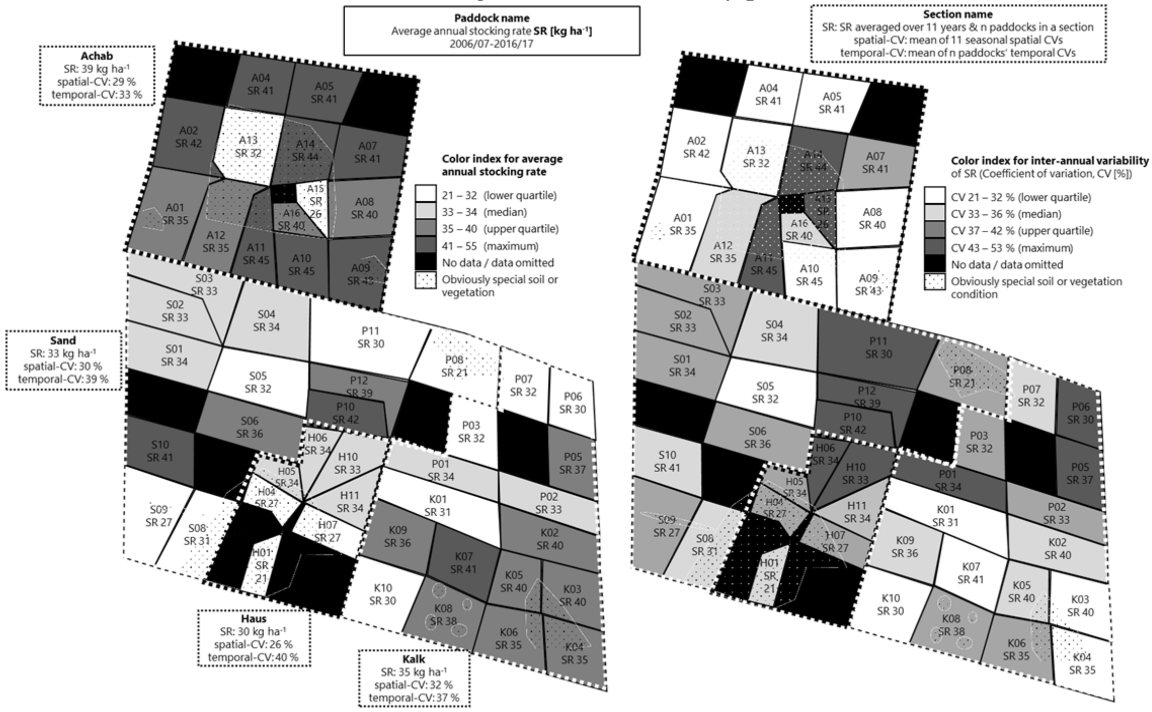

Figure 2: (A) Colour-coded stocking rate levels (left), and (B) colour-coded temporal variability levels (right) showing spatio-temporal variation of stocking rate for 50 paddocks and 4 sections on Farm Springbockvley from 2006-2017

Discussion

Sprinbockvley's manager has increased the average SR over the observed period, even over years with low precipitation. In recent years, the average has been above the region's reported carrying capacity of 30-40 kg ha^{-1} [Mendelsohn et al. 2002; there is a new figure of 15 kg ha^{-1} from Mendelsohn (2006) but the wide variation between data sets is not clear]. The observation period had on the whole above-average rainfall, but also included drought years. The inter-annual variability was comparable to the long-term value. From the available data we could not consider inter- and intra-annual changes in animal weights. The increase in SR thus reflects an increase in the number of animals. The cattle herd increased linearly (approx. doubled) over the study period, while the sheep flock size was more variable with a decreasing trend.

Merging farm sections and herds in 2013 has effectively not caused an increase in total SR, but there has been an increase in stocking density through larger herds. The strong SR decline in 2013/2014 in the house section is striking, although it remains unclear whether this could be attributed more to merging the herds or to the consequences of drought in 2013. At farm level, the decline in 2013/14 can be associated with a 1,000-head decrease in the sheep flock in August 2013. Due to the high internal heterogeneity of the farm sections, they do not really seem to be suitable as spatial levels of analysis. Figure 2 shows that some farm areas were more homogenous than others with regard to their level of mean SR and mean temporal-CV of SR, and that these areas were overall stocked at higher rates. This matter requires further investigation.

Since SR in an Holistic Grazing Planning system is adjusted in response to vegetation parameters, one might reasonably assume that either the vegetation parameters have improved, or the farmer's vegetation assessments and adjustment of grazing has improved overall. However, day-to-day business decision-making also causes deviation from the plan and limits the inference from effectively applied SRs to scheduled grazing. The data do not tell us anything about the possible negative tradeoffs of the increased SR (such as reduced animal condition, weights, fertility), nor do they reflect information on possible detrimental effects on vegetation and the farmer's capability to identify these. Further analysis, linking SR with NDVI data, will permit the identification of any linkage between SR variation and trends in vegetation, and will possibly provide evidence for the adaptive capacity of the applied grazing management.

The data demonstrate that looking at farm averages masks the development of the individual paddocks. Although a linear trend line indicated a SR increase for almost all paddocks, there was a noticeable up and down variation in the values for many paddocks, as is indicated by the average temporal-CV of 37%. The study confirms that setting SR only based on a low-resolution carrying capacity map (still a common practice) does not sufficiently address the spatio-temporal variation and might create over- and underutilization. With regard to temporal variability, it seems generally questionable to what extent a year is a suitable period of comparison. It would be desirable to look again with higher resolution at differences between dry and rainy seasons, at carry over effects and the sequence of "good" and "bad" rainy years.

Conclusions

Analysing long term records on animal numbers and movements - as exist in written form on many livestock farms and in herders memory in many pastoral systems - can provide a high resolution picture of actually applied SR in space and time. This picture reflects management responses in space and time which could, if linked with other data sources such as high resolution NDVI and rainfall data, be a step towards understanding the way how livestock farmers and pastoralists grazing management responds to variability and heterogeneity.

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