

Article

Rangeland Conditions and Grazing Capacities on Livestock Farms During and After Drought in Three Biomes in South Africa

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Abstract

Climate change has intensified extreme weather events worldwide, such as droughts, which have severely affected South Africa's rangelands by reducing productivity and increasing livestock mortality. This study aimed to investigate variability in grazing capacities and stocking rates with respect to land tenure, long-term grazing capacity norms, field surveys, and farmer perceptions during and post-drought conditions in the three biomes in South Africa. In-person interviews and field surveys were conducted with 85 farmers from the Grassland ($n = 25$), Savanna ($n = 35$), and Nama-Karoo ($n = 30$) biomes and vegetation condition was surveyed during or after the drought. Grazing capacity did not differ significantly across land tenure systems in the Savanna biomes ($p > 0.05$), but significant differences were found in the Grassland and Nama-Karoo biomes ($p < 0.05$). Over $> 60\%$ of farmers in the Nama-Karoo biome rated their rangeland condition as poor because of the drought, and field surveys showed that grazing capacities were four times lower than the national recommended grazing capacity norm. Considering the high inter-annual variability in vegetation productivity and differences in farmers' perceptions based on local knowledge, it is recommended that the Department of Agriculture adopt flexible grazing capacity ranges in the regulations of the Conservation of Agricultural Resource Act 43 of 1983.

Keywords: climate change; land tenure; Nama-Karoo; practice theory; Savanna; stocking rate



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1. Introduction

Climate change has been affecting the productivity and quality of rangelands in arid and semi-arid regions worldwide for the last several decades [1]. Projections by the Intergovernmental Panel on Climate Change (IPCC) indicate that the mean annual rainfall may decline by 5% in 2035, and temperatures will increase up to 5.4 °C by 2100 and 2.1 °C by 2065 in southern Africa [2]. In South Africa, mean annual temperatures have increased by at least 1.5 times the observed global average of 0.65 °C over the past five decades and

extreme rainfall events and droughts have increased in frequency [3]. These changes in precipitation and temperature threaten ecosystem functions including food production, and ultimately threaten food security [4].

Drought affects rangelands as it limits their ability to support herbivore populations and life in general. Drought reduces soil moisture availability, which directly limits plant growth and regeneration, leading to a decline in net primary production [5]. This, in turn, compromises forage availability and quality for grazing animals [6]. Over prolonged periods, drought can lead to shifts in plant community composition, often favoring unpalatable and drought-tolerant species over palatable species [7]. Such shifts reduce the nutritional value of rangelands and can affect the long-term carrying capacity for livestock [6]. In extreme cases, plant mortality and soil degradation become prevalent, further diminishing rangeland conditions and slowing recovery even when rainfall returns to normal levels [7].

Rangelands cover half of Earth's terrestrial surface and play a vital role in global food security by providing grazing areas for livestock and wildlife, which supply meat, milk, and other animal products [1]. In South Africa, several biomes, including Grassland, Savanna, and the Nama-Karoo, which are the three largest biomes in the country, provide the main fodder source for the national cattle and small-stock herds as well as for wildlife [8]. These biomes are, however, increasingly coming under pressure from climate-change-induced droughts, erratic rainfall, and extreme temperature [9]. South African rangelands, particularly those in the Eastern, Western, and Northern Cape provinces, experienced a severe multi-year drought from 2015 through to early 2020 affecting approximately 590,000 km² of rangelands, which are mostly in the Karoo biome [10]. Between 2014 and 2016, drought significantly affected the Savanna and Grassland biomes in which provinces such as Limpopo, North West, Free State, and Kwa-Zulu Natal recorded substantial rainfall deficits and vegetation stress [11]. The theoretical understanding of grazing-capacity-involved drought in rangelands must therefore be contextualized within individual biomes, considering both ecological thresholds and socio-economic drivers [12].

Farmers and/or livestock owners are known to use local and indigenous knowledge in decision-making regarding the utilization of rangelands and managing drought [13]. Generations of experience have equipped them with a deep understating of the land, seasonal cycles, and seasonal cues that signal drought [14]. Many livestock farmers monitor vegetation condition, soil health, animal behavior, and rainfall patterns to anticipate droughts. Based on their observations, farmers develop traditional practices such as seasonal grazing rotation, resting of overgrazed areas, and selective use of species-rich pastures to maintain rangeland productivity. In regions such as the Eastern Cape and Limpopo provinces, herders assess grazing capacity not through quantitative measurements but by monitoring changes in forage quality and livestock performance. Elders often serve as custodians of this knowledge, guiding community decisions on herd size, mobility, and grazing schedules. Such indigenous systems emphasize flexibility and responsiveness to environmental variability, contributing to ecological sustainability in semi-arid environments [15]. Therefore, integrating these local insights with scientific rangeland assessments can enhance the accuracy and cultural relevance of grazing management strategies [16]. Managing rangelands might become more difficult for livestock farmers as the frequency and intensity of droughts are forecasted to increase [17]. Drought negatively affects rangelands, regardless of their condition, but its impacts are amplified if poor rangeland conditions prevailed prior to the drought. Managing rangelands prior, during, and after droughts involves a multi-faceted approach, which includes monitoring resources, adjusting livestock use, and implementing adaptive management strategies [18].

The Grazing Capacity Norms in South Africa, established under the Conservation of Agricultural Resources Act 43 of 1983 (CARA)(Government notice R.1048 on 25 May 1984), and amended in 2017 [19], set the legal limits for the number of animals that could be kept per unit area in the various biomes. The Grazing Capacity Norm (GCN) maps were developed using a combination of ecological data, geographic information systems (GISs), remote sensing, and field-based observations to show the grazing capacities (measured in Large Stock Units or LSU, equivalent to a 450 kg cow) a specific area of rangelands can sustainably support [19]. However, The CARA Act is not effectively enforced, limiting its intended impact on sustainable land and rangeland management. Currently, the grazing capacity guidelines issued by government departments are broad spatial scales and may not accurately reflect local conditions at the farm level [20]. As a result, farmers and land managers who rely solely on these generalized norms may either underutilize or overexploit their land resources. Furthermore, climate change is expected to lead to greater drought severity, which threatens the effectiveness of the grazing capacity norms.

As rangelands vary in space and time, livestock farmers have their own views on grazing capacities. In addition, land tenure also affects the number of animals that a farmer can keep, and tenure has been found to impact the conditions of the rangeland [21]. Land tenure also plays a crucial role in how farmers and/or landowners cope with drought and other climate-related stressors. Secure and clearly defined land tenure often encourages farmers and/or landowners to invest in sustainable grazing practices, as they have long-term incentives to maintain land productivity [22]. In contrast, insecure tenure systems where regulatory oversight or traditional governance is weak can lead to overstocking and rangeland degradation [23]. Therefore, the link between land tenure, grazing capacity, and rangeland condition is context-specific and mandated by socio-economic, institutional, and ecological factors. Tenure systems that align user incentives with long-term sustainability goals, supported by appropriate policy and monitoring tools [24], are essential for effective rangeland management.

Theoretical Framework

Practice theory provides a theoretical understanding of how a generalized set of rules (e.g., broad and fixed grazing capacities might be inadequate to explain the variations within and how local realities provide a more accurate understanding of the spatial and temporal variations [25]. Furthermore, practice theory provides a useful lens for understanding the dynamic interplay between ecological processes, management practices, and human decision-making, acknowledging that rangelands are dynamic and adapting to various influences over time and across different locations [26]. Practice theory emphasizes how the embedded nature of actions such as historical experience, cultural identity, and social learning contribute to how individuals and groups engage in activities, make decisions, and create meaning [25].

In the context of South African rangelands, for example, farmers often respond to drought not through abrupt changes, but through adaptive practices. These practices include herd mobility, adapting stocking rates, negotiating access to grazing commons, or altering livestock composition, which are sustained and modified over time [27]. These practices are not purely individual but are shaped by institutions (e.g., customary authorities), social networks, and material infrastructures like boreholes and fences [16]. By focusing on what people do, practice theory reveals how resilience emerges from the continuity and adaptability of daily activities under stress, rather than from externally imposed interventions [28]. This approach complements ecological and technical perspectives by highlighting the social fabric and agency underlying drought management in semi-arid rangelands.

The aim of this study was to understand differences in rangeland conditions, grazing capacities, and stocking rates in terms of grazing capacity norms, field surveys, and farmer perceptions and practices under and after drought conditions in the three biomes, namely the Grassland, Savanna, and Nama-Karoo of South Africa. The effect of land tenure on grazing capacity was also investigated. The objectives of this study were to (i) assess the perceptions of farmers on rangeland conditions and types of degradations that occur on their farms; (ii) assess the grazing capacities across the different tenure systems; (iii) assess the rangeland condition across the three biomes; and lastly, (iv) to compare four grazing variables, (a) farmer's Perceived Grazing Capacity, (b) current stocking rates, (c) calculated grazing capacities from rangeland assessment, and (d) department-recommended long-term grazing capacity norms, within the framework of practice theory to argue the applicability of broad-scale and fixed grazing capacities in variable rangelands.

2. Materials and Methods

2.1. Study Areas

South Africa spreads over 122 million ha with approximately 75% considered rangelands [29]. The country comprises several biomes, thus having a wide range of climate, vegetation, and management regimes. In this study, we used the biome classification developed by the South African National Biodiversity Institute (SANBI). South Africa has nine biomes: Fynbos, Succulent Karoo, Desert, Nama-Karoo, Grassland, Savanna, Albany Thicket, Indian Ocean Coastal Belt, and Forest. However, for this study we focused on three, namely Grassland, Savanna, and Nama-Karoo (Figure 1).

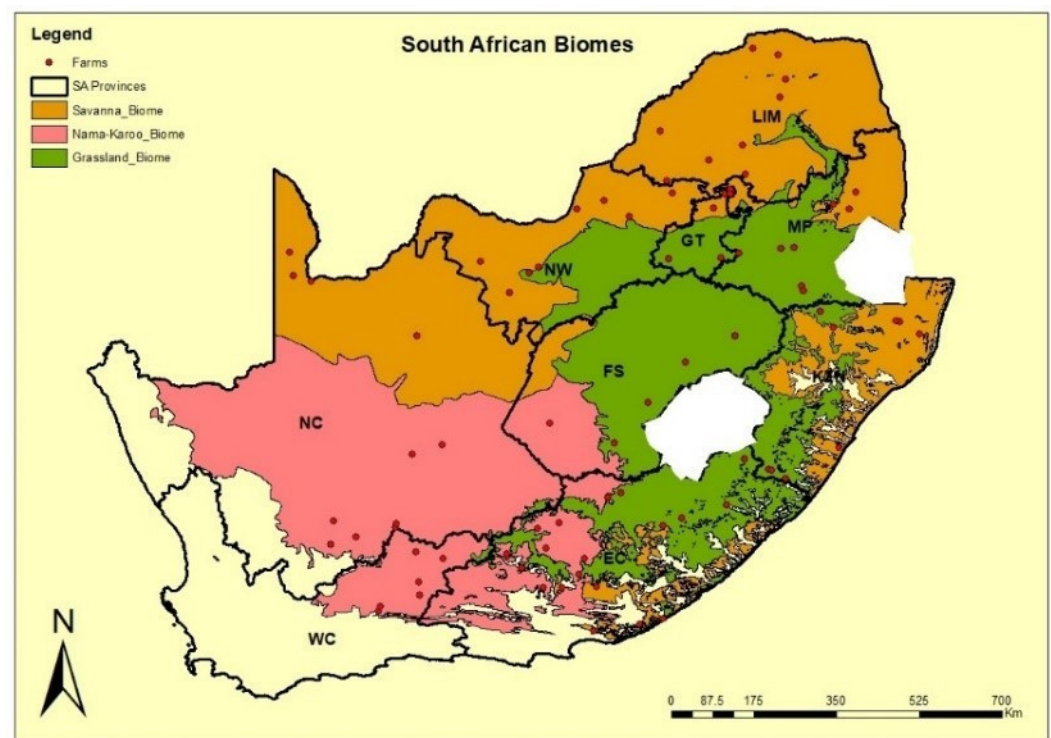


Figure 1. A map of South Africa showing the research sites in the three different biomes and provinces (WC = Western Cape, NC = Northern Cape, EC = Eastern Cape, FS = Free State, LIM = Limpopo, GT = Gauteng, MP = Mpumalanga, KZN = Kwa-Zulu Natal, NW = North West).

These are the largest biomes and represent 85% of available rangelands in South Africa (DALLRD, National Veld Management Strategy, 2025). The number of survey sites in these biomes were Savanna ($n = 35$), Grassland ($n = 20$), and Nama-Karoo ($n = 30$), with a total of

85 sites. The number of sites in each biome was determined by ecological representativeness (biome size). These biomes range from arid, in the west, to humid subtropical in the north and east, while much of the central part of southern Africa is classified as semi-arid and the southwest as Mediterranean. South Africa receives winter rainfall in the southwestern part and summer rainfall in other parts of the country [30]. Figure 2 shows the yearly rainfall pattern over South Africa during the 2020–2022 period.

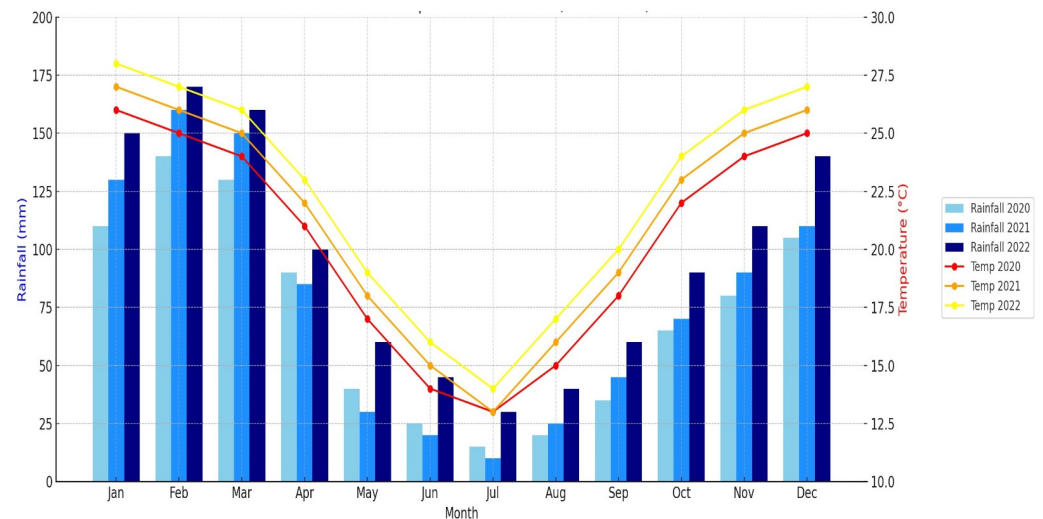


Figure 2. Thermo-rainfall graph illustrating monthly variations in rainfall (mm) and average temperature (°C) across the summer rainfall regions of South Africa for the years 2020–2022. Rainfall data is represented by grouped bars for each year, while temperature trends are shown with line graphs. The graph highlights seasonal climatic patterns, with peak rainfall occurring in the summer months (January–March, December) and lowest values during winter (June–August), while temperatures follow a similar annual cycle with higher values in summer and lower values in winter.

2.2. Data Collection

2.2.1. Farmer Surveys

In-person, interviews were conducted with 85 farmers in the different rangeland areas across the three biomes in South Africa. The selection process involved multiple stakeholders (i.e., agricultural extension officers, researchers, retired scientists, etc.) who were working closely with the farmers in the respective provinces. These stakeholders were provided with a selection criterion and identified the champion farmers in their regions. A champion farmer is referred to as “a passionate farmer who keeps multi-generation livestock and possesses adaptive rangeland management knowledge and skills, which they have developed through trial and error over time, and are resilient to various shocks” [31]. The farmers interviewed represented different livestock farming enterprises (large and small stock) and the different production systems (small-scale and commercial) and land tenure systems (private, communal, land reform with/without a title deed). Figure 3 shows a summary of how the research was designed and its procedures.

Before the commencement of the interviews, the background and aim of the project were explained to all the participants, upon which farmers gave their voluntary consent to be interviewed by signing a consent form. This study was conducted in accordance with the ethical standards of the Protection of Personal Information (POPIA) Act 4 of 2013 and approved by of University of the Western Cape Ethics Committee (Ethics Number: HS20/10/27). This study was conducted from January 2020 to December 2022.

Farmers were interviewed using a semi-structured questionnaire consisting of questions relating to (1) their perceptions of the condition of their rangelands; (2) their current

grazing capacity and current stocking rate; (3) their views on the long-term grazing capacity norms of their area; and (4) the types of degradation that occur on their farms.

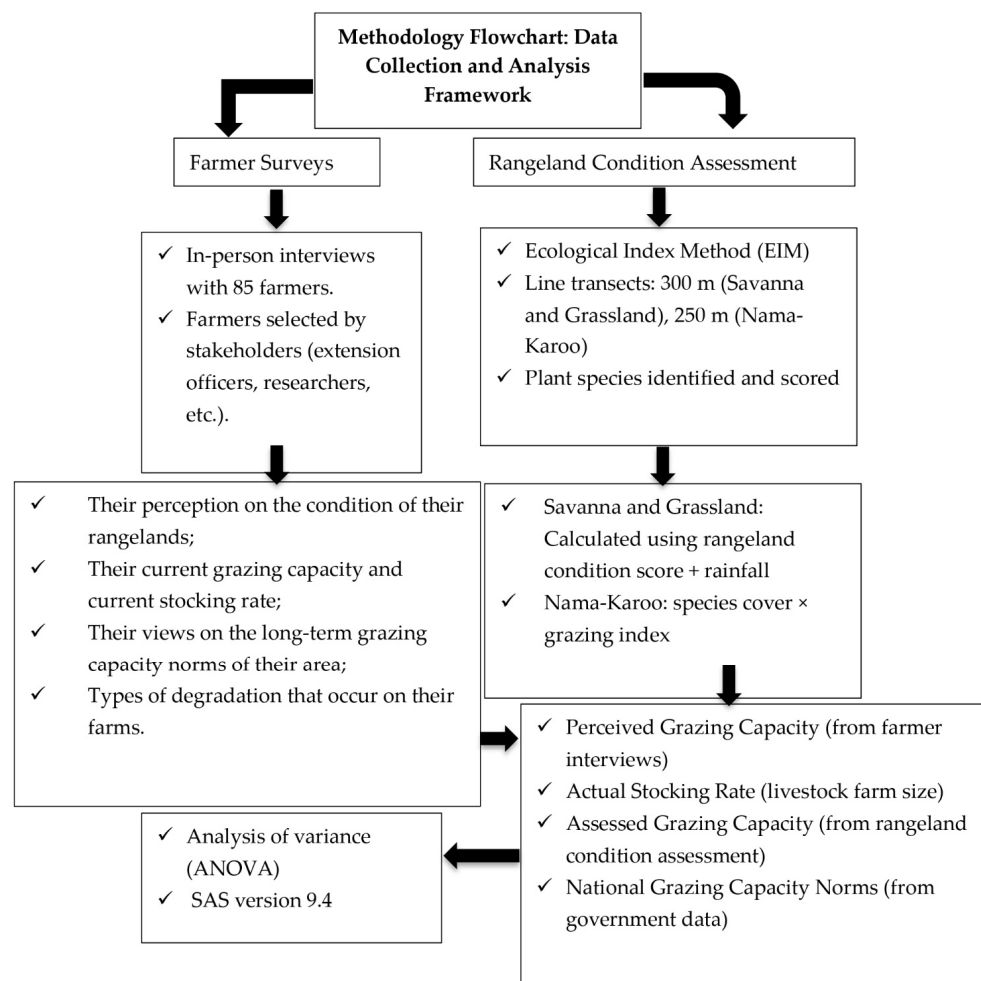


Figure 3. Flow chart of the key components of the research design and procedures. Source: Authors' own analysis.

2.2.2. Rangeland Condition Assessment

The rangeland condition score was determined using the Ecological Index Method (EIM) as described in [32]. The EIM comprises the identification of grasses, typically at 1 m intervals, with each species being categorized into an ecological group based on its ecological characteristics. At each study site, line transects of 300 m (Savanna and Grassland) and 250 m (Nama-Karoo) were laid at different points to determine the plant species composition. One plant species at or nearest to the pointer (spike) was identified and recorded. If the pointer or spike hit the ground, the nearest plant was identified and recorded. The ecological category and corresponding multiplier for each identified grass species were used to calculate the rangeland condition score [33]. The top 10 most abundant plant species formed part of the overall plant species composition at each surveyed site.

2.2.3. Grazing Capacity

The grazing capacity of the selected sites in the Savanna and Grassland biomes was calculated using the following formula [34]:

$$GC = (-0.03) + (0.00289) (X1) + (X2 - 419.7) (0.000633).$$

GC = Grazing capacity in large animal units per hectare.

X1 = Rangeland condition score as a percentage of a benchmark site's rangeland condition score.

X2 = Mean annual rainfall (mm).

Grazing capacity for the Nama-Karoo selected sites is calculated using the method developed for Karoo rangelands. The cover value (%) for each plant species per line transect is multiplied by the “objective grazing index value” for that plant species to obtain a rangeland condition score. The sum of the rangeland condition scores is then used to calculate the grazing capacity for each transect using the following formula: $\times 7.14$. The 550 is the benchmark rangeland condition index, and 7.14 is a factor describing the linear relationship between grazing capacity for the site in hectares per large stock unit (ha LSU–1) and rangeland condition scores.

Grazing capacities using four different metrics were assessed as follows:

- (i) Perceived Grazing Capacity (GC) = the farmer's own perception of the farm's grazing capacity based on his local ecological and farming knowledge. This was performed using a semi-structured questionnaire.
- (ii) Actual stocking rate of the land = the stocking rate the farmer is applying on the farm. This was determined through the questionnaire by considering the number of livestock the farmers owned and the size of the farm/farming area.
- (iii) Assessed GC = the grazing capacity derived from the rangeland condition assessment (see above for formulas used).
- (iv) The long-term GC norm = the department grazing capacity norms for the area according to the government [19] (Figure 4).

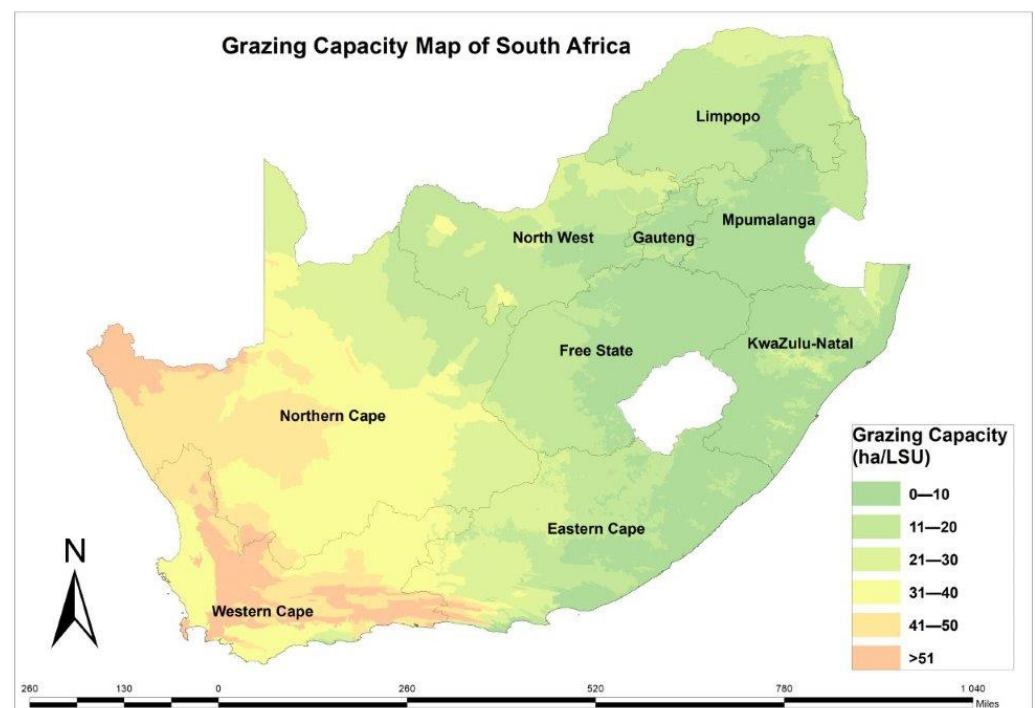


Figure 4. Livestock grazing capacity (ha/LSU) map of South Africa. Reprinted with permission from [19]. Copyright 2017, Department of Agriculture, Forestry and Fisheries.

2.3. Data Analysis

The rangeland condition parameter data was subjected to an analysis of variance (ANOVA). Shapiro–Wilk's test was performed on the standardized residuals to test for de-

viations from normality. In cases where significant deviation from normality was observed due to skewness, outliers were removed until it was normal or symmetrically distributed. Student's t-LSDs (least significant differences) were calculated at a 5% significance level to compare the means of significant source effects. All analyses were performed using SAS statistical software version 9.4 [35].

3. Results

3.1. Farmers' Perceptions of Rangeland Conditions

Regarding farmers' perceptions of the rangeland conditions, their views on the long-term grazing capacity norms, and the types of land degradation that occur on their farms, the results varied widely within the three biomes (Table 1). In the Grassland biome, 50% of the farmers perceived their rangeland condition as good, while 35% rated it as poor. In contrast, the Savanna biome was predominantly rated as moderate (57.1%). The majority (>60%) of the farmers in the Nama-Karoo rated their rangelands to be in poor condition while only 10% rated it as good.

Table 1. Farmers' perceptions of the rangeland conditions, their views on the long-term grazing capacity norms of their area, and the types of land degradation that occur on their farms.

Parameter	Grassland (n = 20)	Savanna (n = 35)	Nama-Karoo (n = 30)
Perceptions of Rangeland Condition			
Good (%)	50.0	28.6	10.0
Moderate (%)	15.0	57.1	23.33
Bad (%)	35.0	14.3	66.67
Agreement with Long-term Grazing Capacity Norms			
Yes (%)	75.0	71.43	60.0
No (%)	25.0	28.57	40.0
Type of Land Degradation			
Soil erosion (%)	25.0	5.71	33.33
Loss of vegetation cover (%)	90.0	28.57	83.33
Bush encroachment (%)	25.0	57.14	16.67
Plant species change (%)	50.0	51.43	60.0
Biomass decline (%)	75.0	71.43	51.43

Loss of vegetation cover accounted for 67% and biomass declined by 65%, and the two forms of degradation were the most cited as affecting the perceived rangeland condition across all the biomes. In the Grassland biome, >90% of the farmers indicated loss of vegetation cover, whilst in the Savanna biome, biomass decline was reported to be the highest (>70%), followed by bush encroachment. In the Nama-Karoo, loss of vegetation cover (>80%) followed by plant species change from palatable to unpalatable (60%) were rated as the highest rangeland degradation challenges faced by livestock farmers.

Across all the biomes, 68% of the farmers agreed with the long-term grazing capacity norms prescribed by the Department of Agriculture (DoA), while 32% of the farmers did not agree with the grazing capacity norms, stating reasons such as long-term experience and generational knowledge of their rangelands, which often contradicted the prescribed norms. Some of the reasons were that regulations were not consistently enforced or that there was no clear incentive or support to comply, and there was economic pressure, with participants expressing that the norms were impractical and unaffordable to follow. These are not statistical results per se but rather explanatory feedback from farmers on why they do not follow grazing capacity norms.

3.2. Plant Species Composition

The results for the most dominant 10 plant species in the three biomes are presented in Table 2. In the Grassland biome, all the dominating plants were grasses, with *Eragrostis chloromelas* (30.37%), followed by *Themeda triandra* (20.73%). In the Savanna biome, all the dominating plants were also grasses, with *Digitaria eriantha* (30%), followed by *Melinis repens* (24.8%) as the most abundant species. In the Nama-Karoo biome, plant species composition was made up of grasses and shrubs, which is typical of the Karoo. The most abundant species was *Stipagrostis obtusa* (grass) (34%) followed by *Pentzia incana* (shrub) (27%), with high and moderate grazing value, respectively.

Table 2. Plant species composition for the (A) Grassland, (B) Savanna, and (C) Nama-Karoo. Plant species and plant characteristics (life form, family, palatability (following and abundance)).

Biome	Plant Species	Life Form	Family	Palatability	Abundance (%)
Grassland	<i>Eragrostis chloromelas</i> Steud.	Grass	Poaceae	Moderate	30.37
	<i>Themeda triandra</i> Forssk.	Grass	Poaceae	High	20.73
	<i>Eragrostis plana</i> Nees	Grass	Poaceae	Low	12.10
	<i>Eragrostis curvula</i> (Schrud.) Nees	Grass	Poaceae	High	8.41
	<i>Cynodon dactylon</i> (L.) Pers.	Grass	Poaceae	High	7.12
	<i>Tristachya leucothrix</i> Trin. ex Nees	Grass	Poaceae	Moderate	6.92
	<i>Elionurus muticus</i> (Spreng.) Kunth	Grass	Poaceae	Low	5.68
	<i>Setaria sphacelata</i> (Schumach.) Stapf & C.E.Hubb. var. <i>sphacelata</i>	Grass	Poaceae	High	5.51
	<i>Heteropogon contortus</i> (L.) Roem. & Schult.	Grass	Poaceae	Moderate	4.25
	<i>Aristida congesta</i> Roem. & Schult. subsp. <i>congesta</i>	Grass	Poaceae	Low	1.65
Savanna	<i>Digitaria eriantha</i> Steud.	Grass	Poaceae	High	30.00
	<i>Melinis repens</i> (Willd.) Zizka subsp. <i>repens</i>	Grass	Poaceae	Low	24.80
	<i>Aristida congesta</i> Roem. & Schult. subsp. <i>congesta</i>	Grass	Poaceae	Low	21.40
	<i>Themeda triandra</i> Forssk.	Grass	Poaceae	High	15.60
	<i>Cynodon dactylon</i> (L.) Pers.	Grass	Poaceae	High	14.80
	<i>Megathyrsus maximus</i> (Jacq.) Hyparrhenia <i>hirta</i> (L.) Stapf	Grass	Poaceae	High	10.21
	<i>Cymbopogon pospischilii</i> (K.Schum.) C.E.Hubb	Grass	Poaceae	Low	8.80
	<i>Cymbopogon pospischilii</i> (K.Schum.) C.E.Hubb	Grass	Poaceae	Low	7.52
	<i>Heteropogon contortus</i> (L.) Roem. & Schult.	Grass	Poaceae	Moderate	6.90
	<i>Trachypogon spicatus</i> (L.f.) Kuntze	Grass	Poaceae	Low	5.41
Nama-Karoo	<i>Stipagrostis obtusa</i> (Delile) Nees	Grass	Poaceae	High	34.6
	<i>Pentzia incana</i> (Thunb.) Kuntze	Shrub	Asteraceae	Moderate	27.6
	<i>Eragrostis chloromelas</i> Steud.	Grass	Poaceae	Moderate	15.2
	<i>Ruschia spinosa</i> (L.) Dehn.	Shrub	Aizoaceae	Moderate	10.8
	<i>Tragus berteronianus</i> Schult.	Grass	Poaceae	Low	7.8
	<i>Aristida congesta</i> Roem. & Schult. subsp. <i>congesta</i>	Grass	Poaceae	Low	6.9
	<i>Eragrostis curvula</i> (Schrud.) Nees	Grass	Poaceae	High	6.4
	<i>Asparagus burchellii</i> Baker	Shrub	Asparagaceae	Low	5.6
	<i>Stipagrostis ciliata</i> (Desf.) De Winter var. <i>capensis</i> (Thunb.) De Winter	Grass	Poaceae	High	4.5
	<i>Galenia fruticosa</i> (L.f.) Sond.	Shrub	Aizoaceae	Moderate	3.9

3.3. Rangeland Condition Scores for the Biomes and Different Tenure Systems

In the Grassland biome, all the three land tenure systems had a similar rangeland condition score ($\pm 52\%$), which indicates moderate conditions across the biome, and no significant differences ($p < 0.05$). In the Savanna biome, communal and land reform tenures had similar rangeland condition scores ($\pm 51\%$), which indicates moderate conditions, and private tenure had a good rangeland score ($\pm 63\%$); however, no significant differences were found between the land tenures ($p < 0.05$). In the Nama-Karoo, the rangeland condition score for communal systems was very poor (19%), and significantly different ($p > 0.05$) from land reform and private systems which had poor rangeland conditions ($\pm 35\%$) (Figure 5).

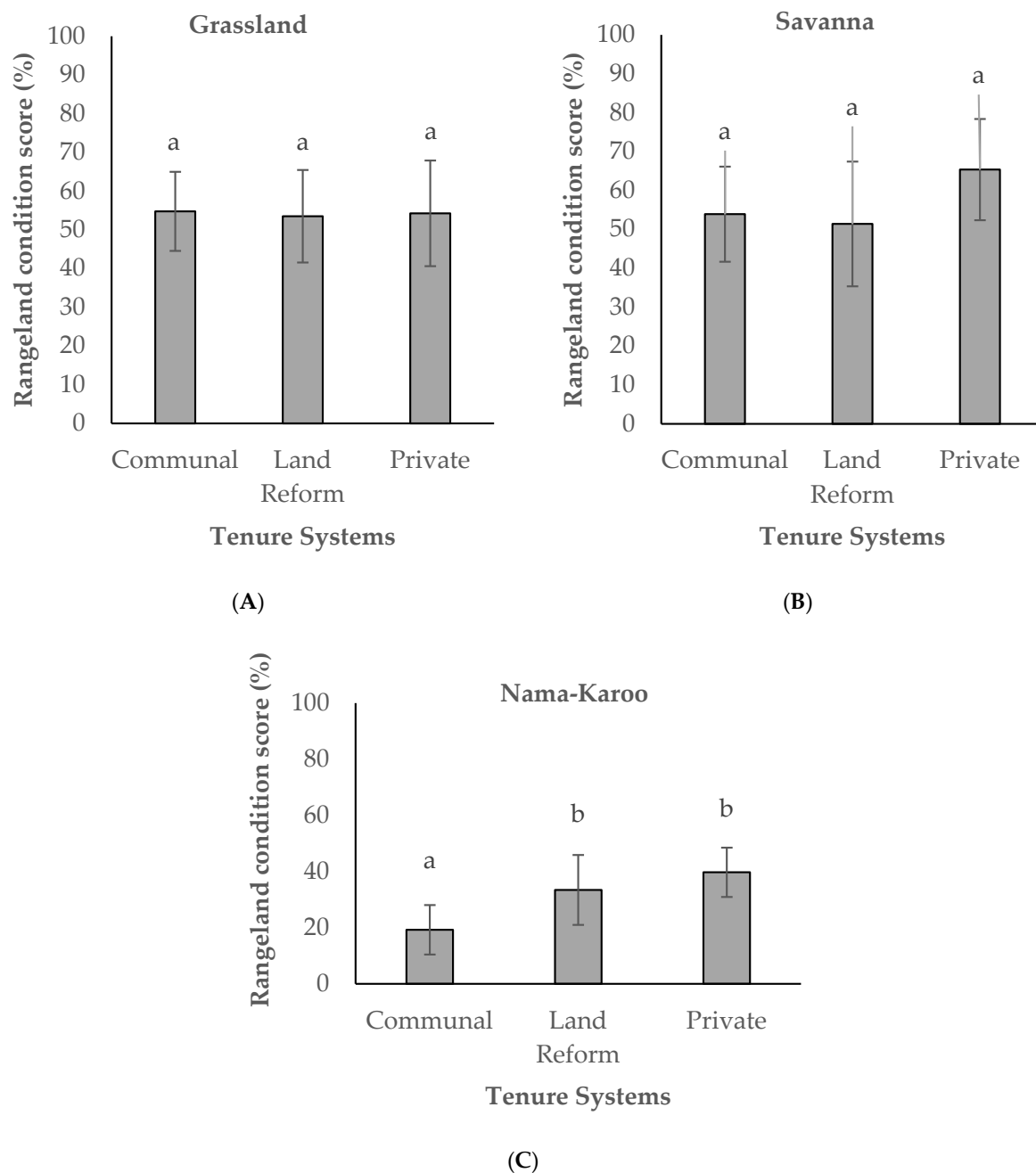


Figure 5. The average rangeland condition scores (%) across sites in the different tenure systems (communal, land reform, and private) compared across the three biomes: Grassland (A), Savanna (B), and Nama-Karoo (C). Different superscripts (a, b) indicate statistically significant differences ($p < 0.05$). Error bars represent the standard error.

3.4. Grazing Capacities for the Different Tenure Systems and Comparisons of the Grazing Capacities for the Different Biomes

The grazing capacities (ha/LSU) assessed in the field across the different tenure systems (communal, land reform, and private) were compared within the three biomes: Grassland (A), Savanna (B), and Nama-Karoo (C) (Figure 6). In the Grassland biome, the Department of Agriculture grazing capacity norm was significantly less than the assessed grazing capacity under communal tenure ($p < 0.05$). There were no significant differences between land tenure types in terms of grazing capacities in the Savanna biome ($p > 0.05$). In the Nama-Karoo, assessed grazing capacity was significantly different between land tenures ($p < 0.05$). The lack of significant differences among tenure systems within the Savanna biome suggests that land tenure type did not influence grazing capacity.

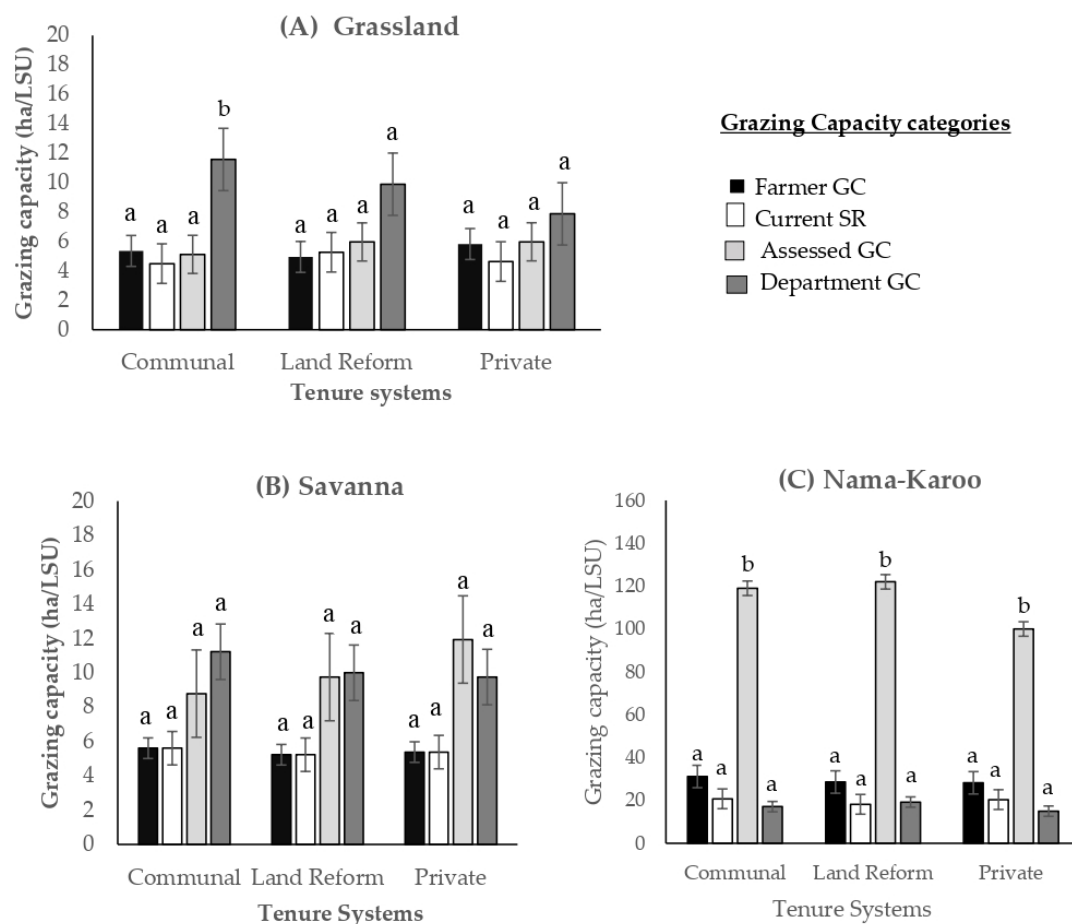


Figure 6. The average grazing capacities (ha/LSU) across sites in the different tenure systems (communal, land reform, and private) compared across the three biomes: Grassland (A), Savanna (B), and Nama-Karoo (C). Different superscripts (a, b) indicate statistically significant differences ($p < 0.05$). Error bars represent the standard error.

No significant differences in grazing capacity were found within the Grassland and Savanna biomes ($p > 0.05$) (Table 3). However, there were significant differences observed in the Nama-Karoo biome ($p < 0.05$). The farmers' current (the actual stocking rate at the time based on animal numbers) and department grazing capacities were not significantly different for the Grassland and Savanna biomes but the assessed grazing capacity was different for the three. In the Nama-Karoo, one Large Stock Unit (LSU) requires a grazing capacity of 116 ha/LSU, which is four-fold lower than what the department recommends.

Table 3. The comparison of the four grazing capacity indices within each biome. Values are mean $\pm$ standard error. Different superscripts (a, b) indicate statistically significant differences. GC = grazing capacity.

Biome	Farmer GC	Current SR	Assessed GC	Department GC
Grassland	5.26 $\pm$ 0.37 ^a	4.87 $\pm$ 0.47 ^a	6.53 $\pm$ 0.97 ^a	10.15 $\pm$ 0.79 ^a
Savanna	6.35 $\pm$ 0.77 ^a	6.37 $\pm$ 0.69 ^a	9.75 $\pm$ 0.95 ^a	10.50 $\pm$ 0.60 ^a
Nama-Karoo	30.7 $\pm$ 2.36 ^a	19.90 $\pm$ 1.98 ^a	116.3 $\pm$ 6.13 ^b	30.1 $\pm$ 0.93 ^a

4. Discussion

One way of studying the condition of rangelands is through interviewing farmers/landowners who have knowledge of their rangeland ecosystem. This can be combined with ecological approaches to assess rangelands, enhancing our understanding of ecosystem, functioning, and aiding the development of grazing capacities for different vegetation types. Our results showed that the rangeland conditions in the Grassland and Savanna biomes are generally perceived to be moderate to good condition by the farmers. This is irrespective of the fact that the two biomes received a drought a few years prior [36]. Thus, this indicates that according to the farmers, both biomes displayed ecosystem resilience, and they bounced back to long term average conditions. However, it should also be noted that the duration of the drought event might have been short enough for vegetation to recover following substantial rain. It might also be that effective rangeland management practices implemented by these champion farmers likely also contributed significantly to the observed recovery and overall resilience of the rangelands.

In contrast, the Nama-Karoo biome had the highest proportion (>60%) of farmers rating their rangeland condition as poor, with only 10% rating it as good. These results are in line with those of [37] that the Karoo is recognized as a drought-prone region, which experienced several severe droughts events between 1926 and 1933 [38] and the recent drought of 2015–2019. Drought is known to significantly degrade rangeland conditions through increased plant mortality and reduced forage quality [37].

The loss of vegetation cover and decline in biomass are the leading degradation indicators across all the biomes. These findings align with global studies on rangeland degradation [39], which indicate declining vegetation cover as one of the leading challenges. Although climate is a key driver of vegetation change, when combined with poor rangeland management practices such as overgrazing, this can lead to a reduction in vegetation cover and increasing mortality in vulnerable plant species [40]. The loss of vegetation cover is particularly concerning, especially in a country like South Africa, where large portions of the country fall within semi-arid and arid climatic zones. In such environments, vegetation recovery is slow due to extreme temperature and variable rainfall, further accelerating land degradation and declines in rangeland productivity.

In general, grass species dominated the plant compositions in both the Grassland and Savanna biomes, with species from the Poaceae family—such as *Eragrostis chloromelas* and *Digitaria eriantha*—being particularly common. These grasses are well adapted to seasonal rainfall patterns and grazing pressures typical of mesic to semi-arid environments [41]. In contrast, the Nama-Karoo biome had a more heterogeneous vegetation structure, comprising a mix of drought-tolerant grasses and woody shrubs, including species such as *Stipagrostis obtusa*, *Pentzia incana*, and *Ruschia spinosa*. This mixed composition is a typical characteristic of arid regions, where low and erratic rainfall, coupled with high evapotranspiration, promotes the dominance of xerophytic shrubs alongside sparse grass cover.

In general, results further show that >60% of the champion farmers follow the grazing capacity norms as set out by the Department of Agriculture (DoA), suggesting a relatively high level of compliance and awareness of sustainable rangeland management practices in

these biomes. Similar findings were reported by [21], who found that over 50% of the land reform livestock farmers in the Bloemfontein Grassland follow the grazing capacity norms recommended by the DoA. These findings suggest that most champion farmers recognize the importance of sustainable grazing management, even though compliance with these norms is strongly influenced by economic and climatic constraints.

Although it is often assumed that a communal tenure system is associated with poor rangeland management practices such as overgrazing, the results of this study challenge this generalization and the tenets of “the tragedy of the Commons” paradigm [42]. Across the Grassland and Savanna biomes, there were no statistically significant differences in farmer GC, current SR, and assessed GC between tenure systems (communal, land reform, and private). Only the department-recommended grazing capacity was significantly different in the Grassland under the communal system. For instance, in the Grassland and Savanna biomes, communal farms achieved similar grazing capacity outcomes to private farms, suggesting that some communal systems can maintain acceptable grazing conditions when management practices are appropriate. This also means that champion livestock farmers across biomes and land tenures share similar principles and attributes [18], hence having similarities in grazing capacities.

The results regarding the land tenure indicate that multiple tenure systems can support sustainable rangeland outcomes when matched with suitable management strategies. These findings support arguments such as [43], who contend that communal systems are not inherently unsustainable, and that outcomes are context-dependent and influenced by local institutions, collective action, and adaptive practices.

Interestingly, in the Nama-Karoo biome, our findings reveal that the assessed grazing capacity is lower than the other three grazing capacity indices. The assessed grazing capacity was four-fold lower than the recommended grazing capacity norm of the Department of Agriculture. The assessed grazing capacity indicated that droughts significantly impacted the Nama-Karoo biome—a semi-arid region characterized by low rainfall and predominantly shrubland vegetation. This impact was primarily due to reduced vegetation cover (which was highlighted as one of the degradation issues facing the biome), leading to a decline in forage available for livestock [44]. Champion farmers in the Nama-Karoo stock their farms with less than the department-recommended grazing capacity norms, which is a good indication as this limits chances of long-term ecological consequences, including vegetation change, degradation, and soil erosion.

The Grassland and Savanna biomes received moderate and good rangeland condition scores across the different tenure systems, whereas the Nama-Karoo biome had poor rangeland condition scores across the three tenures. This variation in rangeland condition scores was expected, as these biomes are very different in terms of vegetation structure, climate, and drought susceptibility. A study in the Savanna biome near Kuruman revealed that communal farms’ stocking rates were similar to those of commercial farms [45]. This suggests that although the communal areas might not have proper infrastructure, including fences and water points, they have good grazing practices which involve tacit and formalized technical knowledge that can be described and modeled [46]. Moreover, the Grassland and Savanna ecosystems are dominated by species that are better adapted to recover from grazing and episodic drought events, thereby enhancing forage availability and maintaining rangeland conditions. Rangelands in the Grassland and Savanna exhibit a high degree of resilience to drought due to factors like evolutionary adaptations, plant functional types, and grazing management practices. While severe droughts can impact these ecosystems, many have the capacity to recover, although recovery times can vary. In the Nama-Karoo, the assessed requirement of 116 ha/LSU is four times greater than the departmental recommendation, reflecting the harsh impact of drought on forage avail-

ability. This underscores the importance of site-specific, drought-adjusted assessments in arid biomes.

Rangelands are inherently variable systems, characterized by fluctuations in climatic conditions, forage availability, and ecological responses. Our findings emphasize the importance of adopting flexible and adaptive management strategies that align with this environment variability. These principles are applicable to other rangeland systems with similar ecological dynamics, such as those in southern and northern Africa, South America, and Australia, where grazing is also a dominant form of land use. Similar conclusions have been drawn in studies from arid and semi-arid rangelands in Australia (e.g., [47]) and South America [48], where adaptive management has been promoted as a means to build resilience under variable rainfall regimes. These examples support the broader relevance of our findings. However, the extent and characteristics of farmers' responses to this variability will have to be adapted to their current socio-economic and local environmental conditions.

5. Conclusions

This study concluded that rangeland conditions across the Grassland, Savanna, and Nama-Karoo highlight significant variability in grazing capacities driven by differences in perceptions, actual stocking rates, vegetation patterns, and grazing management practices. These differences underscore the complexity of managing variable rangelands, where ecological and socio-economic factors intersect to shape land use outcomes. Consequently, region-specific monitoring and adaptive management strategies are essential to ensure sustainable grazing practices and the long-term resilience of these rangeland ecosystems.

Prevalent degradation indicators in the three biomes emphasize the urgent need for improved rangeland management strategies, including adaptive grazing systems and policies. Drought conditions often result in the decline of palatable and productive species, favoring the proliferation of drought-tolerant, unpalatable, or invasive species, thereby increasing grazing capacities and reducing forage quality for livestock. These shifts not only compromise the ecological integrity of rangelands but also threaten the livelihoods of communities dependent on the rangelands, as they reduce grazing capacities.

Given the high inter-annual variability in rainfall, differences in perceptions based on local knowledge, and the vegetation productivity of arid regions, it is recommended that the Department of Agriculture adopt flexible grazing capacity ranges in their guidelines. These ranges should be responsive to prevailing climatic conditions, particularly drought, rather than relying on fixed grazing capacity values that may not reflect temporal and spatial fluctuations in forage availability. To this end, research should prioritize long-term monitoring of the drivers of grazing capacity such as drought, livestock impacts, and livestock practices. We acknowledge that we did not conduct a chemical composition analysis to determine the quality of the plant species. This is a valuable consideration and will be explored in future studies to provide a more comprehensive assessment of rangeland conditions.

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Data Availability Statement: Data for this study is kept for privacy issues as it includes detailed information about where the farms are located.

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