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Communication

Multifunctional Rangeland in Southern Africa: Managing for Production, Conservation, and Resilience with Fire and Grazing

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Abstract: Residents of Southern Africa depend on rangeland for food, livelihoods, and ecosystem services. Sustainable management of rangeland ecosystems requires attention to interactive effects of fire and grazing in a changing climate. It is essential to compare rangeland responses to fire and grazing across space and through time to understand the effects of rangeland management practices on biodiversity and ecosystem services in an era of global climate change. We propose a paradigm of ecologically-analogous rangeland management within the context of multifunctional landscapes to guide design and application of ecosystem-based rangeland research in Southern Africa. We synthesize range science from the North American Great Plains and Southern African savannas into a proposal for fire and grazing research on rangeland in Southern Africa. We discuss how management for the fire-grazing interaction might advance multiple goals including agricultural productivity, biodiversity conservation, and resilience to increased variability under global change. Finally, we discuss several ecological and social issues important to the effective development of sustainable rangeland practices especially within the context of global climate change. The associated literature review serves as a comprehensive bibliography for sustainable rangeland management and development across the savanna biomes of Southern Africa.

Keywords: fire-grazing interaction; pyric-herbivory in Africa; patch burn-grazing; sustainable development; veld management

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1. Introduction

Rangelands worldwide constitute the largest human-impacted biome [1]. In Southern Africa, gaps in the conservation reserve network [2] leave the region's rangeland particularly under-represented in formally protected areas [3,4]. Remaining rangeland in the region is threatened by unsustainable land use [5], specifically overgrazing, mining, plantation forestry, and conversion to cropland [3,6–9].

Livestock grazing has been widely implicated in the degradation of rangeland ecosystems [10–12]. As such, rangeland managers have long sought to perfect strategies that maximize agricultural production with minimal impact on natural resources. Following the conventional wisdom that wise use constitutes an even distribution of grazing pressure and complete forage utilization (e.g., [13]**)**, many management schemes strive for spatially-homogeneous grazing to prevent overgrazing of preferred patches within inherently variable rangelands [14,15]. The result has been the prolific use of rotational grazing schemes across Southern African rangelands [16], but this approach has been criticized by rangeland ecologists [17].

Although sustainable rangeland management clearly requires ecologically-sound strategies, few managers are confident that the ecology of rangeland in Southern Africa is sufficiently understood, especially within the context of balancing sustainable rangeland management with rural livelihoods. This paper is a direct response to O'Connor *et al.* [4], who identified knowledge gaps in the response of floristic diversity to fire and grazing in Southern African rangeland.

We suggest that ecologically-analogous management that replicates the natural disturbance pattern of fire and grazing might contribute to the restoration and conservation of Southern African rangeland. The ecological interaction of fire and grazing—known broadly as pyric-herbivory [18] but referred to as patch burn-grazing in the context of management [19]—has been shown to increase rangeland biodiversity in the North American Great Plains [20–22]. While previous research has established clear links between rangeland ecosystems in Southern Africa and the Great Plains [23–26] and evidence of the fire-grazing interaction has been documented in Africa [27,28], no studies have yet explicitly tested patch burn-grazing in Southern Africa despite calls for such work in the region [29].

We propose to test the effectiveness of patch burn-grazing as an ecologically-analogous range management practice in Southern Africa. However, despite the connections made between Southern African rangeland and the North American rangeland on which patch burn-grazing has principally been developed, important differences must be considered lest poor management decisions outpace research and evaluation. In this paper, we describe potential limitations, specific advantages, and other considerations of fire and grazing management ahead of initiating field studies along several ecological and socio-economic gradients that span savanna and grassland ecosystems of Southern Africa.

2. Challenging Conventional Assumptions of Range Management

Despite conventional wisdom that implicates livestock grazing in rangeland degradation, both the relative contribution of livestock to vegetation changes and the nature of livestock-induced changes are debated [30]. Three elements of the livestock–range degradation issue have been raised:

Firstly, non-equilibrium theory has largely replaced classical equilibrium theories of range management. Three elements of the equilibrium range model include (1) vegetation dynamics occur along a continuous successional gradient, (2) grazing works to counteract secondary succession, and (3) changes in plant communities are reversible and proceed linearly along the same gradient [31,32]. In general, non-equilibrium theory accounts for discontinuous vegetation changes: plant communities assemble into states defined by thresholds, and transitions between states can follow different pathways depending on the direction of change (hysteresis) [32–35]. In African pastoral ecosystems, non-equilibrium theory posits that vegetation dynamics are controlled as much—if not more than—by abiotic than biotic factors [36,37], which suggests that the impact of grazing by both wild and domesticated herbivores is a function of both manageable biotic factors (e.g., stocking rate) and abiotic factors (e.g., spatio-temporal precipitation patterns) [38,39].

Secondly, both the severity and irreversibility of vegetation changes brought by grazing has been called into question [40,41]. Although non-equilibrium theory accounts for discontinuous transitions between vegetation states, not all state shifts are irreversible [42]. Grazing can alter the relative abundance of plants at the community level without negative impacts on native species richness [43], and grazing suppression can negatively affect ecosystems with an evolutionary history of grazing [26,44]. However, system productivity, herbivore characteristics, and spatial scale are important considerations for predicting the effect of grazing on vegetation dynamics [45,46]. Prescribing management across the diverse rangeland of Southern Africa requires that grazing be understood not as a singular disturbance, but rather as a disturbance gradient along which the nature and intensity with respect to ecosystem productivity combine to determine severity and ecosystem effects (e.g., [47]).

Thirdly, degradation is a normative concept and evaluation often does not consider alternative management objectives. For example, non-equilibrium rangeland might include alternative stable states resilient against heavy grazing in communal areas but considered degraded by commercial grazing standards based solely on species composition [30]. In some cases alternative states are actually more productive [48]. When scrutinized with these considerations in mind, rotational grazing schemes have not been found to increase animal production or protect rangeland from degradation any more than continuous grazing without fences and intensive management [17,49].

If rangeland vegetation dynamics are in fact controlled by abiotic variables as much or more than by the stocking decisions of individual managers, grazing management schemes should consider ecological factors to determine the spatial and temporal pattern of grazing.

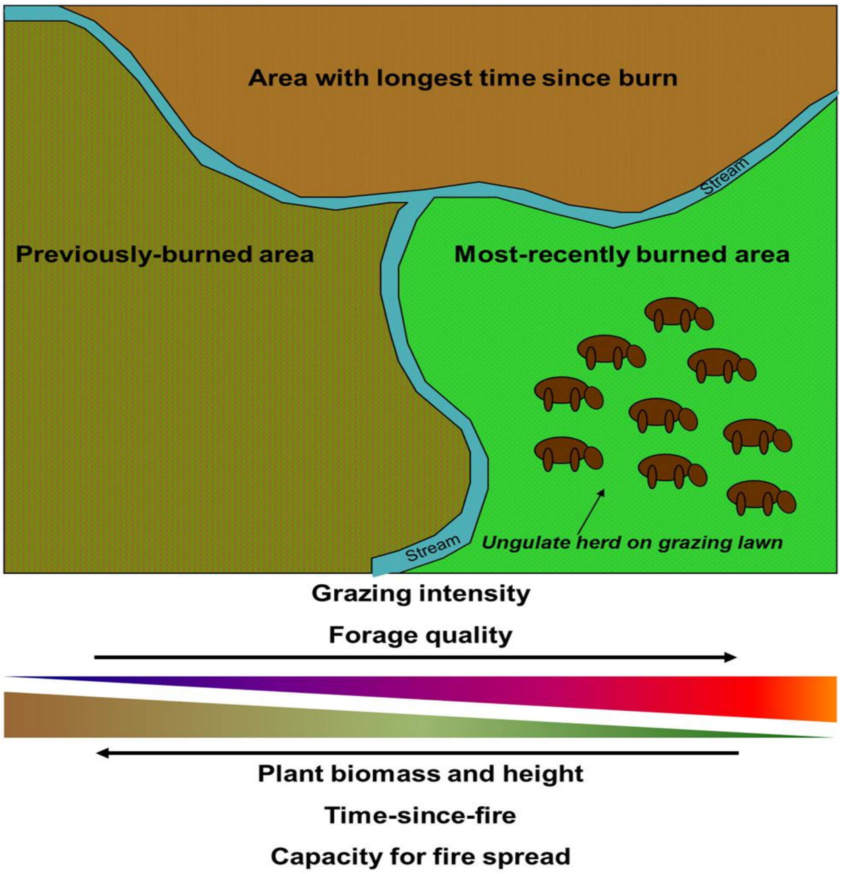
3. Ecological Analogy and Heterogeneity in Multifunctional Landscapes

The conception that land has a single use—e.g., production, preservation, or residence—is changing. A new paradigm holds that landscapes are multifunctional [50,51], with various uses described along a gradient from low-intensity (e.g., wilderness and reserves) to high-intensity uses (e.g., farms, mines, and cities). Rangeland landscapes are working landscapes, in which the “wild and the willed” [52] are reconciled and land is managed for both production and conservation [53]. Concepts of working and multifunctional landscapes have been applied throughout Southern Africa [29,51,54].

3.1. Patch Burn-Grazing as Ecological Analogy

Many rangelands worldwide have evolved under the interaction of fire and grazing, known as pyric-herbivory [18,20]. Pyric-herbivory is the ecological disturbance realized when the spatial pattern of grazing follows the spatial pattern of fire [55], which creates a heterogeneous landscape of plant communities and habitat types (Figure 1) and enhances rangeland biodiversity [19,56,57]. Patch burn-grazing is a management technique in which specific patches—defined by man-made barriers to fire spread—of a ranch or conservation area are intentionally burned to create a green flush of high-quality forage for either domestic livestock or native herbivores [18–20]. This magnet effect [28] creates a grazing lawn [58] of low-stature, high-quality forage that concentrates grazing activity. The grazing lawn contrasts with taller, lower-quality stands that are generally avoided by grazers, creating a deterrent effect [19]. Conventional rangeland managers aim for the even consumption of forage across grazing areas [13], but homogeneity-based management has been shown to decrease habitat quality for many rangeland species [8,57]. Thus, by mimicking the heterogeneous, shifting mosaic under which Southern African grasslands and savannas evolved, patch burn-grazing is an example of ecologically-analogous rangeland management.

Figure 1. A spatially- and temporally-heterogeneous landscape mosaic created by the fire-grazing interaction. Spatially-patchy fire drives the spatial distribution of grazing, causing herbivores to congregate in the most-recently-burned patch. Meanwhile, other patches in the landscape remain ungrazed and accumulate fuel, increasing their probability of burning under future ignitions. Meanwhile, the heterogeneity in vegetation structure created by patches with different time-since-fire creates a mosaic of wildlife habitat. While not all animal activity will be concentrated in the burned area because animals must move about the landscape for water, security, or micronutrients, research shows that animals select recently-burned areas more than any other resource or position in the landscape [20].



Patch burn-grazing advances both agricultural and biodiversity objectives. When rangeland is managed with fire and ecologically-appropriate stocking rates, domestic grazers such as cattle have a similar conservation value as native herbivores [59] and still produce an agricultural product. Cattle gains under patch burn-grazing are competitive with gains of cattle from rangelands not managed with fire [60], and patch burn-grazing might even reduce cattle parasite pressure [61]. Meanwhile, diversity of rangeland flora and fauna is consistently increased under effective patch burn-grazing management [18,19,21,62–64]. From an economic standpoint, the minimal infrastructure required—e.g., no internal paddock fences, fewer water points—reduces capital obligations and maintenance costs and might improve a farm's bottom line.

Although the suitability of patch burn-grazing to Southern Africa remains to be tested, it is likely that some form of spatially-heterogeneous prescribed fire management will advance ecological and economic objectives on grazed rangeland. Three themes from existing research support this position: (1) Native African ungulates clearly prefer recently-burned areas for superior forage quality [27,28,65]; (2) Spatially-heterogeneous fire regimes have been successfully applied in some major conservation areas [28,66,67]; and (3) There is increased interest in fire use on economically-important private and communal rangeland in Southern Africa [29,68]. Based on this work, we propose research testing the application of patch burn-grazing as a management tool in Southern African rangelands.

Rangeland across Southern Africa is ecologically and culturally diverse, spanning several environmental and socio-economic gradients. Two key considerations between rangeland ecosystems of the North American Great Plains—where patch burn-grazing has been widely tested—and those of Southern Africa include (1) The species richness of grazers included in the respective systems, and (2) Ecological gradients such as precipitation and productivity that affect disturbance regime.

Modern North American rangelands are relatively species-poor, and most experimental locations testing patch burn-grazing featured either one native herbivore—the American bison (*Bison bison*)—or one domestic herbivore—British or Continental breeds of cattle (*Bos taurus*). Conversely, African rangelands south of the Sahara have approximately 90 herbivore species [69]. But existing research shows that a breadth of native herbivores match the spatial pattern of grazing to the spatial pattern of fire in when burns occur as patches on the landscape [28,70]. Managers across Southern Africa have sought to accommodate a breadth of herbivores—native and domestic, small and large, grazers and browsers—as a management tool to increase utilization of grazing and browsing resources, control woody plant encroachment, and diversify revenue [29,71,72].

Previous work has shown that patch burn-grazing can achieve management objectives across a precipitation gradient spanning semi-arid to mesic rangeland, so long as the spatial pattern of fire drives the spatial pattern of grazing [19,73]. Ensuring that patch burn-grazing management successfully couples fire and grazing disturbances requires attention to the appropriate spatial extent, season, and frequency of fire; appropriate stocking rates; and sensitivity to the cultural norms and economic necessities of those who rely upon Southern African rangeland for their livelihoods. The remainder of this paper describes these considerations to increase the likelihood that ecological research can make meaningful, successful contributions to rangeland management in Southern Africa.

3.2. Adapting to Global Change Requires Resilient Rangeland

Rangeland science has embraced variability and resilience in sustainable management. While early rangeland managers tried to simply match grazing to annual forage production [74,75], subsequent models account for environmental variability in semi-arid ecosystems and describe non-equilibrium relationships between climate, forage production, and grazing [37,75]. With respect to climate change, the non-equilibrium approach is particularly applicable in Southern Africa, where rangeland is inherently variable [39,76].

Dynamic, adaptive approaches are especially relevant in an era of global change. For example, in South Africa, the Gross Domestic Product is closely associated with climate variability [77], and rainfall has a marked effect on rangeland productivity [38]. Thus, although many Southern Africans depend on rangelands for their livelihoods, these residents are economically vulnerable to drought and climate change [78]. There is clear incentive to reduce the susceptibility of individual farmers to economic and agricultural fluctuations due to climate variability. Sustainable rangeland management seeks to understand how rangeland is affected by climate change and increase resilience to change, which at a basic level consists of matching animal numbers to available forage. However, the issue rapidly becomes more complex [79] in rangeland ecosystems with substantial intra-annual and inter-annual variability in forage production due to equally-variable precipitation patterns.

Two broad philosophies have emerged in livestock management to deal with environmental variability: the constant conservative model and the opportunistic tracking model [80]. For example, should managers conservatively stock animals below the carrying capacity of the range—all season, every season—to ensure forage demand rarely exceeds forage availability? Or should managers attempt to take advantage of greater forage availability during periods of high rainfall by tracking animal numbers with precipitation pattern? Each comes with tradeoffs—the former might "waste" forage in periods of high rainfall while the latter requires flexibility in animal numbers and runs a high risk of overstocking. Fynn [39] provides a thorough review of the interactions between the seasonally-dynamic forage requirements of multispecies herbivore communities and spatio-temporal variability in forage resources in grazing systems.

From an ecological perspective, managing the spatial distribution of grazing across a heterogeneous landscape is a critical component of adapting grazing regimes to a changing environment [39,76]. This varies from a purely economic model that deals exclusively with animal numbers and does not consider the spatial relationship between forage demand and forage availability. Patch burn-grazing might increase biodiversity conservation and ecosystem resilience while reducing the variability associated with environmental and socio-economic risk in Southern African rangeland.

Evidence suggests that increasing spatial heterogeneity in rangeland biomass might reduce temporal variation in forage production [22,39], which suggests that patch burn-grazing might increase rangeland resilience and increase adaptive capacity in the face of climate change. With respect to ecological theory, this is a novel application of landscape heterogeneity and would constitute additional understanding of the relationships between ecological diversity and ecosystem stability and variability. Considerable research has associated several measures of biodiversity—including species richness, functional diversity, and response diversity—with greater ecosystem productivity and stability [81–84]. However, relatively little work has addressed diversity-stability relationships at broad scales (but see [85,86]). Existing research on habitat heterogeneity in rangelands—showing that spatial heterogeneity in plant biomass increases spatial habitat diversity and reduces inter-annual variability in community composition [56,62,64,87]—suggests that these same patterns of spatial heterogeneity might reduce temporal variability in forage production because in these studies, measures of habitat structure correlate with aboveground biomass production [88,89]. However, these relationships have not been specifically tested and we propose additional research to establish a clear link between spatial heterogeneity and temporal variability in rangeland forage resources.

4. Considerations for Heterogeneity-Based Rangeland Management in Southern Africa

Southern African savannas present specific challenges and considerations for rangeland management [90], but the region's long history of research can guide the establishment of resilient, productive, and conservation-minded rangeland practice and policy. For example, multi-decade datasets from the Kruger National Park in South Africa and broad-scale, region-wide information from satellite imagery offer insight into temporal and spatial land use patterns.

It is apparent that fire and human land use generally shape Southern Africa's rangeland: millions of citizens rely on a variety of timber, grazing, and non-market natural resources derived from Southern African rangeland [91,92], approximately 11%–15% of which burns in a given year [93]. But land tenure and use is far from homogeneous in Southern Africa: for example, less than 10% of northern Botswana burns annually, but just across the Namibian border 29%–55% of the Caprivi region burns in the average year [94]. Some fire research has been synthesized into distinct programs with specific fire behavior thresholds to achieve specific management objectives [95].

4.1. Land-Use Categories

A literature review outlines the history and practice of rangeland management across Southern Africa among three major land-use categories: Protected areas, commercial rangeland, and communal rangeland. Supported by this literature, we discuss the application of heterogeneity-based management with respect to each land-use type and highlight specific considerations for each.

4.1.1. Protected Areas

Given the ungulate diversity of Southern Africa [69], grazing has long been an inherent component of protected areas management in the region. Fire, however, has had a less consistent history, and generally follows the historical patterns of equilibrium *versus* non-equilibrium models in rangeland management [67]. Initially, fire policies in national parks and other protected areas focused on suppression and prohibition, but in some areas of the region fire was recognized as an effective means to promote grass and control bush. Several aspects of fire regime—e.g., seasonality, frequency, and spatial extent—can be manipulated to achieve specific vegetation management goals (e.g., structure) related to biodiversity conservation [96,97]. Conversely, even in large protected landscapes, extensive wildfire can have catastrophic effects on wildlife [98].

More recently, some major conservation areas in South Africa have adopted patch-burning regimes [28,66,95,99]. While these projects highlight the positive effects of managing for ecologically-analogous fire regimes in Southern Africa, long-term research indicates that fire use must fit within an adaptive ecosystem-scale management framework [100]. For example, while frequent burning can control woody plant encroachment, it can also promote the invasion of alien plants [101]. As such, fire management must be adaptive and consider multiple outcomes.

4.1.2. Commercial Rangeland

The second dominant land-use category in Southern Africa is privately-owned and commercially-operated farm and rangeland. The proportion and geography of commercial land varies by country, as does the specifics of title: for example, in Namibia, 43% of the country is private, freehold farmland, is quite contiguous, and centrally-located within the country [102], and landowners have full title. Contrast this pattern and policy with commercial land in Zambia, where 6% of the land is leased under 14 or 99-year agreements for commercial agriculture, and is generally scattered about the country among land under traditional authority [103,104].

Differences in geography and land tenure preclude a universal response to conservation issues across commercial rangeland in Southern Africa. For example, game ranching has grown in popularity across the region, prompting changes to wildlife ownership and management laws to transfer ownership of wildlife to landowners and tenants [105,106]. Many laws also provision collective management of game populations among neighbors in recognition of the fact that many arid and semi-arid wildlife species require ranges larger than individual commercial tracts [106,107]. In countries where commercial landownership is fairly contiguous (e.g., Namibia and South Africa), it is relatively easy for neighbors to create conservancies to collectively manage game populations across several farms as a single unit. This is much more difficult in a landscape mosaic such as that found in the Zambian countryside, where commercial game farmers are usually isolated within a matrix of different land uses [29]. Certainly, contiguity is no guarantee of successful collective management, but other things equal, isolated farmers often have less access to benefits such as resource heterogeneity to safeguard wildlife productivity [39], shared cost of management activities like game counting, and the exchange of hunting clients among neighbors less invested in marketing and guesthouse operations [29,54]. Different fence laws and customs from country to country must also be considered in terms of ownership structure and population ecology [54].

Despite differences in the spatial scale of management across Southern Africa, commercial rangelands might present the best opportunity for the introduction of patch burn-grazing from the North American Great Plains, where land tenure, decision-making, and economic objectives are similar. But yet again, national differences in prescribed fire policy across Southern Africa and the associated culture of fire in each Southern African country preclude a universal application of patch burn-grazing management. For example, commercial farmers in Namibia recognize the role of fire in preventing bush encroachment and increasing grass cover but are wary of its use and liability; meanwhile Zambian farmers often use fire but have expressed frustration on how it fits into the ecology of game and cattle ranching [29]. Thus, while patch burn-grazing demonstrations in Southern African rangeland might translate ecologically across national boundaries, the practice must be sensitive to sub-regional differences in fire culture, practice, and policy.

4.1.3. Communal Rangeland

Although land use in rural, communal areas is characterized by relatively low-input agriculture, these areas make important social and economic contributions to the livelihoods of millions of Southern African citizens [91,108,109]. Ecological differences between communal and commercial rangeland have been widely documented, but as discussed above, it is debatable whether differences in plant species composition [110] constitute degradation [30]. In savannas, land uses other than livestock grazing, such as fuel wood gathering and the exclusion of mega-herbivores and fire, can have substantial effects on vegetation [111,112]. Thus, socio-economic and cultural differences must be taken into account when attempting to introduce an ecological approach to communal rangeland management. The challenges of community-based conservation programs might serve as a lesson: efforts to get rural communities behind wildlife conservation are frequently stymied by economic challenges in rural areas [113]. To advance ecological goals on communal rangelands, economic needs and cultural values must be considered.

Two important differences between commercial and communal rangeland are the socio-economic role and types of livestock. For example, livestock often provide non-market value, such as cultural and spiritual resources [114]. Small-stock—sheep and goats—are common, and cattle are often used for traction, milk, and reserve capital rather than for meat or market [114]. Different livestock breeds are often found on communal rangeland than their commercial counterparts, as many indigenous breeds like Nguni cattle are better suited to low-input management [115]. Different types of livestock and even different breeds can have unique dietary requirements that must be considered when timing the spatial extent and seasonality of disturbance, such as prescribed fire. Stocking rates might be more or less flexible depending on livestock owners' incentives for raising animals and their access to alternative grazing within communal grazing areas.

Fire has long been a component of the rural environment in Southern Africa, but the motivation and effect of these disturbance patterns vary widely depending on type of land use and country [94]. Fire is important to rural livelihoods, but cultural and political considerations seem to dominate how fire is applied and might even act as barriers to sustainable fire regimes [116]. Towards this end, programs are being introduced to incorporate patch-mosaic burning into the management of communally-grazed rangeland [68].

Rangeland management in communal areas must strike a balance between the feasibility of top-down scientific recommendations and overly-romanticized local knowledge [117]. To facilitate this balance, scientists and stakeholders must create hybrid knowledge to apply scientific principles meaningfully, and in an adaptive manner, within the broad socio-ecological system [118,119]. The challenge of such a process is daunting, especially to those unfamiliar with collective decision-making processes. To achieve a sustainable result, we suggest managers and policy-makers consider how ecological structure and function can maximize the resilience and adaptive capacity of the integrated economic—ecological system by focusing on native plants, natural or analogous disturbance regimes, and optimizing spatial resource heterogeneity to reduce temporal variability.

4.2. Environmental Variability

Along with differences in land tenure and policy, environmental variability is an essential consideration in the transfer of rangeland management knowledge. Recipe-like management guidelines which specify particular stocking rates or rest periods simply cannot be universally applied; management must be driven by broader environmental criteria and ecological objectives. Adherence to fixed management regimes do not increase plant and livestock productivity [17] and risk rangeland degradation [49]. Even flexible stocking regimes that attempt to track precipitation patterns risk range degradation if proper rest periods are not observed [120]. Clearly, rangeland managers must take cues from the environment to ensure sustainable production.

The form of ecologically-analogous, heterogeneity-based management will not only vary across land-use types in Southern Africa, but also across the broad gradient of rangeland ecosystems. Livestock production potential and efficiencies vary across veld types [121,122], and the pattern of fire varies at broad scales along precipitation, fertility, and geomorphological gradients [123,124]. Thus it is essential that landscape heterogeneity be included in rangeland management policies, especially when fire is involved [97].

Ironically, rotational grazing schemes were intended to prevent heterogeneous grazing at broad spatial scales by concentrating grazing activity ("overgrazed and understocked" [14]). But their failure arises from the imposition of grazing schedules through a fixed grid of fenced paddocks permanently established within spatially heterogeneous and temporally variable landscapes. The ecological solution is to consider the spatial pattern of the landscape and the temporal pattern of primary productivity and effect grazing distributions that follow these patterns [39,49]. By making use of the fire-grazing interaction, patch burn-grazing can effectively alter grazing distribution in an ecological manner, but the timing, location, and spatial distribution of prescribed fire must be carefully determined for a specific landscape.

5. Conclusion

Within the broad movement to manage Southern African rangeland sustainably—savannas and grassland alike—is an opportunity to focus on the multifunctional nature of these ecosystems. Millions of Southern Africans depend on rangeland for economic and cultural products, in addition to ecosystem services. Reconciling these diverse interests and outcomes is of great importance, especially in the context of global climate change, which threatens to make natural systems less predictable and thus less reliable for food production and ecosystem services.

We suggest that the restoration of natural disturbance regimes on Southern African rangeland will enhance environmental, social, and ecological outcomes. In fact, ecosystem resilience to global climate change might increase and reduce the susceptibility of Southern African economies from the home to the national scale. We specifically suggest that the fire-grazing interaction, a natural interaction of ecological disturbance that has been observed in rangeland worldwide, be restored to Southern African rangeland through localized applications of patch burn-grazing management. Successful implementation of ecologically-analogous management will require additional research on fire and grazing across several economic, cultural, and environmental gradients that define the inherent social and ecological heterogeneity of Southern African rangeland.

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Conflict of Interest

The authors declare no conflict of interest.

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