Evaluating functional diversity as potential early-warning indicator of rangeland degradation

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Abstract

Droughts and overgrazing play a crucial role in the degradation of semi-arid rangelands. This is evident in the loss of palatable long-lived grass species and bush encroachment. Early warning indicators are needed to mitigate long-term degradation and decline in essential forage provision. Functional diversity provides valuable information on ecosystem health. However, functional diversity indices have not yet been tested regarding their applicability as early warning indicators, revealing non-linear threshold behaviour. We therefore examined the following questions: (1) How do functional diversity indices respond to grazing pressure? (2) Does land tenure affect the relationship between functional diversity and grazing pressure? (3) Are functional diversity indices suitable early-warning indicators? To answer these questions, we conducted a space-for-time substitution of land use intensity of semi-arid rangelands in Namibia. Some 16 grazing gradients were selected, each starting at a cattle watering point where grazing pressure was highest. Gradients were located in four communal and four freehold farms. Communal farms were characterised by continuous grazing, while freehold farms by rotational grazing. In each transect we recorded plant species composition of the grass layer in 9 plots of 10 × 10 m each (N = 162 plots). Within each transect, these plots were logarithmically distributed. Various plant functional traits—all relating to plant life history or resource acquisition strategy—were measured for 142 dominant species, accounting for more than 80 % of the biomass, and indices of functional diversity were calculated. We found potential threshold behaviour in functional richness on freehold farms. Certain functional diversity indices revealed non-linear patterns in rangelands but are currently not a user-friendly early-warning indicator. To harness functional diversity, we need a more standardized method of calculation, and more functional trait databases for sub-Saharan species.

Introduction

Climate change is likely to increase the frequency of extreme drought events and decrease mean rainfall in southern Africa (Shongwe et al. 2009). Since Namibia is the driest sub-Saharan African country, its farmers are particularly vulnerable to climate change (Menestrey Schwieger 2022). The semi-arid savannas can mostly only be used for grazing and are existential for the subsistence agriculture of a large part of the population. Arid ecosystems can be severely—and sometimes irreversibly—damaged by the dual stress of drought and overgrazing. To prevent tipping points from being crossed and essential ecosystem services from being lost, early warning indicators are a means to enable timely intervention. Functional diversity enjoys enormous popularity and is used in many ecological studies. However, whether it is a useful early warning indicator in terrestrial systems has rarely been studied. To understand and prevent a permanent loss of perennial pastures, we initiated a multi-discipline study of ecological factors in the Namibian Greater Waterberg Landscape. Here we present the evaluation of functional diversity as potential early-warning indicator for the permanent loss of perennial grasses. We hypothesized that (1) functional diversity indices have a negative relationship with grazing pressure, (2) relationship patterns depend on land tenure and (3) functional diversity indices are applicable early-warning indicators. If the response pattern is non-linear and characterized by a sudden shift, this could be an indicator of threshold or tipping point behaviour.

Methods and Study Site

The study was conducted at the Greater Waterberg Landscape in Namibia. The area belongs to the Tree-and-Shrub Savanna biome and has an annual rainfall of 350–400 mm (Atlas of Namibia Team, 2022). To examine potential tipping points in our study system we employed a space-for-time substitution on communal and freehold rangelands. Communal rangelands were characterized by year-round grazing in a fairly open area around a village, while freehold rangelands were characterized by rotational grazing and the use of fenced cattle camps. In total 16 transects on eight rangeland areas were established. In each transect, nine plots were selected, where distance from an artificial watering point was used as proxy for grazing pressure. To ensure that sites were comparable, only sites characterized by the Arenosols soil type were selected. In each 100 m² plot, we recorded species composition and abundance as percent cover in four, representative 1 m² vegetation relevés, and we sampled plant functional traits for the dominant herbaceous species. Sampling was conducted from February to April 2021, during the rainy season. In addition, a large amount of information on important functional traits was collected from databases such as World Flora Online (WFO 2022). To capture grazing pressure more accurately we calculated a grazing index based on distance from watering point supplemented with additional information such as cattle activity (based on presence of dung and signs of grazing and trampling), grazing offtake, distance from nearest fence or natural watering point, and presence of moribund material. The index ranges from zero to one, with zero representing the lowest grazing pressure and one representing the highest grazing pressure for the particular land tenure system. We calculated five functional diversity indices (functional richness, functional evenness, functional diversion, functional dispersion, Rao's quadratic entropy) following De Bello et al. (2020) with the traits presented in Table 1. Potential threshold behaviour was explored via the comparison of linear (linear, log-transformed) and non-linear (concave/convex, sigmoidal, piecewise linear) models (sensu Sasaki et al. 2007). Best fitting was compared via the Akaike information criterion (AIC).

Table 1. Functional traits and categories (if applicable) used to calculate functional diversity indices. Grouping indicates that the weight of traits was adjusted to reduce overrepresentation of collinear traits.

Trait variable	Group	Type	Categories
Leaf area	Leaf trait	numeric	-
Leaf dry matter content	Leaf trait	numeric	-
Specific leaf area	Leaf trait	numeric	-
Plant height	No grouping	numeric	-
Growth form	No grouping	categorical	Forb, Graminoid, Shrub
Life cycle	No grouping	categorical	Annual, Perennial, Annual/Perennial
Nitrogen fixing	No grouping	binary	Yes/No

Results and Discussion

General Outcome

Functional richness was slightly lower on communal farms than on freehold farms, which is likely due to higher overall grazing pressure in that land tenure system. In general, we found a very low or no correlation between the various functional diversity indices and the grazing index. For communal rangelands (with year-round grazing) we found weak correlations between three functional indices (functional richness, functional dispersion, and Rao's quadratic entropy) and grazing index. On freehold farms (with rotational grazing) we found weak correlations between two functional indices (functional richness and functional dispersion) and grazing index. When comparing various types of linear and non-linear models for the relationship of functional richness and grazing with the help of the AIC, the linear model had the best fit for the communal dataset. In these rangelands, we found a weak non-significant positive relationship between functional richness and grazing (Figure 1A), suggesting the absence of tipping point behaviour. On the freehold rangelands, however, the best model fit was a piecewise linear regression between functional richness and grazing (Figure 1B). We observed a negative relationship between grazing index and functional richness, but only for plots with a relatively high grazing index, i.e. high grazing pressure. This pattern could be related to peculiarities of the cattle camps, where the entrance areas are particularly disturbed. In the case of communal rangelands, on the other hand, we studied open terrain where such distinct entrance areas were absent. However, although the piecewise regression model is the type of non-linear pattern that would support our hypothesis, we are cautious to call this a tipping point outright, since both the number of observations with high grazing pressure and the explanatory value of the model are rather low. Still, these results warrant further investigation and possible validations elsewhere. In this context we also plan to examine whether species composition changes in response to grazing are non-linear, as observed elsewhere (e.g., Sasaki et al. 2007). In general, however, the negative relationship between functional richness and grazing index supports our hypothesis and observations in other ecosystems (e.g., Chillo et al. 2017).

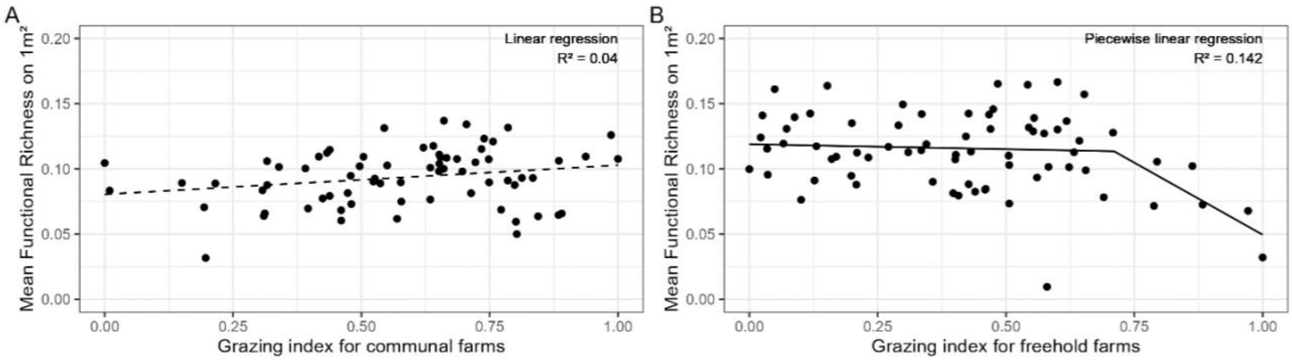

Figure 1. Best fitting models for the relationship of functional richness and grazing pressure on (A) communal farms (n=72), and (B) freehold farms (n=72) located in the Greater Waterberg Landscape, Namibia. (A) For communal rangelands a linear regression is shown (F = 3.882, df = 68, p = 0.0529). (B) For freehold rangelands a piecewise linear regression is shown (1st segment: F = 6.503, p = 0.0131; 2nd segment: F = 8.083, p = 0.0059; df_{error} = 67). The calculated grazing index ranges from 0 (low grazing pressure) to 1 (high grazing pressure).

Feasibility

To make an early-warning indicator useful for farmers, the calculation of a specific indicator need to be as straightforward as possible. Even though functional diversity is widely used and has great flexibility in terms of input variables, there are challenges concerning reproducibility. Therefore, a standardized method or protocol is necessary (Palacio et al. 2022). Even if this condition is met, the challenge remains that in many semi-arid regions there are only small or no databases on plant functional traits. Improvements are needed to make functional diversity indices applicable without major hurdles.

Conclusions

Functional diversity indices, such as functional richness, are correlated to grazing pressure. The degree and pattern of such correlation, however, depends on the management system. While we could not prove a threshold behaviour, we found some indications for it. Before functional diversity can be used as an indicator of semi-arid rangeland health, or as an early warning indicator, its applicability needs to be developed in more details.

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