Long-term South African arid region study shows relationships between rainfall, SPI, and ungrazed perennial plant cover amid climate change

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Abstract
Climate change is projected to diminish the rainfall and lead to more frequent droughts in the cold arid desert of the west coast of South Africa. Long-term area-wide precipitation trend analysis indicates all-year reductions, but particularly in autumn (March–May), driven by the poleward contraction of mid-latitude storm tracks. The region has historically reliable winter precipitation and generally very dry summers. This study analysed the 60-year rainfall and 56-year ungrazed perennial plant cover recorded at Nortier Research Farm in the West Strandveld bioregion to identify possible climatic shifts, and the relationships between rainfall, Standardized Precipitation Index (SPI) and perennial cover. The hypotheses were that rainfall in a certain period preceding the plant survey is a strong predictor of perennial cover, and that climate change is already driving changes in cover. No significant rainfall trends were found but there was a shift towards wetter summers in the last 30 years. The Standardised Precipitation Index (SPI) indicated moderately to extremely dry years in 1966–1973. Apart from 1978 and 2017, no other drought periods (SPI ≤ -1.0) were identified. Around eight years were moderately to very wet (SPI ≥ 1.0) and occurred randomly. The study found a strong positive correlation (r^2 = 0.524) between the rainfall of the previous 18 months and the perennial plant cover, supporting the hypothesis that preceding rainfall is a strong predictor of perennial cover. However, no discernible changes driven by climate change were found. Rangeland managers should take the rainfall of the previous 18 months into consideration when making grazing decisions. Weather monitoring is continuing to track possible long-term climate changes. This research contributes to understanding the impact of climate change on arid regions.

Introduction
Perennial vegetation forms the basis of terrestrial ecosystems and rainfall is a key driver of vegetation dynamics. In semi-arid regions, plant cover is sensitive to rainfall variability, seasonality and cyclic droughts (Munson et al. 2016). Projected more frequent and extended droughts and rising temperatures under climate change will reduce water availability and negatively impact the vegetation.

The semi-arid southern west coast of South Africa has a Mediterranean-type climate with very dry summers and reliable winter rainfall, receiving less than 250 mm of rain per annum (Mucina and Rutherford 2006). The region is renowned for the high species diversity and endemicity of the Fynbos and Succulent Karoo biomes. A moderate and stable climatic history is key to this diversity, and the vegetation could be highly vulnerable to climate change

(Midgley and Thuiller 2007). Grazing of more palatable species and rainfall variability combine to determine plant cover in semi-arid south-western South Africa (Saayman et al. 2022). While research has focused on leaf- and stem-succulent shrubs and rare species, little information is available on total perennial cover in relation to short- and long-term rainfall dynamics, especially when livestock are excluded over a long period.

In this region, climate change will likely reduce rainfall, and droughts will become more frequent and intense. Some sub-regions may experience much stronger rainfall reductions than others due to different climatic drivers (Wolski et al. 2020). The long-term (1900–2020) area-wide precipitation trend analysis (Jack et al. 2022) shows a significant reduction in autumn (March–May) rainfall, associated with the poleward contraction of the rain-bearing mid-latitude cyclones and the dynamics of the Southern Annular Mode (Wolski et al. 2020).

This study focused on a coastal area that is historically cool and semi-arid with winter rainfall but is projected to shift in future towards hot and arid. Changes in perennial plant cover are expected to be driven by both short- and long-term rainfall dynamics. The hypotheses for this study spanning 57 years (ungrazed vegetation) were that rainfall in a certain period preceding the plant survey is a strong predictor of perennial cover, and that climate change is already driving changes in cover.

Methods

The study was conducted on the Nortier Research Farm near Lambert's Bay (-32.03524; 18.33274) on the west coast of South Africa. It is situated in the West Strandveld bioregion, a transitional zone between the Fynbos and Succulent Karoo biomes (Mucina and Rutherford 2006) and receives on average 205 mm rain per annum. Fifty eight percent of the rain falls during the winter months of June to August with only 8% falling during the summer months.

Daily rainfall data were collected on the farm since 1964. Livestock grazing was excluded from one of the paddocks, the Reserve, from 1965. Forty-six plant surveys, measuring plant cover and species composition, were done from 1967 until 2023. For the plant surveys the descending-point method (Roux 1963) consisting of 1000 points on a fixed line was used, recording canopy-spread cover of all the plants encountered at each point.

Using the data for 1964–2023, the Standardised Precipitation Index (SPI) was calculated to assess the degree of meteorological drought (National Drought Mitigation Center 2018). The monthly rainfall and ungrazed perennial plant cover data for 1967–2023 were analysed using Principal Component Analysis (PCA), Ward's Clustering and ANOVA to determine significant differences between clusters. Linear regressions were performed to determine if rainfall can predict perennial plant cover. All data was analysed using XLSTAT (Addinsoft 2023).

Results

The SPI shows moderate to extreme dry years (SPI < -1) from 1966 to 1973. Thereafter, there were no more periods of drought, except in 1978 and 2017. In the 60-year period, there were eight years that were moderately to extremely wet (SPI > 1), but these occurred randomly (Fig. 1).

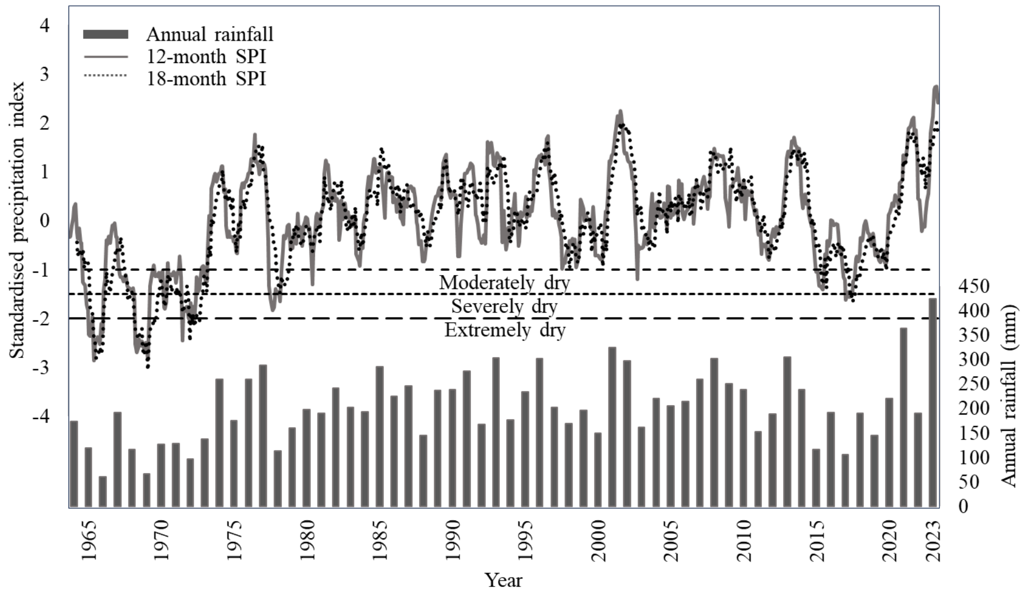

Fig. 1 Annual rainfall at Nortier Research Farm in 1964-2023 (bars) and expressed as Standardised Precipitation Index (SPI) for 12-month and 18-month periods, highlighting periods of increasing dryness.

To determine if there were any trends in the rainfall over time, further analysis using Principal Component Analysis (PCA), was done. Ward's clustering grouped the rainfall into five clusters, namely, driest years (all seasons), drier summers than usual, drier winters than usual, wetter summers than usual, and wetter winters than usual. From the PCA and Ward's clustering there were no definite trends, except for a shift towards wetter summers in the last 30 years (Fig. 2). The year 2023 was an outlier with a wetter summer than normal, and the wettest winter on record.

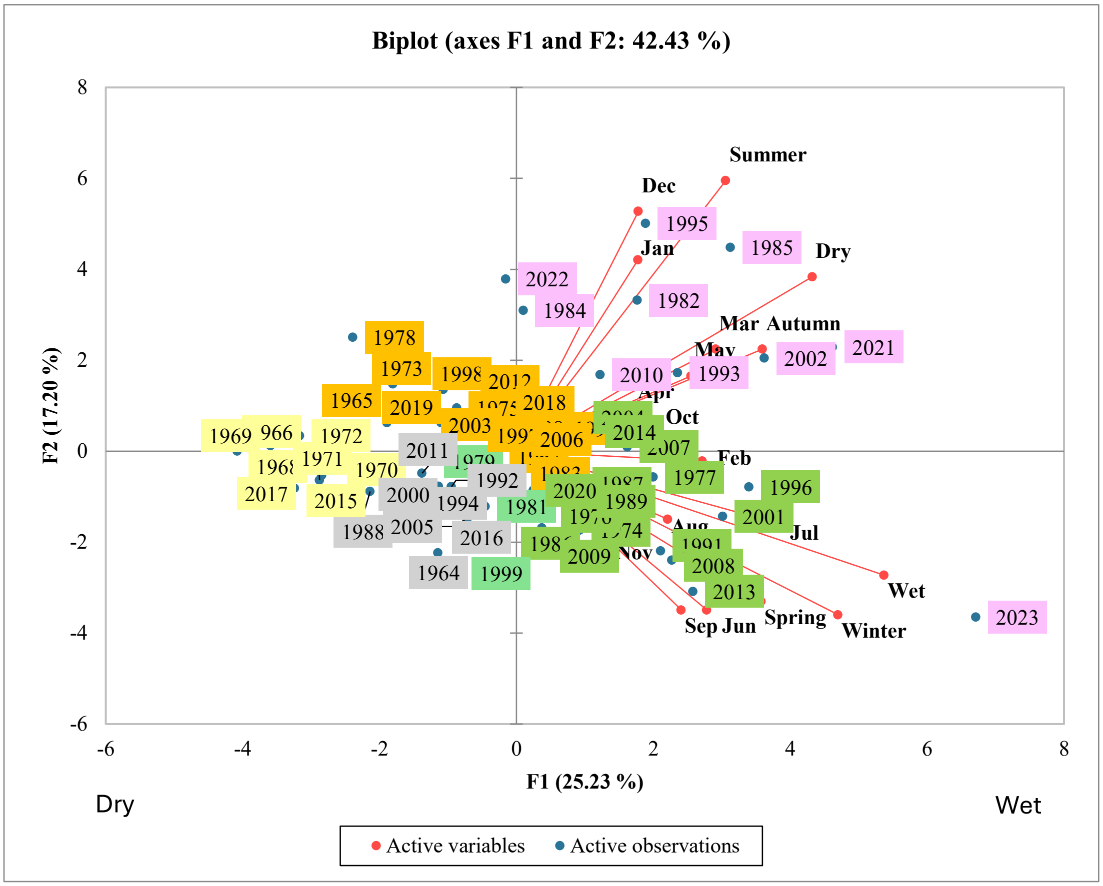

Fig. 2 Principal Component Analysis (PCA) of rainfall data from 1964–2023 at Nortier Research Farm. Ward's clustering is indicated with different colours (green = wetter winters; pink = wetter summers; grey = drier winters; orange = drier summers; yellow = driest years overall).

The study found a relatively strong positive correlation ($r^2 = 0.524$) between the rainfall of the previous 18 months and the perennial plant cover. A highly significant linear regression model ($p < 0.0001$) using the previous 18 months rainfall (18moPr) was developed to predict the perennial vegetation (Perennial = 27.613+0.178*18moPr). All the recorded plant cover values fell within the 95% confidence limits of the predicted plant cover.

Discussion

In a previous study of the succulent karoo (Hoffman et al. 2009), SPI analysis also identified drought periods in the 1960s–1970s and no significant trends in mean annual rainfall for 1900–2000. Despite the severely dry year of 2017 and an extended dry period in 2015–2019 at Nortier, the mean annual rainfall during the last 30 years (1994–2023) was higher (+37.2 mm) than in the first 30 years (1964–1993). Wolski et al. (2020) analysed the 2015–2017 rainfall anomalies across the southern winter rainfall region in the context of the 1900–2017 data set. Spatially and seasonally different rainfall trends in the short- and long-term are influenced by different climate drivers. The sub-region around Nortier commonly showed a wetting trend in 1981–2014, and the Nortier station itself experienced a weaker drought in subsequent years.

Our findings of summer wetting at Nortier align with previous studies (Wolski et al. 2020; Jack et al. 2022). This trend is likely associated with local, non-hemispheric process drivers such as cut-off lows, ridging highs, and convective summer rainfall. A possible increase in the latter may be associated with the increased convective available potential energy (CAPE) and regional synoptic changes brought about by climate change. Advective moisture-bearing coastal fog associated with the cold Benguela current is prevalent in summer, but analyses of trends and future projections of fog are unavailable (Midgley and Thuiller 2007). These drivers require further research.

The relatively strong positive correlation found between rainfall in the preceding 18 months and the perennial plant cover indicated that rainfall is a strong predictor of perennial plant cover in the absence of grazing and that there is a carry-over effect from the rainfall received in the previous seasons (Hoffman et al. 2009). This implied that there will be less cover following dry years and the vegetation will take longer to recover after a drought (Munson et al. 2016). If droughts along the west coast become more frequent it will negatively impact the perennial vegetation and ultimately the fodder availability for herbivores, increase the soil erosion potential and have a negative effect on essential ecosystem services (Munson et al. 2016). Rangeland managers should take the rainfall of the previous 18 months into consideration when making grazing decisions to lower the impact of droughts.

The second hypothesis, that climate change is already observed and driving changes in plant cover, was not supported. The 60-year observed Nortier data set showed no evidence of long-term reductions in annual or seasonal rainfall as projected (Jack et al. 2022). This may, however, change in the future as hemispheric and local climatic drivers respond. Therefore, weather and vegetation monitoring efforts are continuing to track possible long-term climate changes and their impact on the vegetation.

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