A SUMMARY OF RAINFALL AT THE CARNARVON EXPERIMENT STATION, 1931-2013

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INTRODUCTION

The Carnarvon Experiment Station (31.0086° S; 21.8939° E) lies in the Western Upper Karoo (Mucina & Rutherford, 2006). A key feature of the station is the long-term research trials established in 1989, which have been maintained to date. The trials were originally set up to understand the effects of stocking rates on animal performance and veld composition, but currently are set to offer useful scientific insight into other issues such as biodiversity, degradation, the scale and pattern of ecosystem processes and functioning, and environmental responses to global change.

An important (possibly the most important) driver of ecosystem processes in semi-arid or arid environments is rainfall. Rainfall patterns and trends have been described in Africa from continental (Nicholson, 1989) to local (Gertenbach, 1980; Du Toit & O'Connor, 2014) scales, and South Africa has received significant attention (Tyson et al., 2002; Kane, 2009; MacKellar et al., 2014). A particular focus of attention has been the interaction between rainfall and vegetation dynamics in the arid and semi-arid regions of the country (Hoffman & Cowling, 1990, 1991; Hoffman et al., 1995, 2009; Todd & Hoffman, 2009).

Cyclicity in rainfall in South Africa has been proposed at various temporal scales ranging from months to decades (Tyson, 1971; Dyer & Gosnell, 1978; Kane, 2009; Jury, 2013). Du Toit & O'Connor (2014) provided evidence from a site in the eastern Karoo that rainfall patterns may be related to two interacting cycles, one of approximately half a century, and the other of approximately 20 years.

This report is a summary and interpretation of the monthly rainfall recorded at the Carnarvon Experiment Station, and a test of whether there is evidence of the double-cycle identified by Du Toit & O'Connor (2014).

MATERIALS AND METHODS

There were two independent data sets. The first was from the South African Weather Service, and the second was the records kept by the farm manager at the research station. The Weather Service data set comprised monthly rainfall data from 1931 to July 2012. Years 1931 and 1998 to 2006 inclusive had missing monthly data and were removed from the data set. The farm data comprised a complete record of monthly rainfall from 1991 to the present-day (2014).

The first step was to construct a complete data set from 1932 to 2014. This was done by using Weather Service data from 1932 to 1997 and farm data from 1998 to 2014. Overlapping records (1991-1997 and 2007-2011) provided an opportunity to determine the similarity of the two independent rainfall data sets. Data were compared using a paired t-test, which showed that the two populations were not significantly different (t_{143} = 0.835, P = 0.405). A linear regression was also highly significant ($F_{1,142}$ = 1433, P < 0.0001; R^2=0.958) (Figure 1).

Data were expressed seasonally from the local interpretation of the beginning of the growing season (1 September) until to 31 August of the following year. For the cyclicity analysis, seasonal rainfall data were smoothed using a 10 year running mean. A single-wave (Equation 1) and a double-wave regression (Equation 2) were fitted following the methods of Du Toit & O'Connor (2014). The best model was determined using Akaike information criterion (AIC) values.

$y = a\cos\left(\frac{2\pi x}{c} + d\right)$ ....Equation 1

$y = a\cos\left(\frac{2\pi x}{c} + d\right) + e\cos\left(\frac{2\pi x}{f} + g\right)$ ....Equation 2

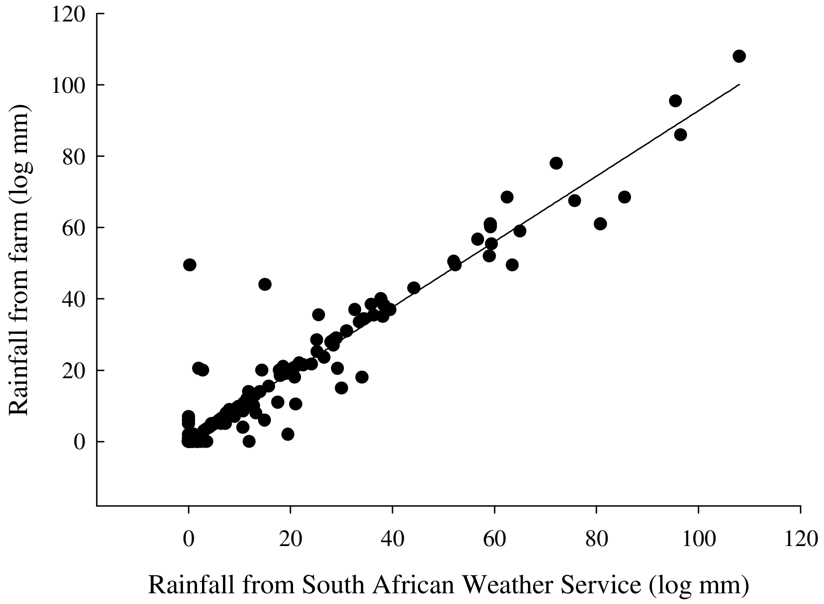

Figure 1. Comparison of rainfall recorded by the South African Weather Service and by the Carnarvon Experiment Station

RESULTS AND DISCUSSION

Summary of annual data

Summary parameters are given in Table 1. Rainfall distribution was positively skewed, meaning that there was a higher probability of experiencing a year of below average (mean) rainfall than above mean rainfall. This is an expected pattern for a semi-arid region in South Africa (Schulze et al., 1997).

Table 1. Seasonal rainfall parameters at Carnarvon

Parameter	Value
Number of seasons recorded	83
Average rainfall (mm)	215.0
Standard deviation (mm)	84.64
Coefficient of variation (%)	39.36
Minimum rainfall (mm)	61.0
Maximum rainfall (mm)	486.2
Range (mm)	425.2
Skewness	2.46
Years of above-mean rainfall	33
Years of below-mean rainfall	50

Summary of monthly data

Rainfall was unimodal, peaking in March (Figure 2;). Rains from February to April comprised 45% of annual rainfall. Winter rain (June to August) was low, with an average of 24.3 mm, and comprising only 11% of the average annual total.

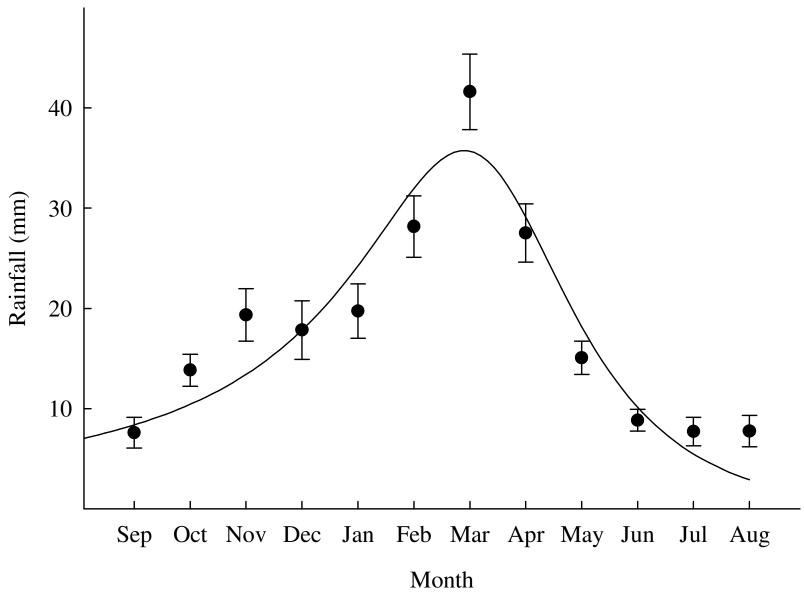

Figure 2. Monthly distribution of rainfall at Carnarvon Experiment Station. Bars are standard errors; regression a 4-parameter rational function

Table 2. Monthly rainfall parameters at Carnarvon

Month	Number of records	Average (mm)	Standard deviation (mm)	Coefficient of variation (%)	Minimum (mm)	Maximum (mm)	Range (mm)
Jan	83	19.74	24.76	125.4	0	103.6	103.6
Feb	84	28.18	28.21	100.1	0	145.3	145.3
Mar	84	41.63	34.59	83.1	0	174.0	174.0
Apr	84	27.53	26.56	96.5	0	114.7	114.7
May	84	15.07	15.20	100.9	0	66.0	66.0
Jun	84	8.83	10.02	113.4	0	40.0	40.0
Jul	84	7.72	13.06	169.1	0	56.7	56.7
Aug	84	7.76	14.31	184.3	0	93.3	93.3
Sep	84	7.61	14.05	184.8	0	73.5	73.5
Oct	84	13.83	14.53	105.1	0	65.1	65.1
Nov	84	19.35	24.09	124.5	0	108.0	108.0
Dec	83	17.85	26.60	149.0	0	132.0	132.0

Time series descriptions

In general, annual rainfall decreased until about 1972, when there were heavy rains. Rainfall increased from then until the present-day (Figure 3 and Figure 4). Before 1972, 36% of years experienced higher than average rainfall, while since 1972 this value is 43%. Since 1972 the months of December, January, February, and April received higher rainfall (Figure 5) than before 1972, while rainfall during the month of March remained consistently the highest.

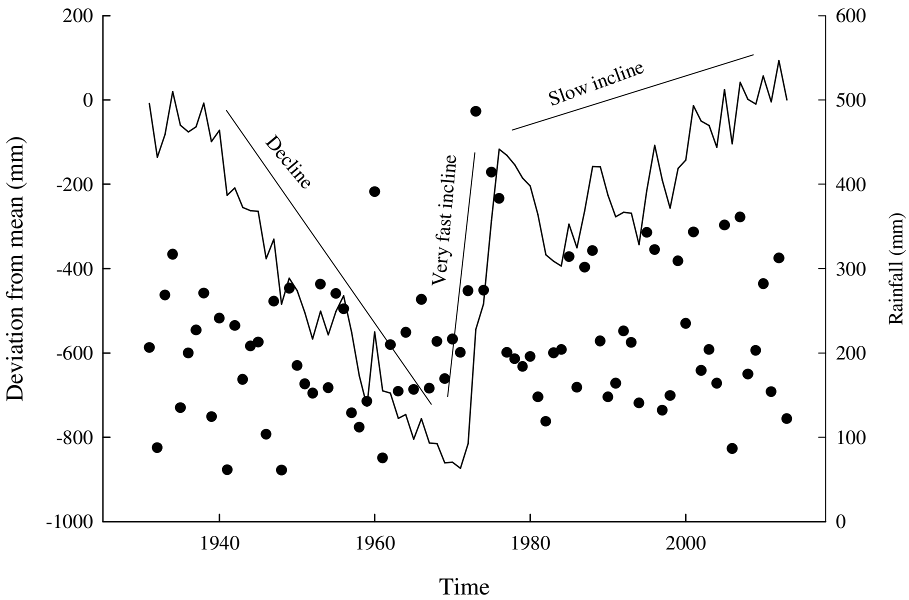

Figure 3. Rainfall expressed as cumulative deviation from the mean for Carnarvon, with periods of decline and incline annotated. Dots are seasonal rainfall

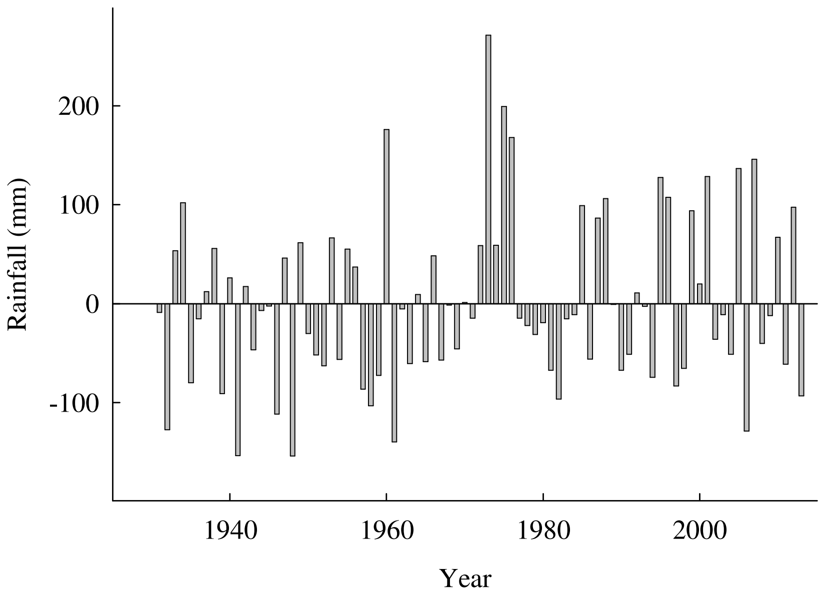

Figure 4. Annual rainfall at Carnarvon expressed as deviation from the mean

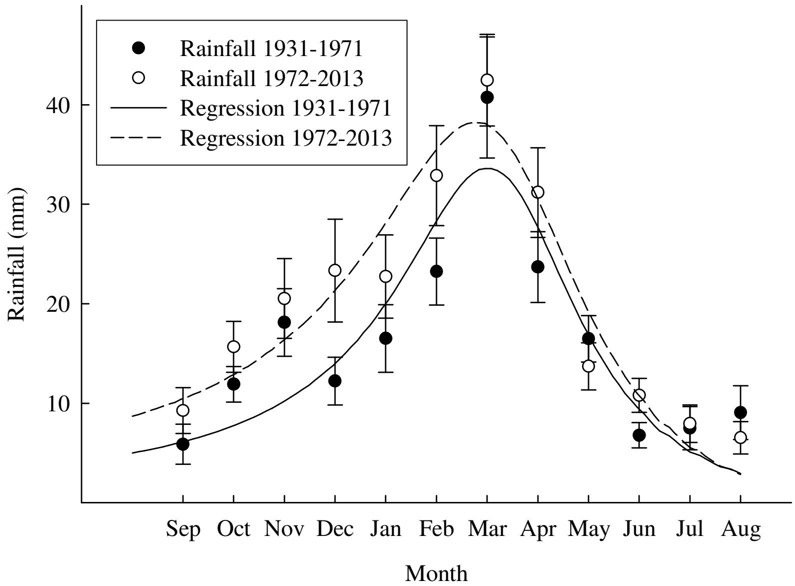

Figure 5. Average monthly rainfall (markers) for the periods 1931-1971 and 1972-2013. Bars are standard errors; lines are rational model regressions

Cyclicity

There was evidence of double-wave cyclicity, with the double-wave regression providing a better model than the single-wave regression. The period of the first wave was 43 years, and the second wave 22 years. All parameters were highly significant. However, the high rainfall years in the mid-1970s may have had an excessive influence, forcing the regression to identify the 43-year cycle where in reality the only true cycle is 22 years (43 being approximately double 22). Therefore, while this is interesting statistically, it should not be taken as evidence of two interacting cycles. The evidence for the 22-year cycle is stronger (there are more full cycles) and is a well-documented parameter of rainfall in South Africa (Tyson & Dyer, 1975, 1978; Dyer & Gosnell, 1978; Vines & others, 1980; Jury & Levey, 1993; Kane, 2009; Du Toit & O'Connor, 2014).

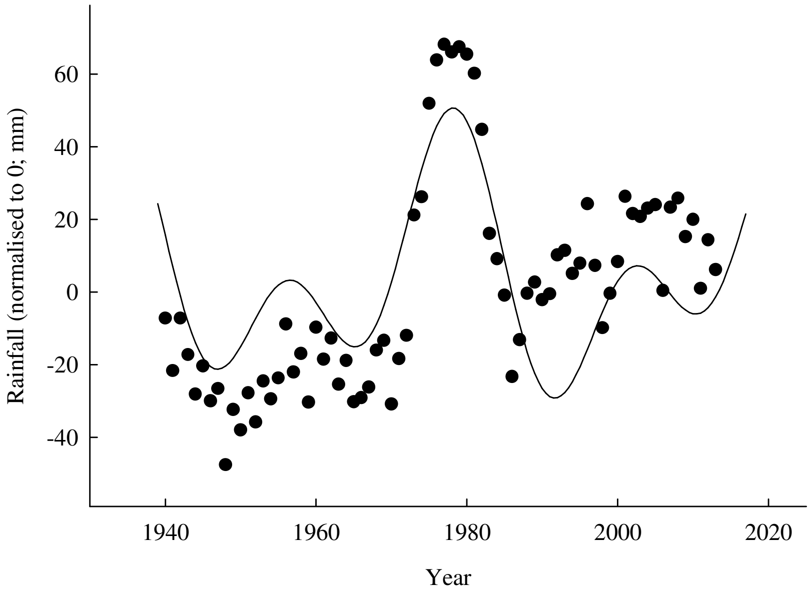

Figure 6. Rainfall data smoothed using a running mean of 10 years for Carnarvon (each dot represents the previous 10 years' rainfall). The regression is a double wave-form (see text)

CONCLUSION

Carnarvon Experiment Station rainfall data were typical of low-rainfall areas. Variation was high, and most years experienced below-average rainfall. The period from 1931-1971 was drier than after 1972, reflecting the general decrease in rainfall until 1971, and the sharp, then tapering, increase in rainfall thereafter. There was evidence of cyclicity, consistent of a 22-year period reported by many authors. The evidence of this cycle, as well as the recent higher-than-average rainfall is similar to the results from Grootfontein. In contrast, the Carnarvon site differed from the Grootfontein site in that there was limited evidence for a 40 to 60 year cycle, and the recent rainfall was not proportionally as high at Carnarvon.

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