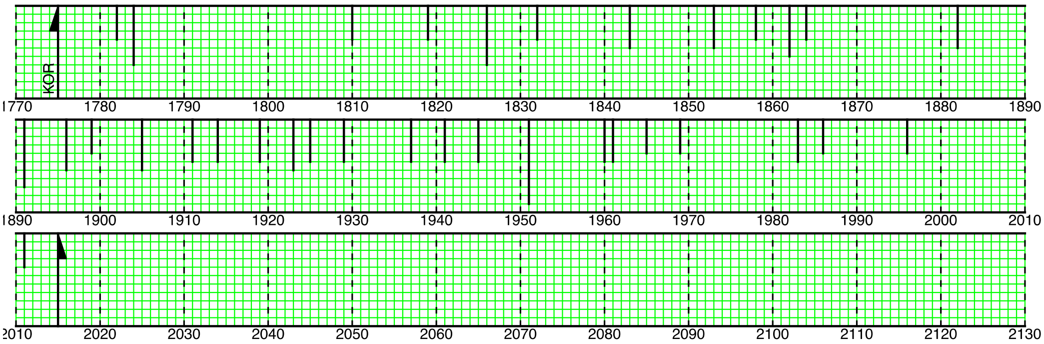
Supplementary Information

Appendix S1. Is there a missing ring in the MUR chronology at 1951?

A possible missing ring in the MUR chronology at 1951, the point at which the visual relationship between the series appears to break down (Figure 3), may be responsible for slightly greater variability in correlations with climate at MUR (Figures 4,S3-6). Drew et al. (2011) have noted that missing rings are more likely to occur in grove trees that isolated trees, and the MUR trees were sampled from groves (Hammer et al. 1981), whereas – at least at the time of sampling - KOR trees mostly grew as isolated individuals. However, not only is a missing ring in all (~50) series at MUR (Figure S2) that include this period site highly unlikely, but inserting one in all series from MUR at this point did not noticeably improve the relationship between the two chronologies (data not shown). Additionally, a comparison of the skeleton plots for the two sites shows no strong evidence either for or against a missing ring at MUR in 1951 (Figure S1). For example, signature rings noted in the skeleton plot for KOR include 1960, 1961 and 1965 while for MUR, 1960, 1964 and 1965 are identified as signature rings (Figure S1), making it difficult to assess the likelihood of a missing ring. Without concrete evidence of a missing ring in a well-replicated chronology, there is no reason to insert one.

A



B

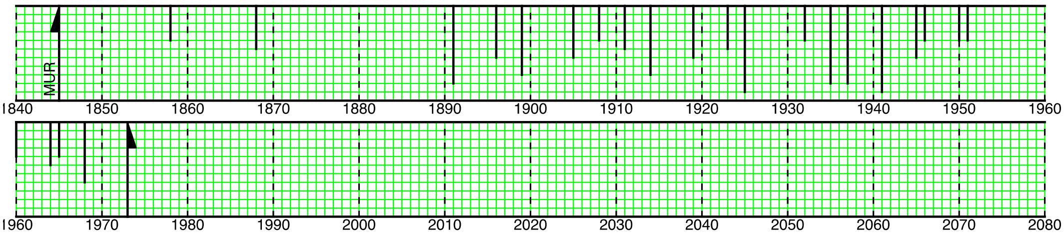
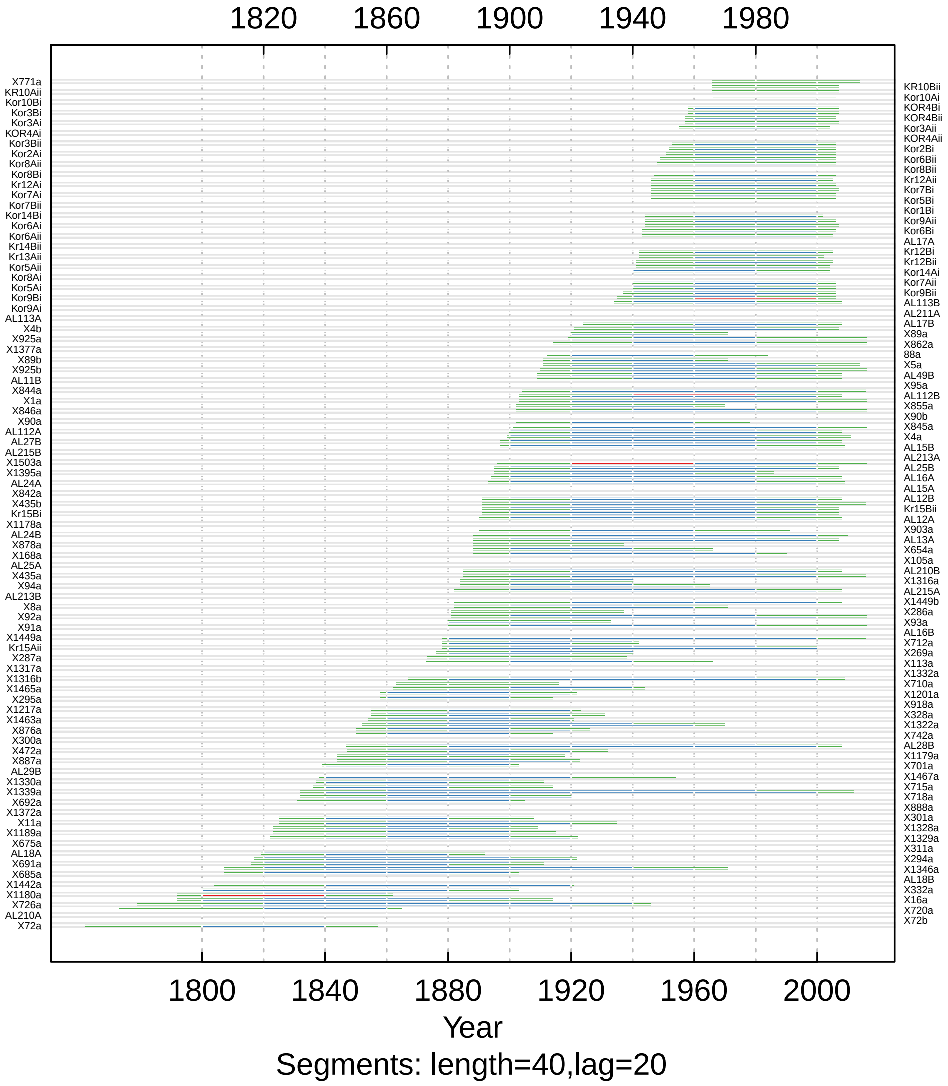


Figure S1 Skeleton plots for the two sites, produced using dplR (Bunn 2010). A: KOR; B. MUR. Rings that are particularly narrow relative to the 3 neighbouring rings on each side are shown on the plot. The longer the line, the narrower the ring relative to its neighbours.

A


1820
1860
1900
1940
1980
1800
1840
1880
1920
1960
2000
Year
Segments: length=40,lag=20

29

B

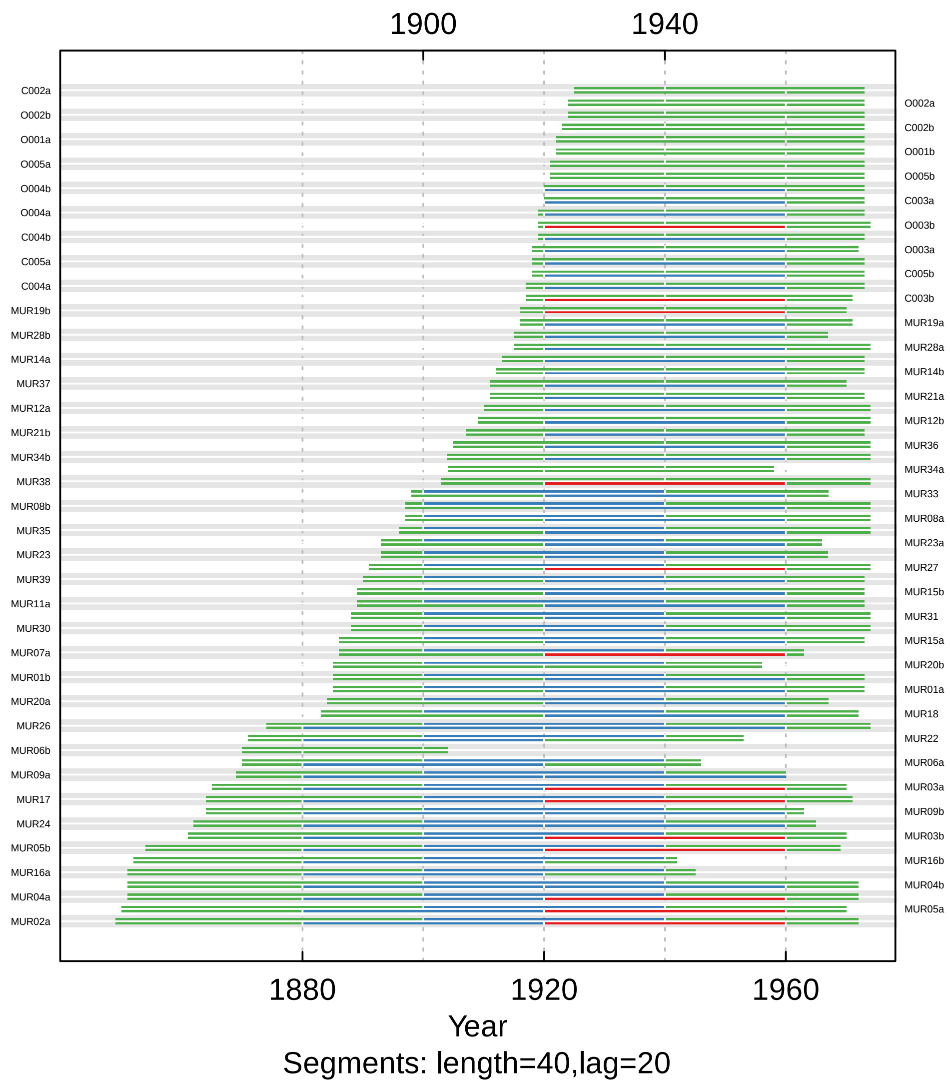


Figure S2 Plots of 40-year segments, overlapping by 20 years of all series in each site chronology. Each segment has been correlated (Spearman Rank) with a master series for the site that excludes the series in question. Blue indicates correlations significant at the *p* = 0.1 level, red indicates correlations not significant at this level and green represents segments for which no correlations have been calculated due to incomplete temporal overlap with the master series. A is KOR and B, MUR. Non-significant correlations, indicating potentially problematic segments, are most likely due to microsite factors, rather than dating errors. Package dplR (Bunn 2008; 2010) was used to generate these plots.

Appendix S2. Relationship of chronologies with climate

S2.1 Monthly climate correlations: temperature, precipitation, evapotranspiration

Our results indicate consistent monthly patterns in mean temperature-ring width relationships across the region for both KOR and MUR (Figure S3). Strongest positive and significant ($p \leq 0.05$) monthly grid-point correlations between both chronologies and mean temperature occur from July to October. Strongest negative (and generally significant, $p \leq 0.05$) monthly correlations occur from March to May. Overall, there is slightly more spread in correlations for MUR relative to KOR.

While the general pattern of correlation with monthly maximum temperature is broadly similar for the two sites, variability across the gridded data is greater for most months at MUR. There are statistically significant positive correlations between both chronologies and maximum July-August temperature for all gird points. Statistically significant negative relationships with maximum temperature during March-May exist for most grid points at KOR only. Positive relationships between minimum temperature and the chronologies (significant at KOR; $p < 0.05$) occur over the July-October period. Negative correlations over the January-March period are appreciably stronger for MUR than KOR, displaying mostly significant ($p \leq 0.05$) correlations. A comparison with monthly temperatures at the Darwin ACORN-SAT station, is consistent with those for the gridded data (Figure S4).

The pattern of correlations between the chronologies and gridded monthly precipitation is more difficult to discern than for temperature due to substantial variability in monthly correlations at both sites (Figure S3). There is a general tendency for both sites to have positive relationships with precipitation from July – October and from March to April. As for the temperature data, relationships with single point monthly data at the two closest long-term high quality stations (Oenpelli 1910-2013 and Warruwi 1916-2017) is consistent with correlations shown for the gridded precipitation data (Figure S4).

Gridded potential evapotranspiration across the study area is strongly (and mostly significantly) negatively correlated with ring width at KOR from March to May and with MUR from April-May.

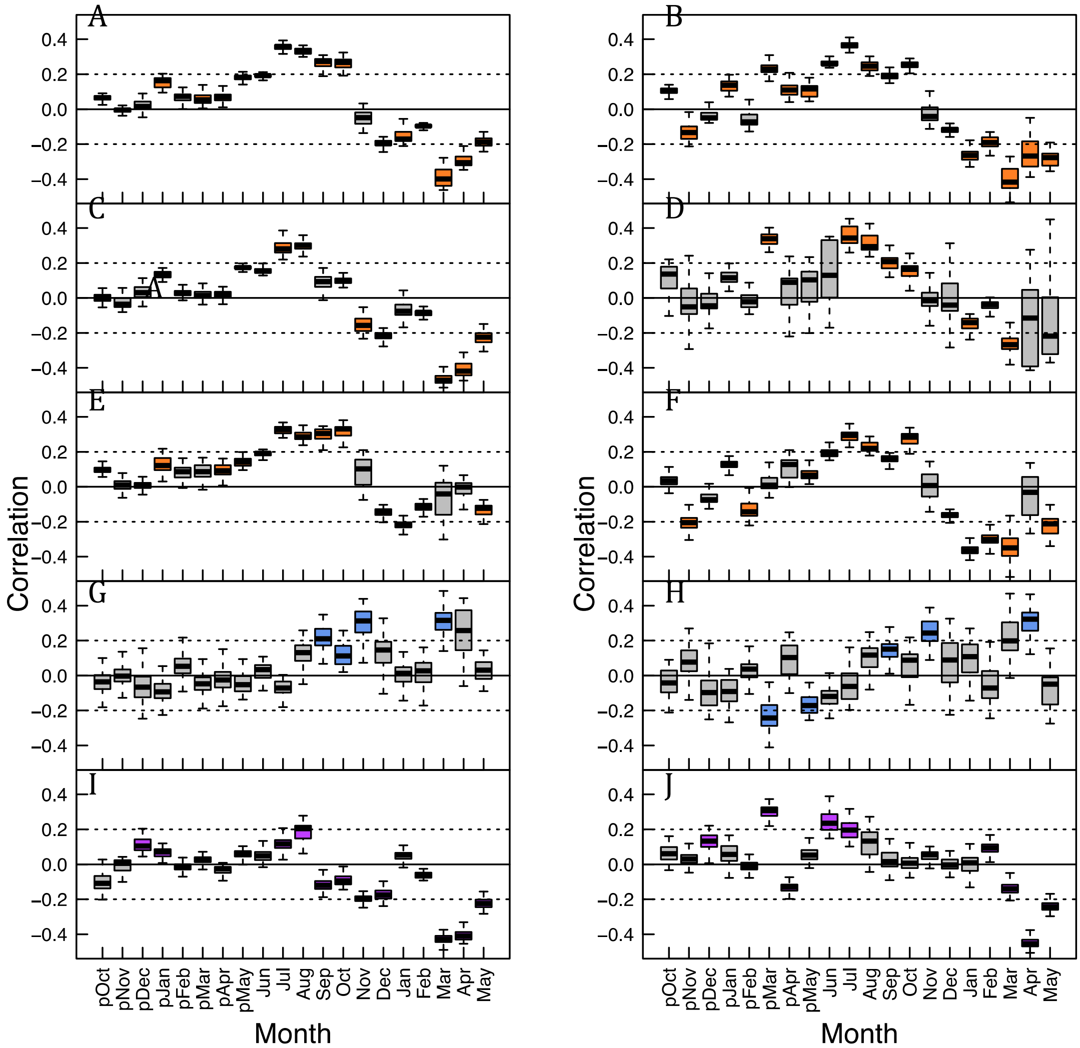


Figure S3 Boxplots of regional monthly correlations of the two chronologies with A - B mean temperature; C-D maximum temperature; E-F minimum temperature; G-H precipitation; I-J potential evapotranspiration. The left column shows monthly correlations for KOR and the right, MUR respectively. Coloured boxes are those for which all correlations are positive (negative) and dashed lines represent the 95% significance limits. A ‘p’ in front of the x-axis label denotes the year prior to growth.

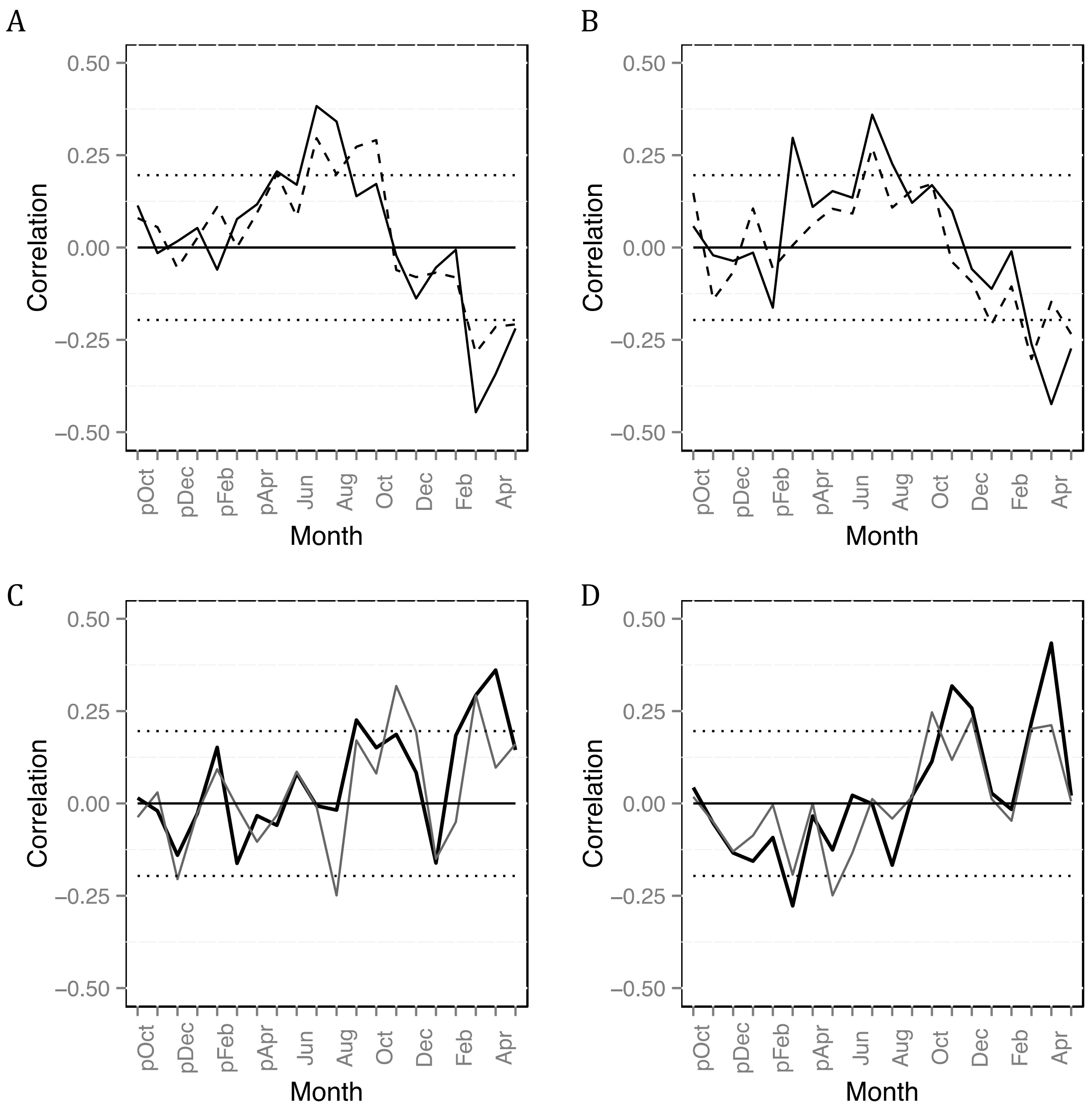


Figure S4 Correlations between the two chronologies and site temperature and precipitation. Left: KOR, Right: MUR. A and B Relationships with maximum (solid line) and minimum (dashed) temperatures at Darwin. C and D Relationships with Oenpelli (thick black line) and Warruwi (grey line) precipitation. Dotted lines represent the 95% significance level.

S2.2 Correlations with the drought indices

The pattern of correlations with the gridded SPEI scaled at 1, 3, 6 and 12 months (SPEI-1, SPEI-3, SPEI-6, SPEI-12) is shown in Figure S5. While the Figure in the main text simply shows the SPEI-3 correlations for the seasons as defined in the main text, here we show the values for each month; i.e. the 3-month SPEI value for October reflects the August-October period and that for February reflects December-February. The pattern in correlations is similar for the two chronologies (Figure S5) with greater spread evident for MUR. In broad terms, relationships with SPEI-1 and SPEI-3 tend to be positive from September-May although there is an hiatus in January – February (more obvious at KOR). SPEI correlations for KOR are positive and mostly significant ($p < 0.05$) from March - May at all timescales (Figure S5). MUR exhibits relatively strong negative correlations with the SPEI-6 from the previous March through to August while correlations for this same period at KOR are negligible. The relationship between both chronologies and the SPEI-12 is nominally negative until about March when it becomes positive.

Correlations with the sc-PDSI for 1 and 3 months are weak from the previous October until August for KOR (Figure S6), and from the previous October until the previous March-May at MUR when they become nominally negative. This pattern is very similar to that for SPEI1 and 3. The relationship steadily becomes positive over the next 3 (KOR) -6 (MUR) months. There are strong positive (significant for KOR) correlations with the 12-month sc-PDSI over the June-November period at which point, the strength of correlations drops and then steadily increases until May. These positive correlations are not observed for the 12-month SPEI, and neither are the high positive correlation values for single months for the 6-month sc-PDSI (Figures S5 & S6). These differences in responses to the two drought indices at longer time-scales, particularly at the 12-month scale demonstrates it may be unwise to attempt to model drought at these longer scales without better understanding the reasons for the considerable differences in correlations with the two indices at these longer time scales.

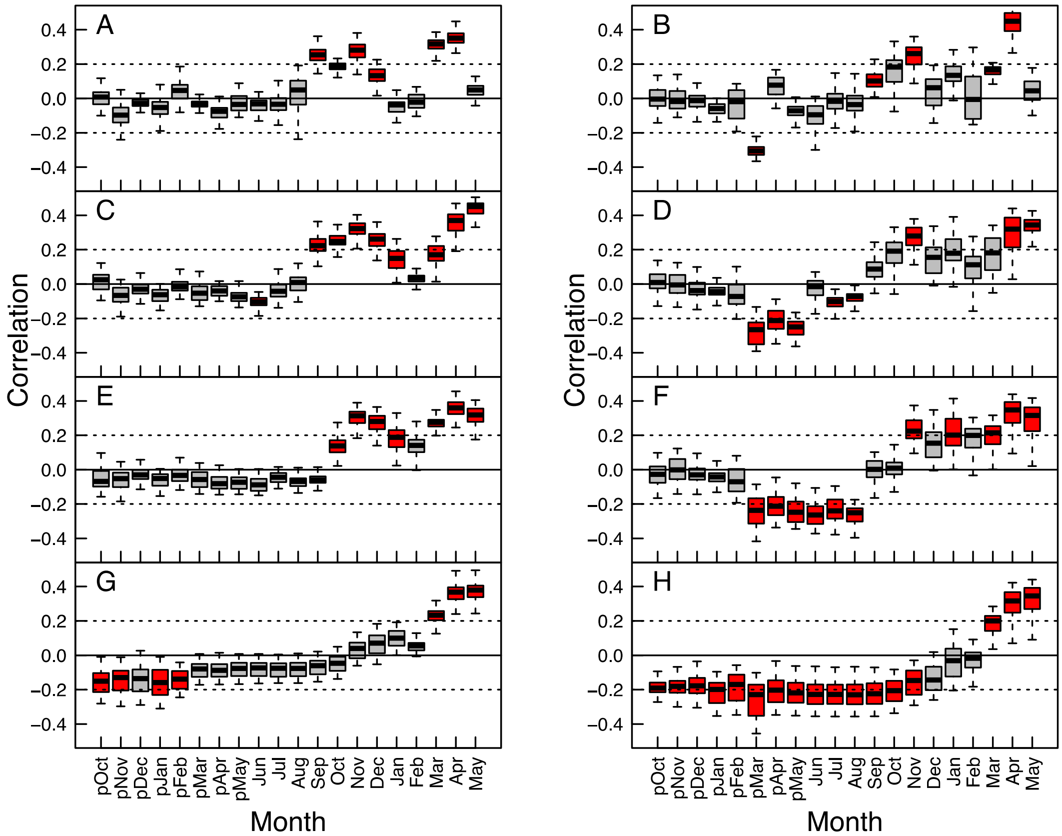


Figure S5. Boxplots of Pearson correlations of KOR (A, C, E, G) and MUR (B, D, F, H) with variously scaled SPEI indices. A box plot for December 3-month SPEI relates to the SPEI scaled over Oct – Dec. A and B monthly: SPEI-1; C and D SPEI-3; E and F SPEI-6; G and H SPEI-12. A ‘p’ in front of the x-axis label denotes the year prior to growth.

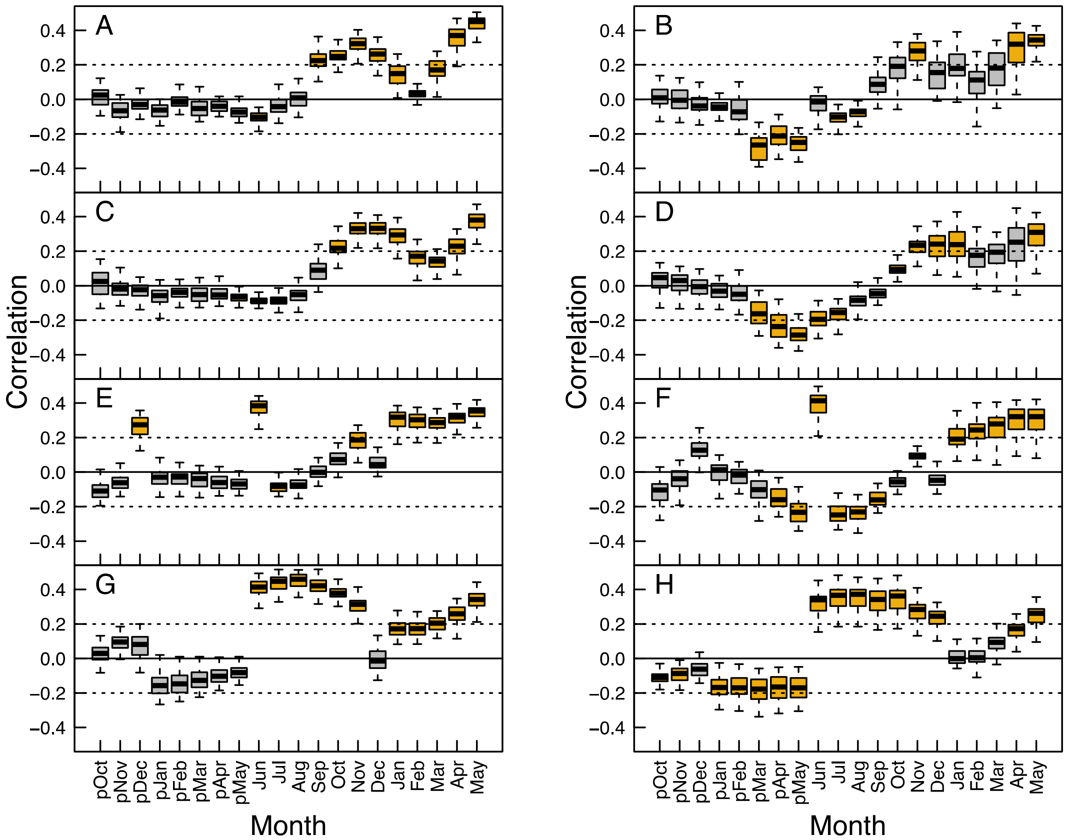


Figure S6. As for Figure S3, but for scPDSI-1 and scPDSI averaged over 3,6,12 month periods.

S2.3 Site differences in climate relationships at the monthly scale

As previously identified by Baker et al. (2008), there can be important differences between climate sensitivity at different sites. With lower variability in correlations with most climate variables (Figures S3, S5-6), the slightly inland site, KOR appears to better represent climate across the region than does the more coastal MUR. There are, however, several important factors that must be considered in relation to this lower variability.

The first is the slightly different period over which correlations were calculated for the two sites, and the second is simply related to geographic distance from each site to the centroid of each grid point for the gridded data. However, based on the drought indices for the period September – May (chosen to account for, on average, 99% of annual moisture input; Figure 2A), neither of these two factors appears to be important for months when relationships are relatively strong (Figures S7 & S8). The most obvious differences associated with these two factors are: a change from a weakly negative to weakly positive correlation between KOR and the January-February SPEI-1 for the 1903 – 1973 period; a stronger correlation between ring width at KOR and the November – May period sc-PDSI for the 1903 – 1973 period; and some small geographical differences in correlations, again for months with relatively variable and weak correlations (Figures S7 and S8).

The broader area from which the MUR trees were sampled may also have resulted in greater variability in responses. Finally, the competitive environment of the trees sampled may matter. Differential sensitivity of isolated and grove trees can lead to important differences in growth and its timing in *C. intratropica* (Drew et al., 2011). Trees in more densely populated groves are more sensitive to water availability and develop greater water deficits more rapidly than isolated trees. In contrast, isolated trees experience a more rapid recovery from severe water deficits at the start of the following wet season (Drew et al., 2011). The slightly earlier positive relationship between the KOR chronology (relative to MUR) and the drought indices at the start of the wet season may be consistent with the results of this detailed physiological work. However, our descriptions of the two sites relate only to what was observed at a point in time, and may not reflect growing conditions prior to this. Therefore, our comments here are very tentative. Drew et al. (2014) concluded that, where possible (and obviously subject to the constraint that prior growing conditions are not necessarily known) hydroclimate reconstructions based on *C. intratropica* should use sites that incorporate both isolated trees and trees from groves.

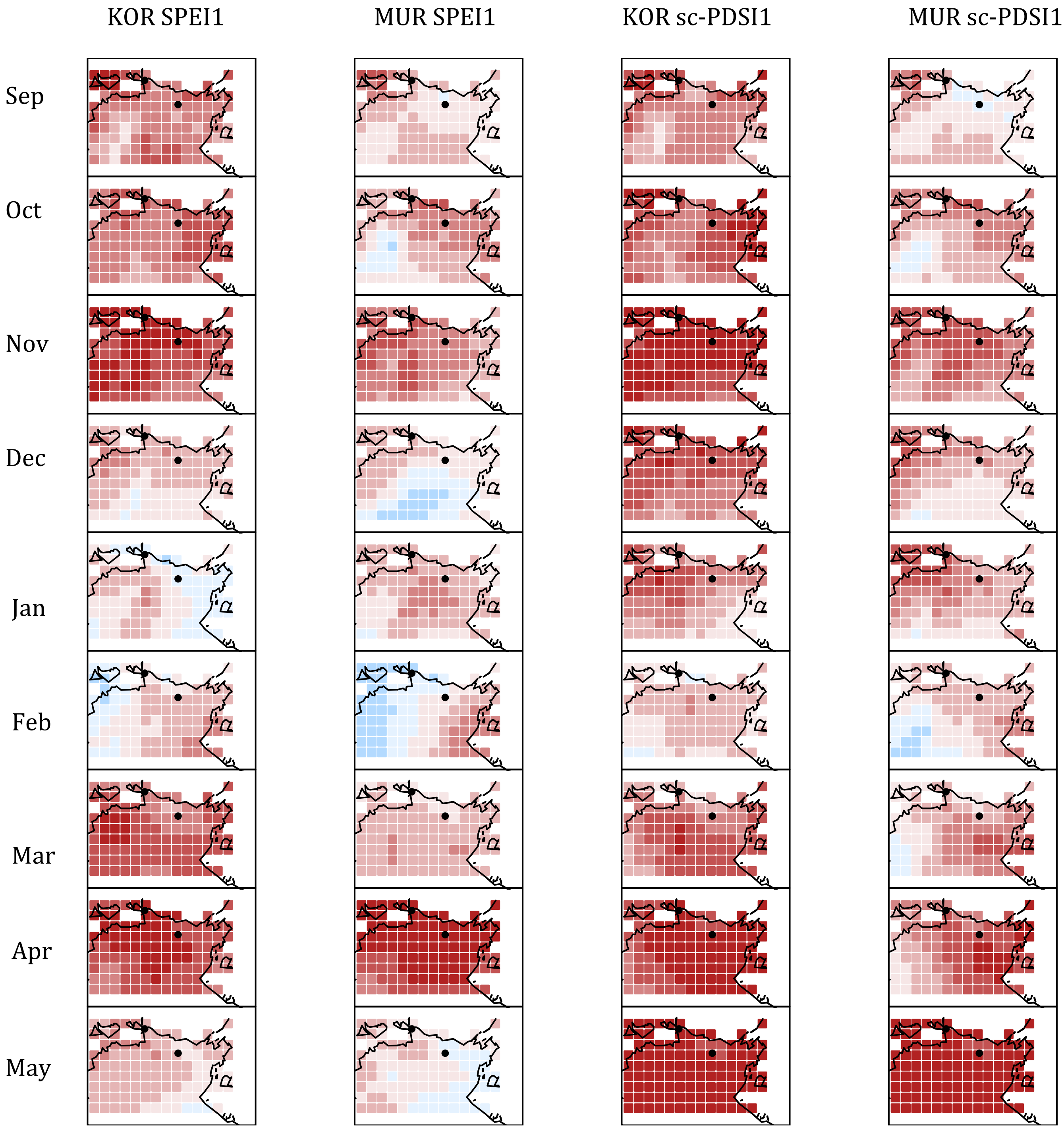


Figure S7. Correlations across space, KOR and MUR with SPEI1 and sc-PDSI1 (1903 – 1973), period in common between chronologies

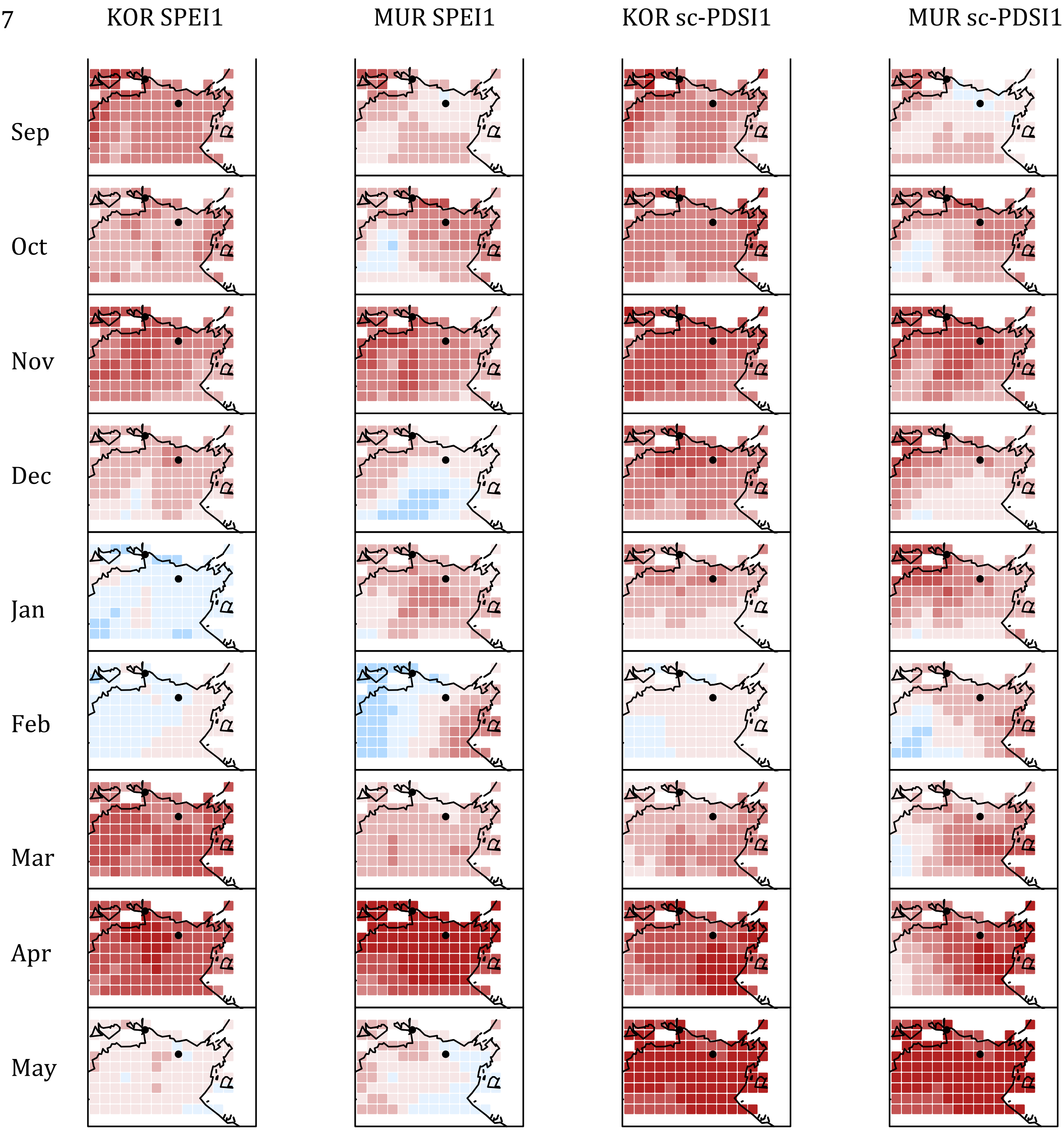


Figure S8. Correlations across space, KOR and MUR with SPEI1 and sc-PDSI1, period in common between climate data and each chronology respectively (KOR 1903 – 2015; MUR 1903 – 1973)

S2.3 Spatial correlations amongst gridded data

Overall, spatial correlations amongst gridded data are highest for temperature (~0.88) data and lowest for precipitation (0.59) and then the drought indices (0.69; Table S1). The lower correlation in precipitation across the region is consistent with the greater variability in relationships with the chronologies (Figure 4, Figure S3).

Variable	**Average correlation**	**Standard deviation**
Mean temperature	0.91	0.04
Maximum temperature	0.89	0.03
Minimum temperature	0.86	0.07
Precipitation	0.59	0.07
Potential evapotranspiration	0.89	0.03
SPEI	0.69	0.06
Sc_PSDI	0.69	0.06

Table S1: Average intercorrelations amongst all gridded climate data for each variable. Values calculated are based on monthly data and then averaged for the year.

Year	KOR	MUR	Oenpelli total annual rainfall	Warruwi total annual rainfall	Oenpelli days of rain	Warruwi days of rain
1911	*	*				
1912						
1913						
1914 E	*		-1.97		-1.78	
1915						
1916 L						
1917 L						
1918					-2.33	
1919 E	*		-1.06	-1.07	-1.93	
1920						
1921						
1922						-1.84
1923	*			-1.21		
1924 L						
1925 E	*	*	-2.02		-1.38	-1.84
1926						-1.66
1927						
1928 L				-1.66		
1929	*					-2.28
1930				-1.06		-2.03
1931				-1.27	-1.02	
1932						
1933						
1934			-1.10			
1935		*	-1.21	-1.63	-2.63	-1.66
1936						
1937		*				-1.53
1938 L						
1939						
1940 E						
1941 E	*	*	-2.34	-1.31	-2.58	-1.10
1942 L						
1943					-1.78	
1944					-1.18	
1945	*	*	-1.03			
1946 E			-1.22	-1.03	-1.28	
1947						
1948						
1949 L						
1950 L						
1951 E	*		-2.17	-1.38	-1.78	-1.35

1952						
1953						-1.47
1954 L						
1955 L						
1956 L						
1957 E						
1958						
1959						
1960	*		-1.44			
1961	*					
1962						
1963 E						
1964 L						
1965 E						
1966						
1967						
1968	*					
1969 E			-1.35	-1.63		-1.04
1970						
1971						
1972 E						
1973 L						
1974 L						
1975 L						
1976				-1.62		
1977 E						
1978	*					
1979	*					
1980	*					
1981						
1982 E						
1983						
1984						
1985						
1986						
1987 E			-1.02			
1988 L						
1989						
1990						
1991 E			-1.60			
1992						
1993 E			-1.12			
1994 E						
1995						
1996	*					
1997 E						

1998 L						
1999						
2000						
2001				-1.98		
2002 E				-1.71		-1.22
2003						
2004					-1.23	-2.28
2005						
2006 E				-1.25		
2007 L			-1.05	-1.04	-1.18	
2008 L						
2009 E						
2010 L						
2011 L						
2012						
2013						
2014						
2015 E				-1.43		

Table S2: Narrow rings (identified after filtering series with a 32-year spline to remove low frequency variability) and years in which precipitation, and days on which precipitation fell, were well below average (more than one standard deviation below average). One (two) * indicates a ring at least one (two) standard deviations below the mean are listed for individual chronologies. Also shown are years in which El Niño or La Niña events began (data obtained from http://www.bom.gov.au/climate/enso/lnlist/). Shaded areas show the periods covered by the different records. Both precipitation values apply to the August – July period. Warruwi rainfall data extends from 1916 – 2018 and Oenpelli from 1910 – 2013. Individual station data has been used here rather than the gridded product because it is this information is not available for individual grid points in the monthly GPCC data set.

References

Bunn, A.G. (2008). A dendrochronology program library in R (dplR). *Dendrochronologia* 26: 115-124