Tree rings & rainfall patterns in Western Australia

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Climate and *Callitris* in southern WA

Louise Cullen

Cullen & Grierson (2009). Multi-decadal scale variability in autumn-winter rainfall in south-western Australia since 1655 BP as reconstructed from tree rings of *Callitris columellaris*. *Climate Dynamics* 33, 433-444.

Sgherza, Cullen & Grierson (2010). Climate-isotope relationships in tree rings of three *Callitris* species from semiarid woodlands in south-western Australia. *Aust J Botany* 58, 1-13.

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Yun Li & Rex Lau

CSIRO Mathematical and Information Sciences

A Statistical Downscaling Model for Southern Australia Winter Rainfall

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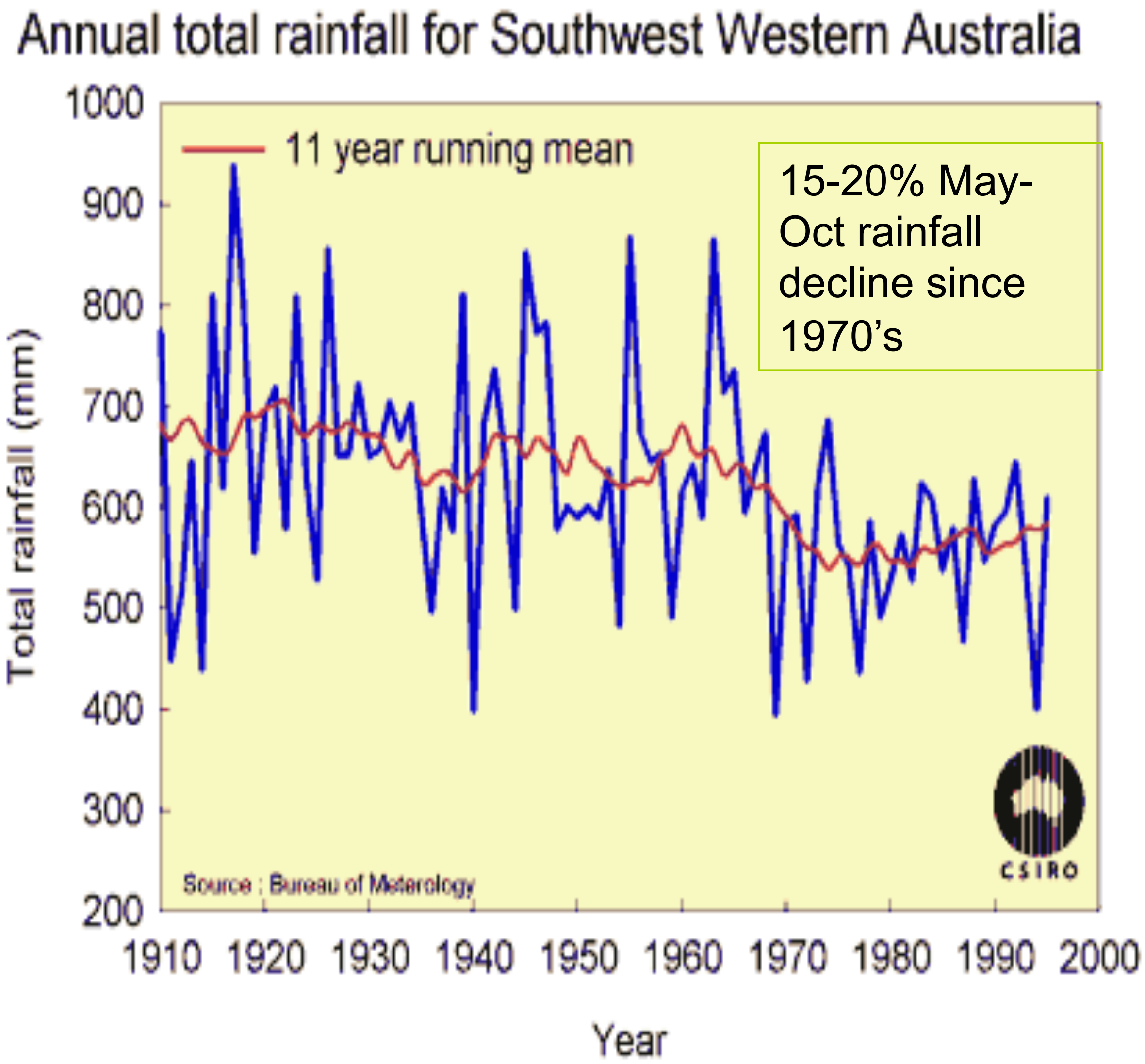
ABSTRACT

A technique for obtaining downscaled rainfall projections from climate model simulations is described. This technique makes use of the close association between mean sea level pressure (MSLP) patterns and rainfall over southern Australia during winter. Principal components of seasonal mean MSLP anomalies are linked to observed rainfall anomalies at regional, gridpoint, and point scales. A maximum of four components is sufficient to capture a relatively large fraction of the observed variance in rainfall at most locations. These are used to interpret the MSLP patterns from a single climate model, which has been used to simulate both present-day and future climate. The resulting downscaled values provide 1) a closer representation of the observed present-day rainfall than the raw climate model values and 2) alternative estimates of future changes to rainfall that arise owing to changes in mean MSLP. While decreases are simulated for later this century (under a single emissions scenario), the downscaled values, in percentage terms, tend to be less.

Li Y & Smith I (2009). *Journal of Climate* 22, 1142-1158.

Proxies to understand our changing rainfall?



Rainfall in SW-WA

Type 1: prefrontal air masses, N/NW direction – dominates regional rainfall, May-Oct (mainly May-July)

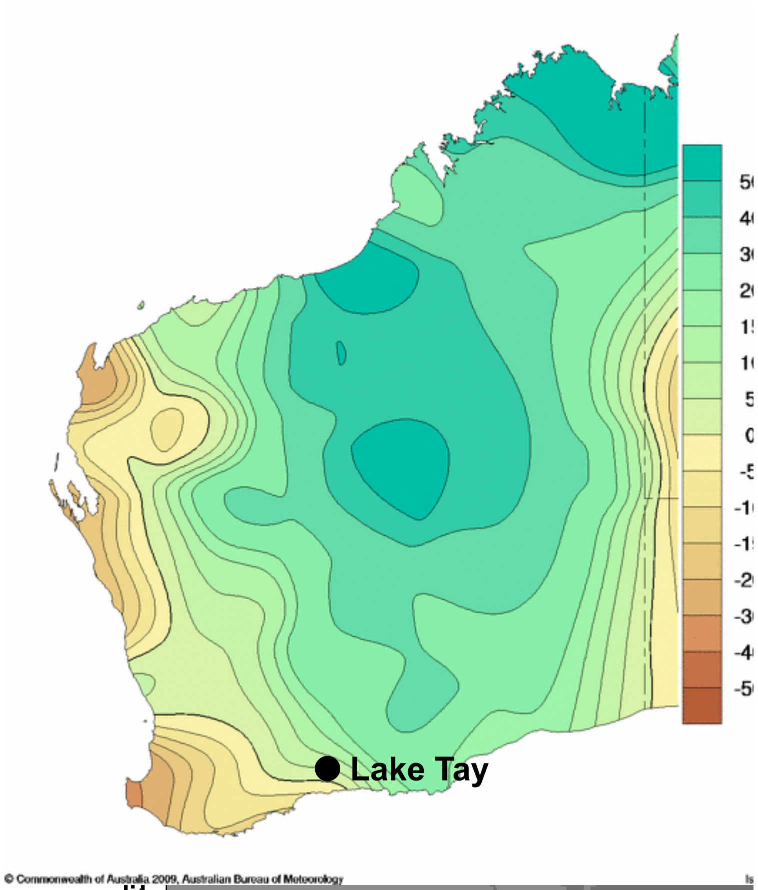
Type 2: from onshore southerly flow, less dominant except in south, distribution more even – increased 1960-1990

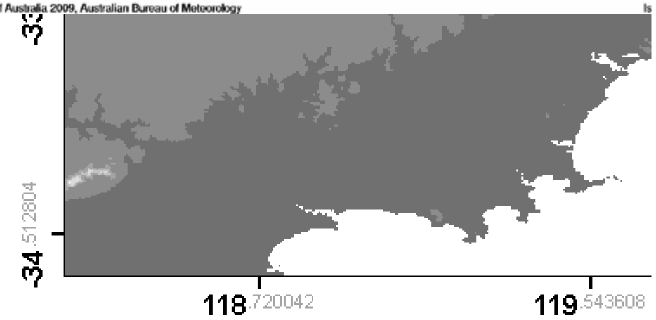
→ **recent decline likely due to less Type 1 rainfall**

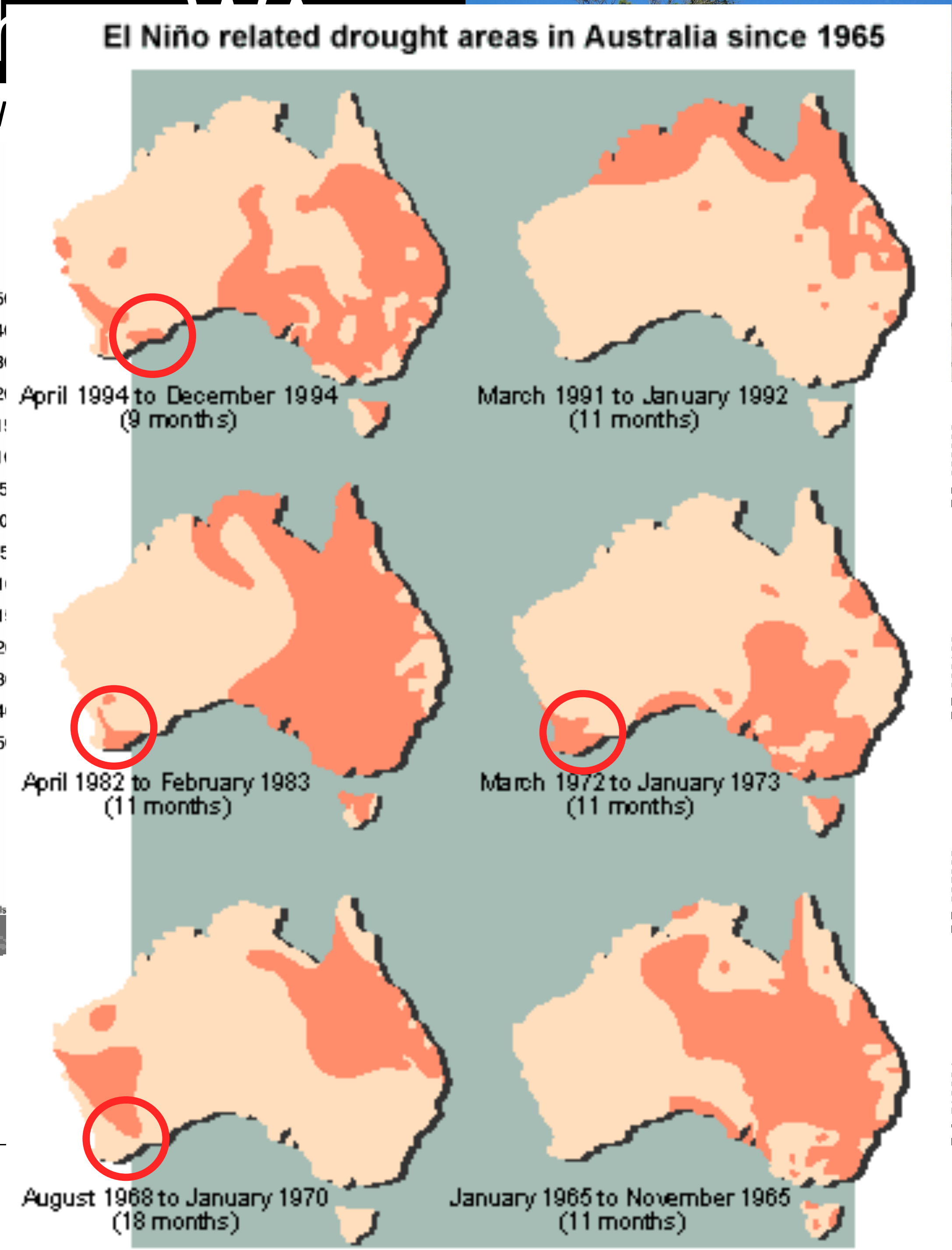
Hope et al. 2006, Cimate Dynamics 26; Van Ommen and Morgan 2010 *Nature Geoscience* (7 Feb)

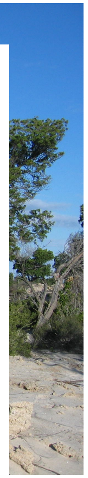
Lake Tay, south

Trend in total annual rainfall 1970-2008 (mm/



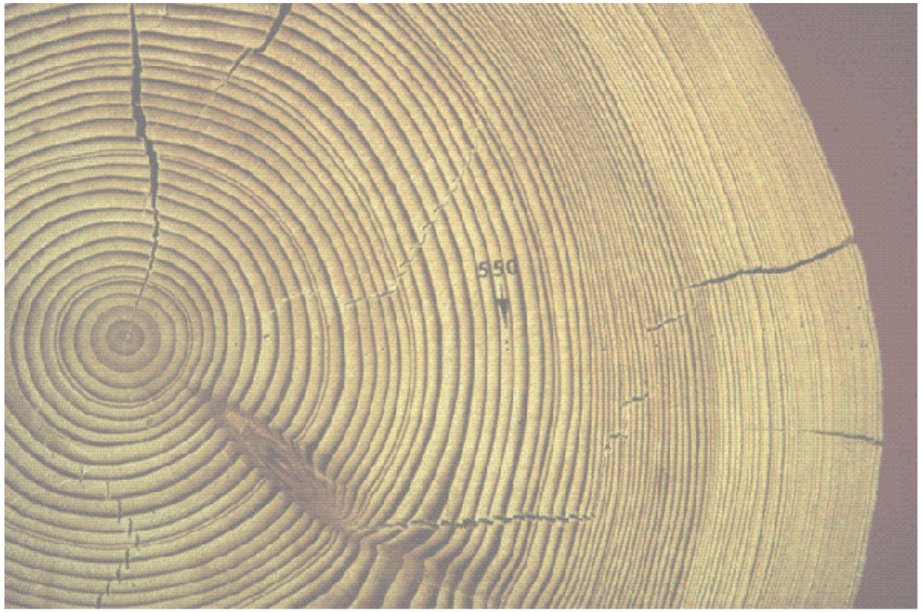






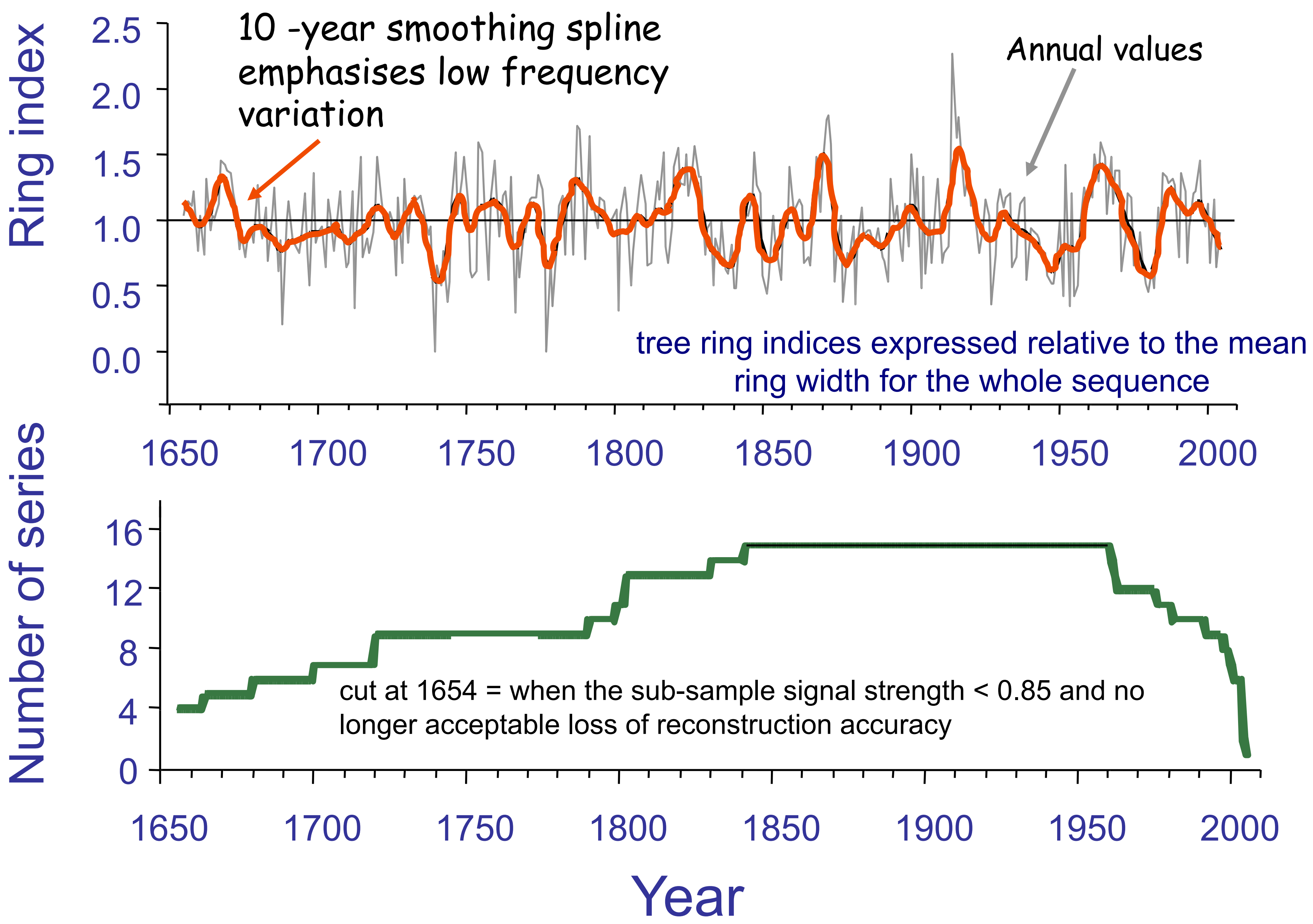
How old are *Callitris* at Lake Tay?

- Individual tree ages 160-397 yrs
- Average age of trees included in the chronology 235 yrs.
- Cross-dated measurements extended back to 1601 AD.



…. Longer chronology possible (preserved material)

Tree-ring width chronology of *C. columellaris* at Lake Tay



2-step standardisation & detrending procedure in ARSTAN40c, Cook and Krusic 2006

Descriptive statistics for three *C. columellaris* chronology types

standard (STD) chronology - autocorrelation unique to each series is retained, retains disturbance as well as climate effects

Chron. type	MS	SD	EPS	Mean correl.	Var (%)
STD standard	0.341	0.345	0.947	0.543	57.7
RES residual	0.368	0.307	0.950	0.560	59.1
ARS arstan	0.331	0.333	-	-	-

residual (RES) chronology - all autocorrelation is removed through autoregressive modelling

common persistence (ARS chronology) used for subsequent analysis of climate-growth relationships and reconstruction of rainfall - retains long-term trends related to climate & dampens long-term trends related to non-climatic processes.

he relative change in ring-width from one year to next I.e. high

ean index value (scaled to be 1.0). = measure of low frequency

between all series.

ined by the 1st eigenvector of a PCA.

which quantifies the degree to which the chronology represents the hypothetically perfect chronology (a 0.85 threshold)

Mean correl., Var (%) and EPS were calculated for the period common to all series, 1841 – 1960.
Mean correl., EPS and Var (%) are not produced for the ARS chronology.

Descriptive statistics for three *C. columellaris* chronology types

No. trees / cores	Time span[1]	Missing rings (%)	Chron. type	MS	SD	EPS	Mean correl.	Var (%)
11 / 15	1654-2005 (4)	1.62	STD standard	0.341	0.345	0.947	0.543	57.7
			RES residual	0.368	0.307	0.950	0.560	59.1
			ARS arstan	0.331	0.333	-	-	-

MS (mean sensitivity) is a measure of the relative change in ring-width from one year to next I.e. high frequency variation)

SD (standard deviation) is about the mean index value (scaled to be 1.0). = measure of low frequency variation

Mean correl. is the average correlation between all series.

Var (%) is the percentage variance explained by the 1st eigenvector of a PCA.

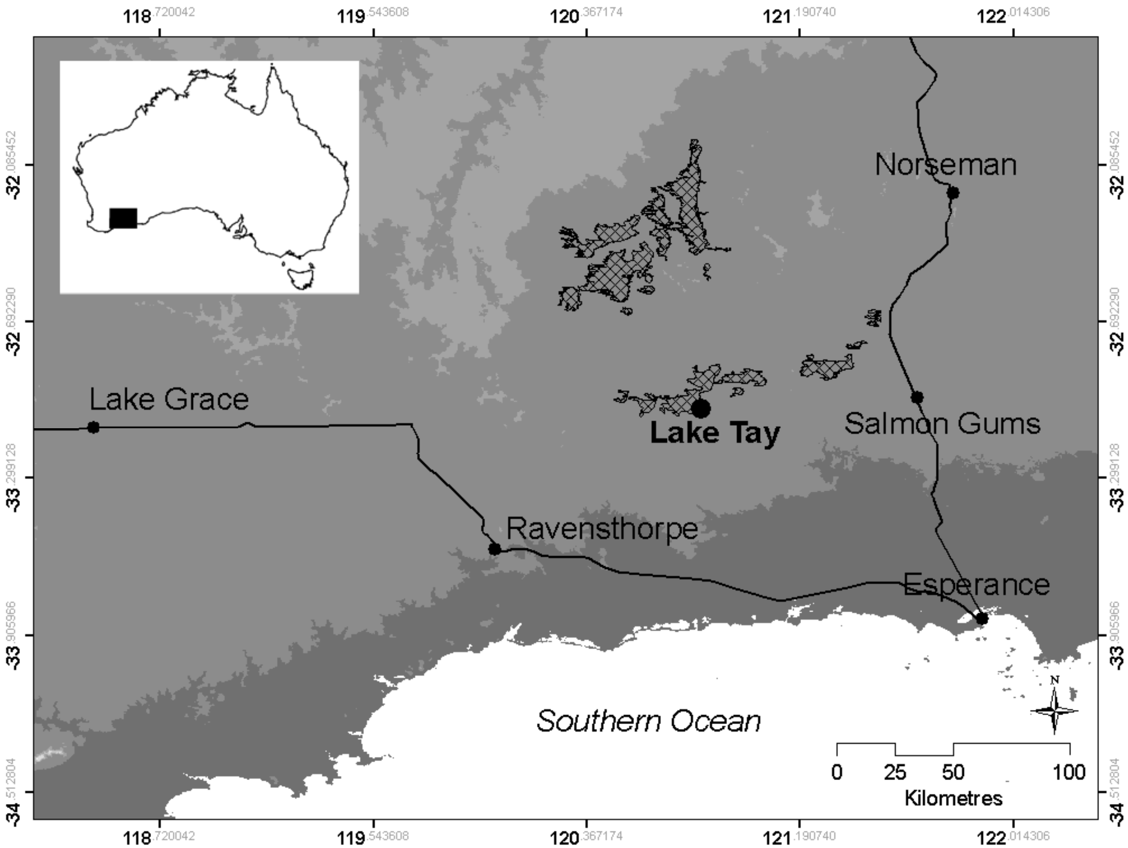
EPS is the Expressed Population Signal - quantifies how well the chronology represents the hypothetically perfect chronology (a 0.85 threshold)

Mean correl., Var (%) and EPS were calculated for the period common to all series, 1841 – 1960.
Mean correl., EPS and Var (%) are not produced for the ARS chronology.

Climate signals in the Lake Tay chronology

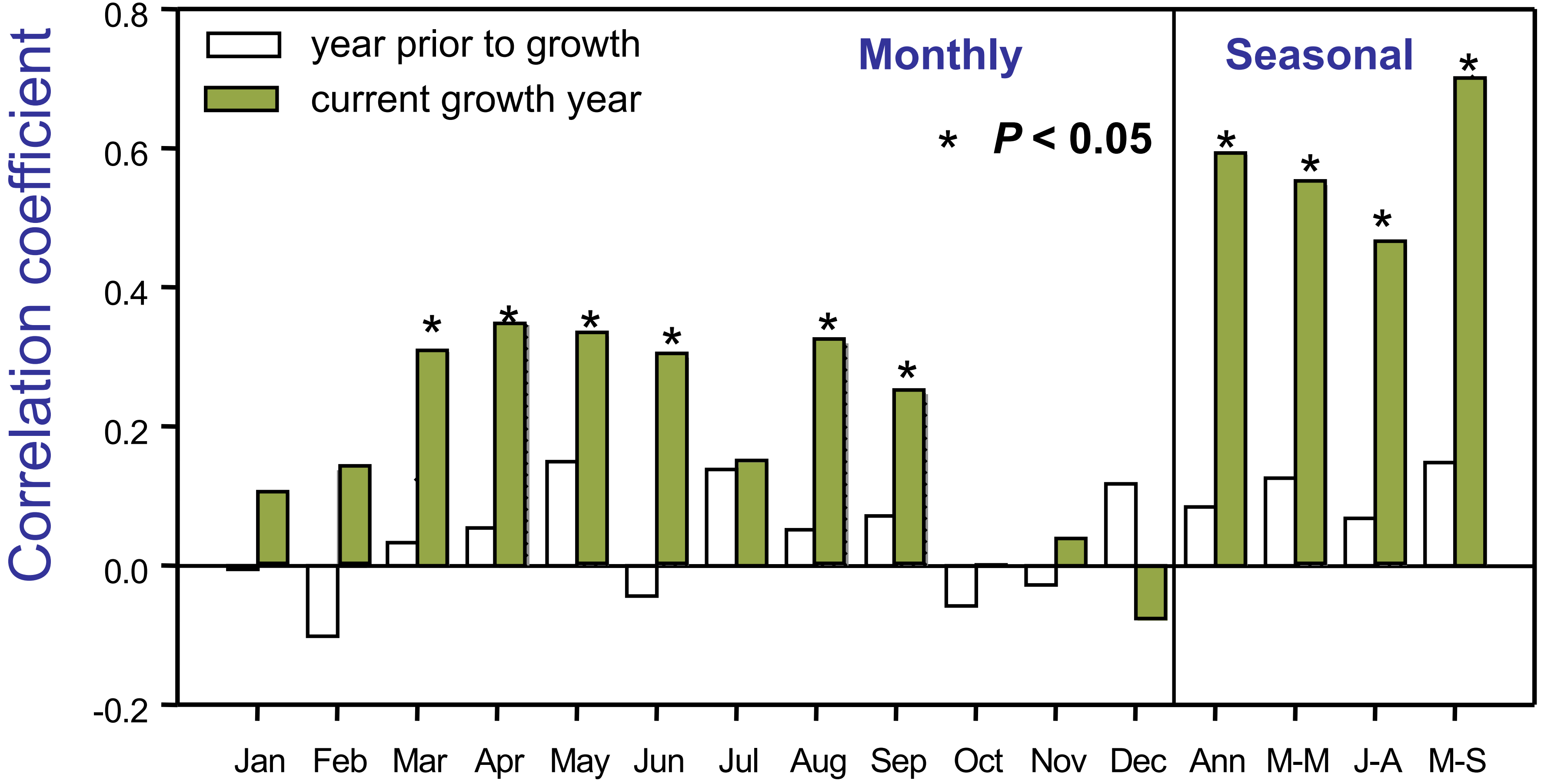
'Data Drills' used to determine variability of climate within sites (Queensland Department of Natural Resources and Mines).

Grids of climate data (1889 - present) interpolated from point observations of Bureau of Meteorology



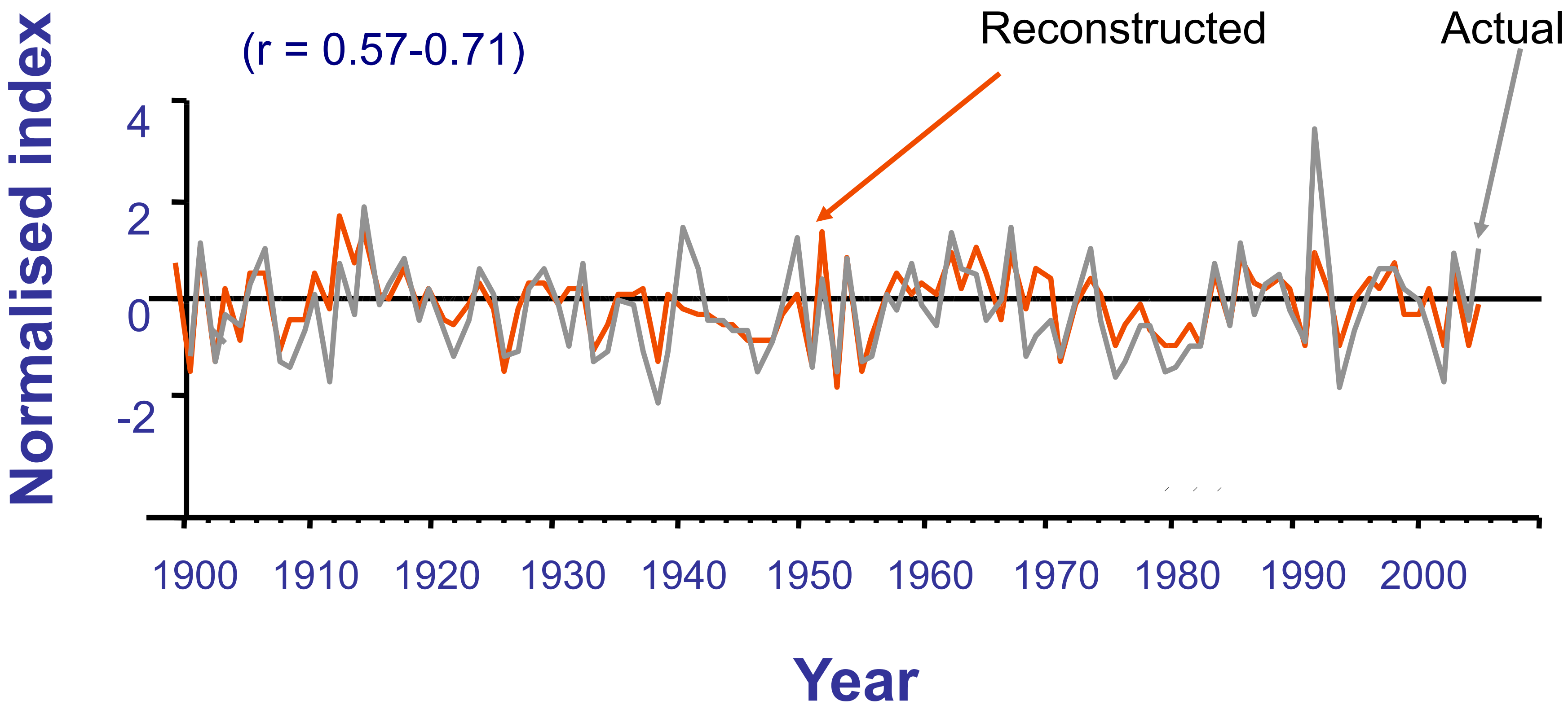
Ravensthorpe (1902 – current)
Norseman (1897 – current)
Salmon Gums (1933 – current)

Growth-climate relationships: Lake Tay ARS chronology of ring widths & rainfall anomalies



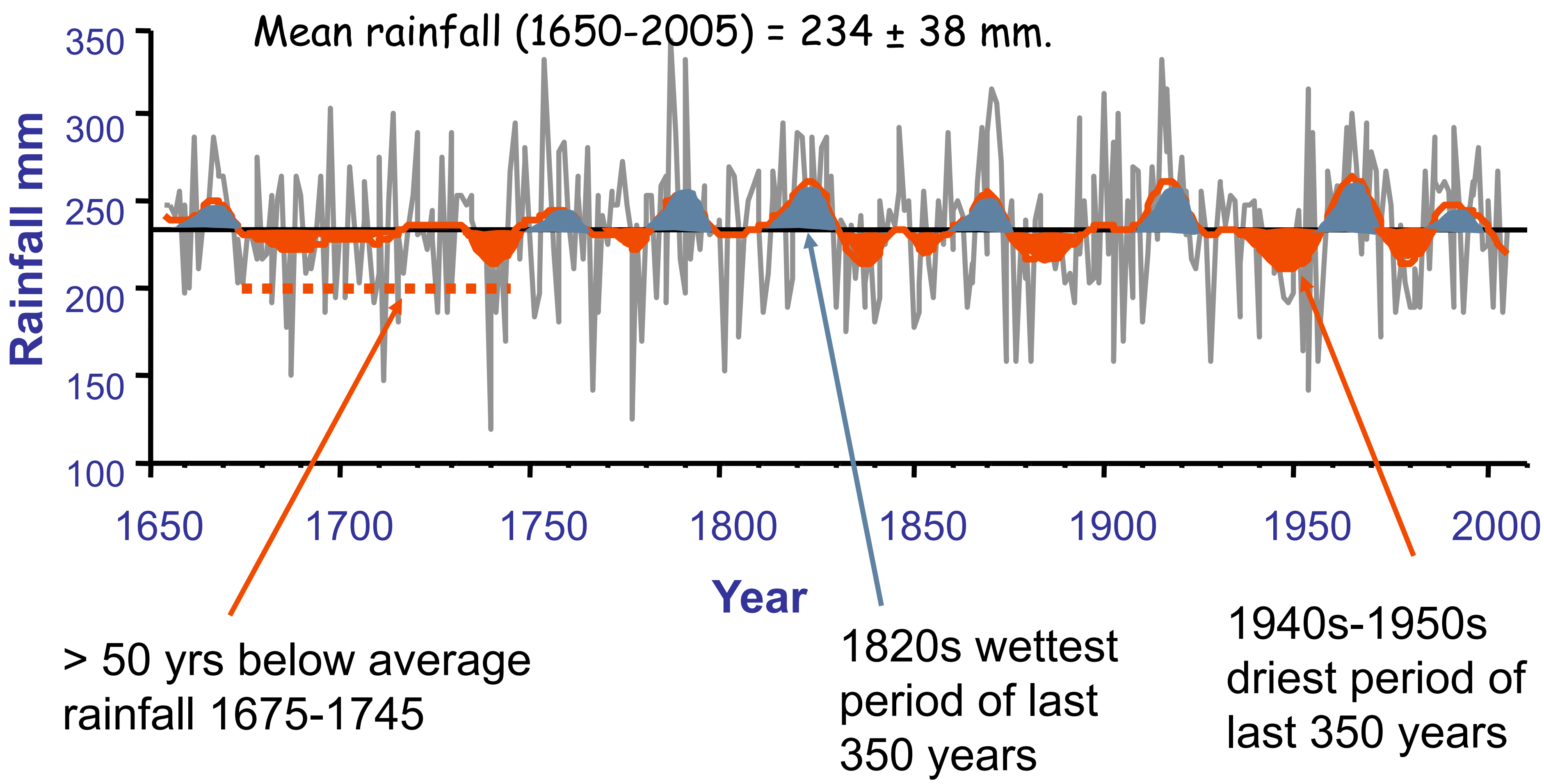
- chronology more strongly correlated with annual or seasonal rainfall than individual mo
- chronology most strongly correlated with rainfall from March-Sep (autumn-winter) of the current growing year (r = 0.70)
- no “carry-over “ effect of growth of the preceding year

Reconstructed autumn-winter rainfall for 1902 - 2005 using the Lake Tay ARS chronology against actual



- no linear trend in the difference between predicted and actual rainfall
- 21-year running correlation between actual and reconstructed rainfall always significant

Reconstructed autumn-winter (Mar-Sep) rainfall for Lake Tay

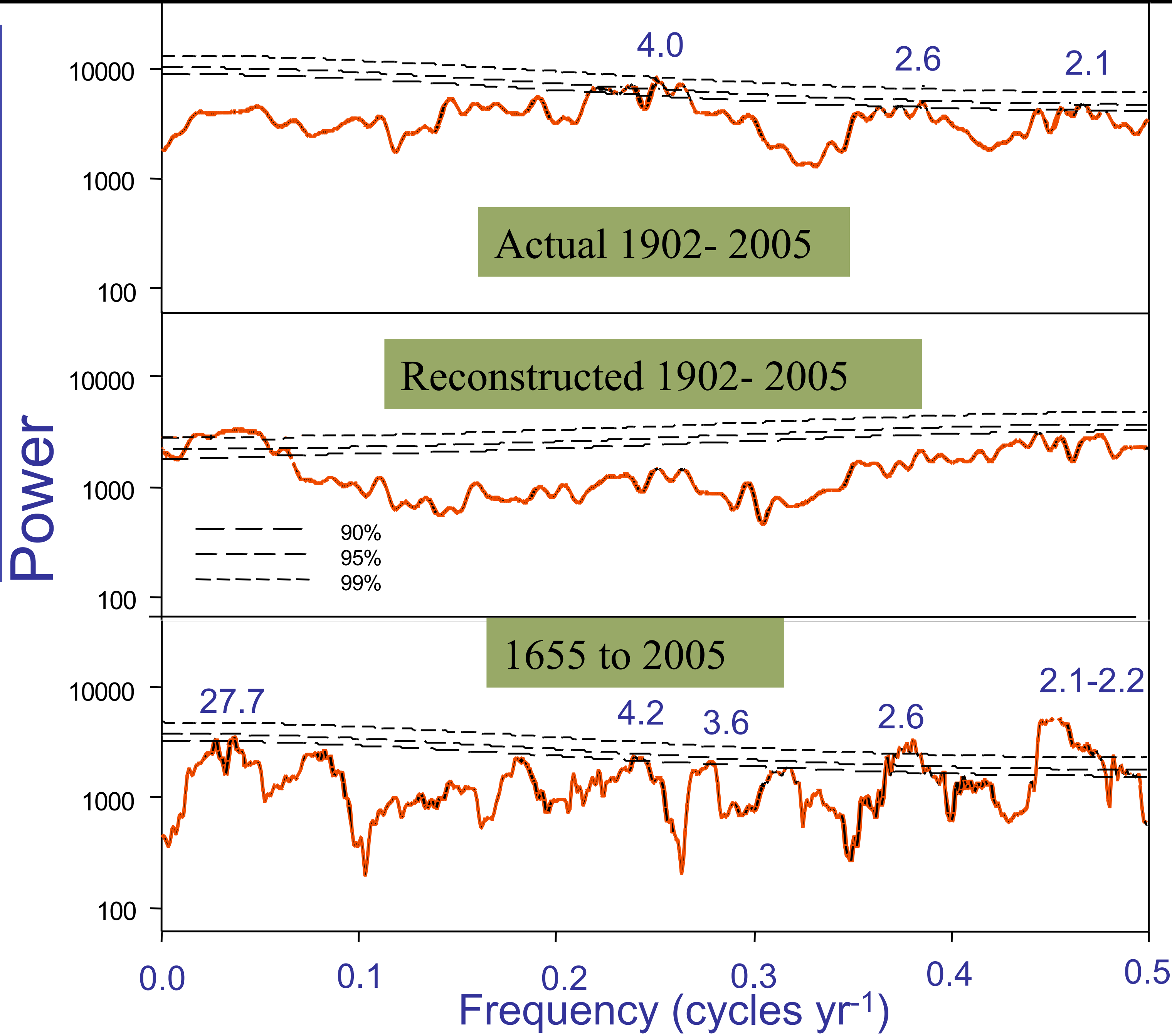


- multi-decadal cyclicity of rainfall over last 350 years
- dry periods often last 20 - 30 years with periods of above average rainfall that tend to persist for only 15 years or so.
- dry periods have persisted for > 50 years in recent past

Spectral correspondence of reconstructed rainfall since 1655

- multi-decadal cyclicity also evident (28-30 years years)

- low frequency cycles in rainfall (2-7): ENSO?



Climate indices for the SW

1. CSIRO Mark 3 model : Rainfall cycles an expression of variation in high-intensity rainfall events associated with inter-decadal variability in SAM, the principle mode of variability in Southern Hemisphere climate. Decline in rainfall in recent decades of SW coincides with an upward trend in SAM since 1965.

OR

1. Decline in rainfall associated with a large-scale climatic shift over the southern and western Indian Ocean, evident as a switch from negative to positive SSTs around 1970 (Samuel et al. 2007)

Can we see these climate signals in our tree ring chronology?

SOI = Climatic Research Unit's Southern Oscillation Index
Niño4 = sea surface temperature anomalies in the Niño 4 region
SAM = the Southern Annular Mode (SAM)
SI-SSTs = sea surface temperature anomalies in the southern Indian Ocean
TWI-SSTs = sea surface temperature anomalies tropical western Indian Ocean

Lake Tay ARS chronology only correlated to SOI (ENSO)

		Climate Index				
		SOI	**Niño4**	**SAM**	**SI-SSTs**	**TWI-SSTs**
	Correl. period	1866-2005	1950-2005	1957-2005	1856-2005	1856-2005
	Season					
Previous year	Annual	0.03	0.08	-0.14	-0.08	0.05
	Mar-May	-0.05	0.14	0.01	-0.04	0.08
	Jun-Aug	0.11	0.04	-0.24	-0.08	0.04
	Mar-Sep	0.06	0.08	-0.16	-0.06	0.07
Current year	Annual	**0.20***	-0.13	-0.10	-0.09	-0.07
	Mar-May	0.10	-0.13	-0.04	-0.05	-0.10
	Jun-Aug	**0.25***	-0.08	-0.08	-0.13	-0.07
	Mar-Sep	**0.21***	-0.11	-0.07	-0.09	-0.09

SOI = Climatic Research Unit's Southern Oscillation Index
Niño4 = sea surface temperature anomalies in the Niño 4 region
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Cullen & Grierson 2009

Summary for the SW from our *Callitris* tree ring data

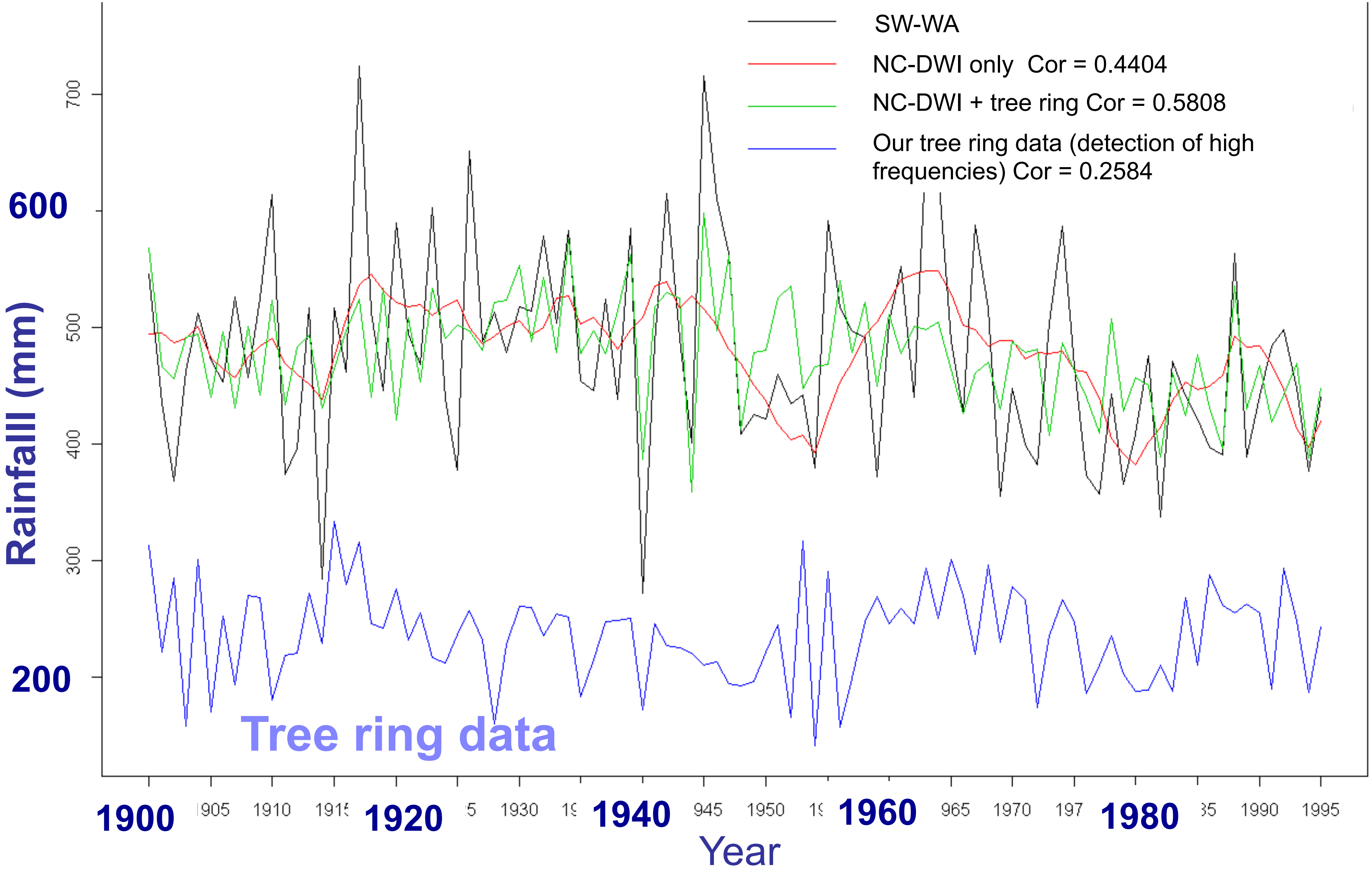
1. 350-year chronology most strongly correlated with autumn-winter rainfall & SOI values averaged over June to Aug
2. Climate of the south-west is marked by multi-decadal oscillations that produce significant changes in regional precipitation over timescales from one to several decades.
3. Rainfall since 1655 has naturally varied in the Lake Tay region from relatively dry periods lasting 20-30 yrs, with ~ 15-yr periods of above average rainfall (relative to last 350 yrs)
4. Variability in rainfall may reflect low-frequency variation in the El Niño-Southern Oscillation - SAM or SST role unresolved BUT …..
5. Impact of ENSO on Australia's climate modulated by the Inter-decadal Pacific Oscillation (IPO), an index of sea surface temperatures over the **Pacific Ocean** and cycles over a 15-30 year period

$\Longrightarrow$ consistent with cycles in tree growth at Lake Tay.

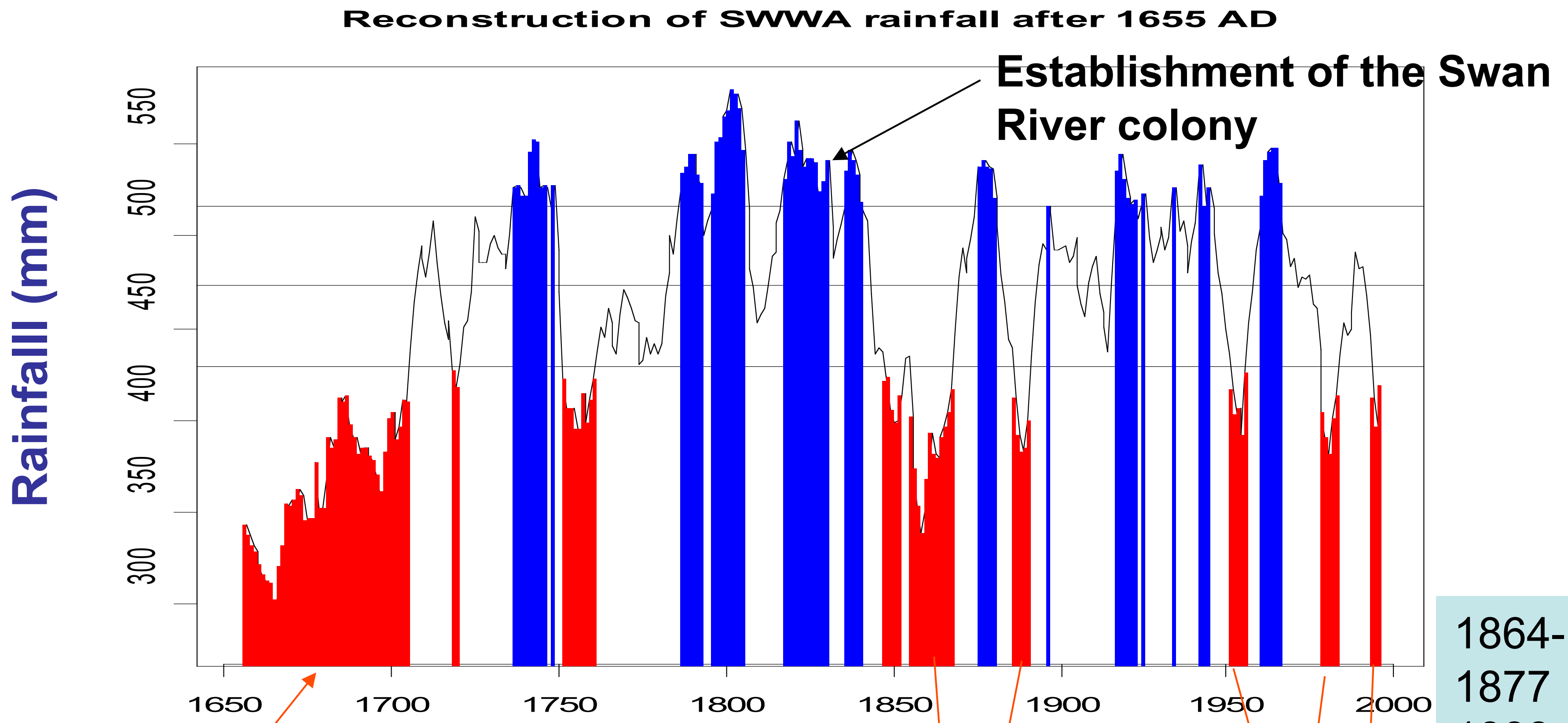
with Yun Li & Rex Lau, CSIRO - Understanding rainfall variability in the SW of Western Australia by examination of teleconnections in climate and monsoon variability between WA and northern China

Reconstructed SWWA rainfall compared to proxies from SWWA (our data) and northern China, NC (1900-1995)

DWI=dry-wet index based on rainfall in the summertime rainy season in China



SWWA wet and dry periods in 1665-1996 (300 years) reconstructed by using North China rainfall proxy



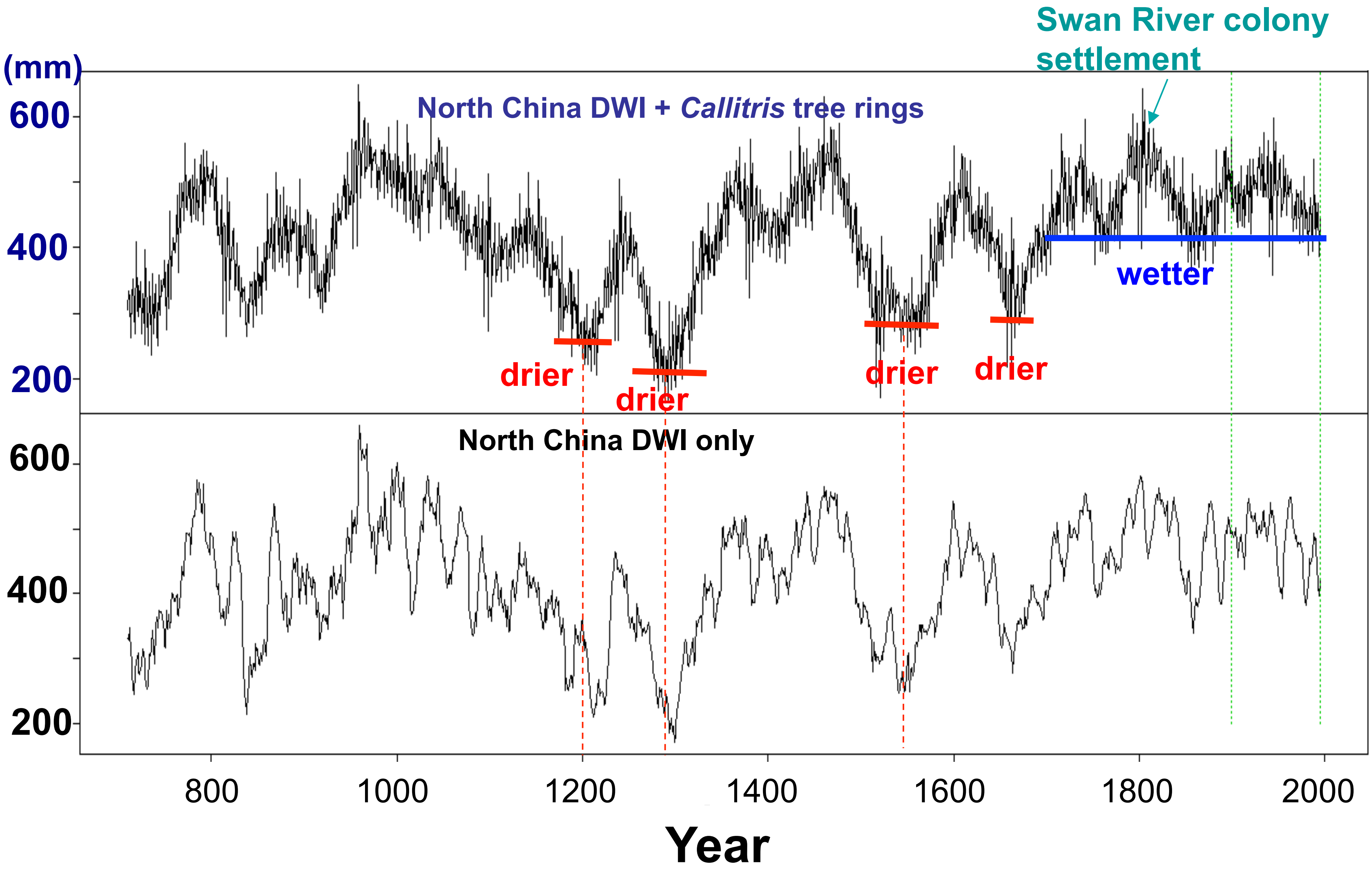
~ 50 yrs below average rainfall 1655-1715, in tree- ring

Recorded droughts in SWWA

Obs droughts

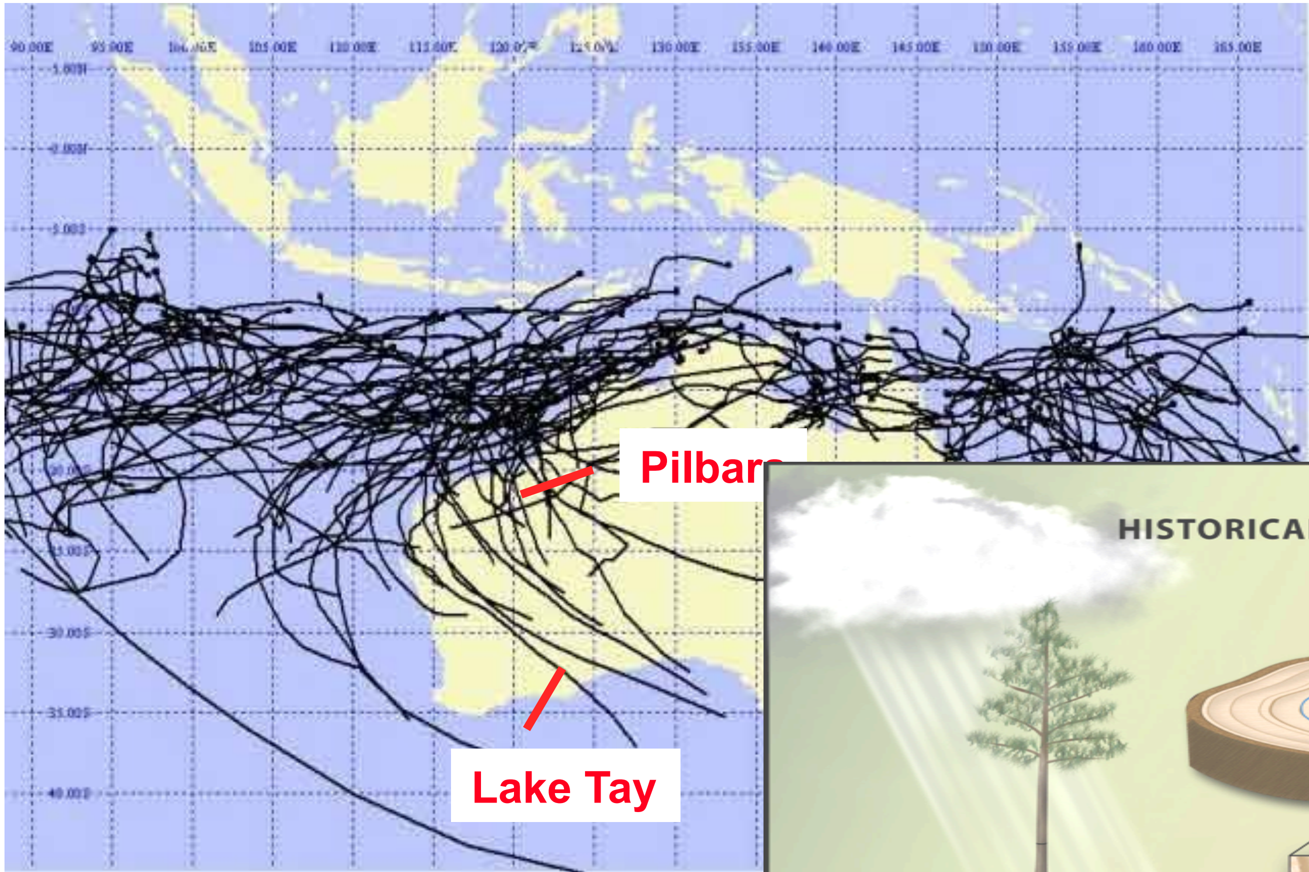
1864-1866
1877
1888
1895-1903
1911-1916
1937-1944
1952-1953
1969
1972-1987

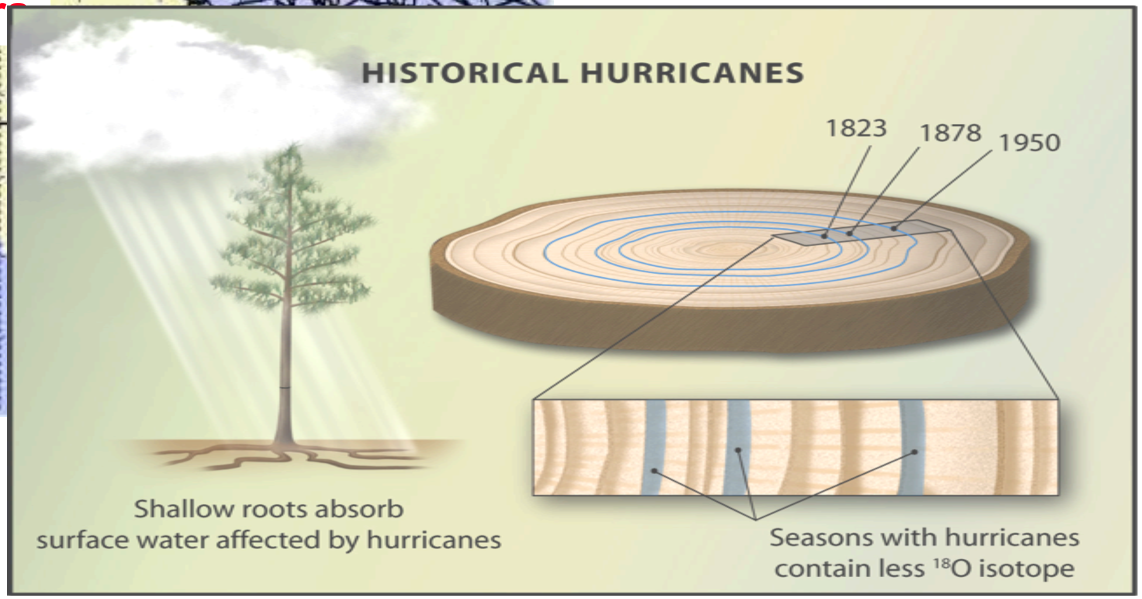
Reconstructed mean SWWA March-Aug rainfall using North China rainfall and SWWA tree-ring rainfall proxies since ~ 700 yrs AD



Other records to demonstrate teleconnections between NW and SW WA (e.g. from tropical cyclones)?

Examine $\delta^{18}O$ in rings
See if patterns match NW WA (Pilbara)





Oxygen isotopes ($\delta^{18}O$) – don't forget the physiology

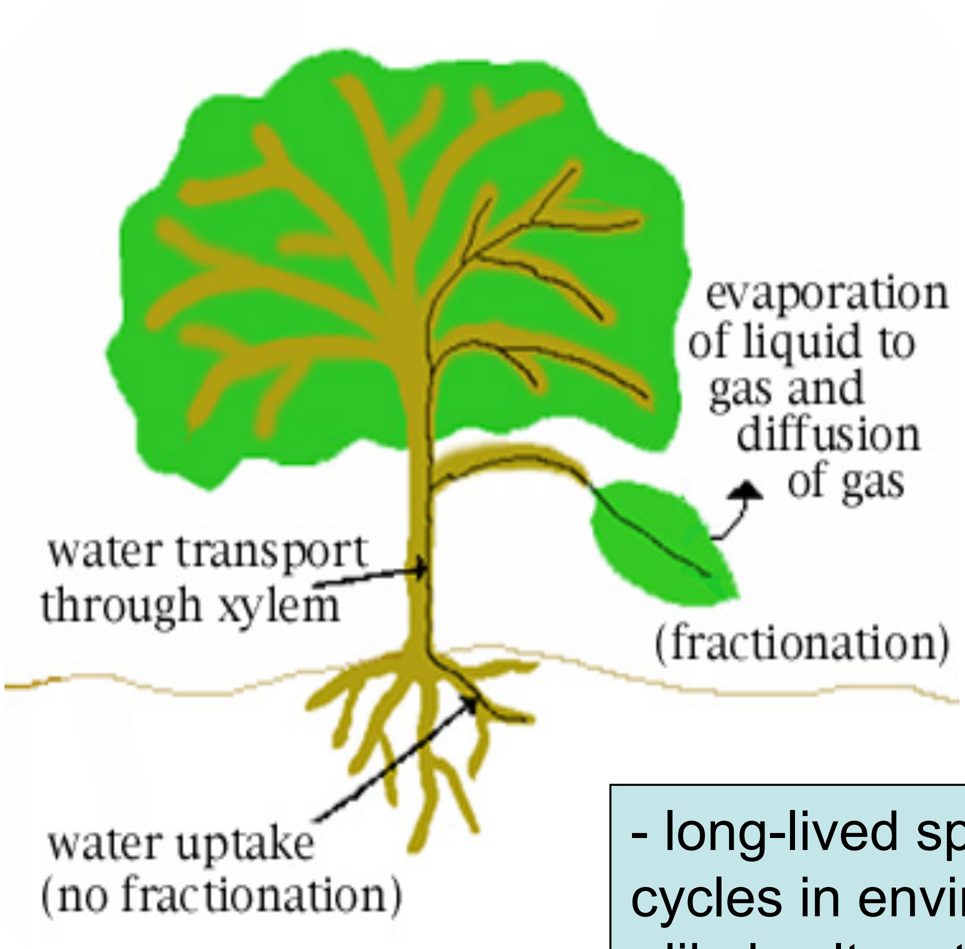


Figure from Biosphere-Atmosphere Stable Isotope Network (BASIN) web page: http://basinisotopes.org

- Lighter isotope (^{16}O) lost more quickly from leaves than heavier isotope (^{18}O)
- Leaves and wood **enriched** in ^{18}O
- Humidity influences stomatal conductance & hence transpiration
  - Drier air – more enrichment
  - Moister air – less enrichment

- long-lived species experience multi-decadal cycles in environmental conditions
- likely alter stomatal properties

e.g. CO_2 enrichment in the atmosphere reduces stomatal density, with the effect being more noticeable only at decadal or longer time-scales.

Plant-related processes that potentially influence the carbon and oxygen isotopic composition of tree rings

Carbon isotopes ($\delta^{13}C$)

Photosynthetic carbon isotope discrimination (Farquhar *et al.* 1982)

$\delta^{13}C$ CO_2

$\delta^{18}O$ of source water (xylem)

$\delta^{18}O$ of mesophyll water

Oxygen isotopes ($\delta^{18}O$)

Evaporative enrichment and Péclet effect (Dongmann *et al.* 1974; Roden & Ehleringer 1999; Farquhar & Lloyd 1993)

Equilibrium fractionation (Sternberg & Deniro 1983)

Source: Gessler et al. 2009. Plant, Cell & Environment 32, 780–795.

Post-carboxylation C isotope discrimination in autotrophic tissues

$\delta^{13}C$, $\delta^{18}O$ of primary assimilates (3-phospho-D-glycerate)

Leaves

$\delta^{13}C$, $\delta^{18}O$ of leaf-exported sucrose

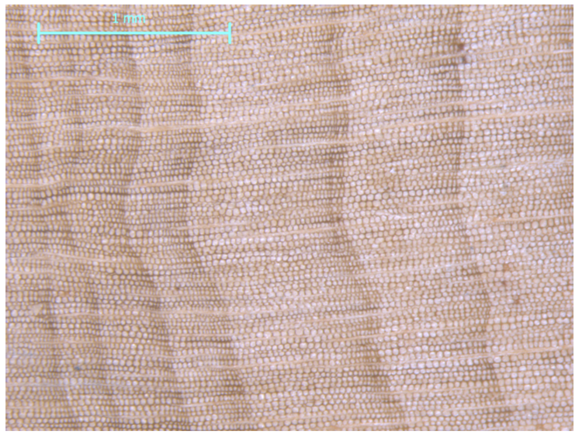
Heterotrophic tissues

Post-carboxylation C isotope discrimination in heterotrophic tissues

$\delta^{13}C$, $\delta^{18}O$ of sucrose in sink tissues

Exchange of organic O with non-enriched trunk water during cellulose synthesis

$\delta^{13}C$ and $\delta^{18}O$ of cellulose or wood



Correlations of $\delta^{13}C$ and $\delta^{18}O$ as predictors of stomatal function.

A_{max} = maximum rate of photosynthesis (photosynthetic capacity), g = stomatal conductance, C_i = intercellular CO_2 concentration

	$\delta^{13}C$ - $\delta^{18}O$ correlation	Interpretation
1	Positive	Strong stomatal control of C_i with stomata operating over a wide range
2	Negative	Stomata operating within a limited range and variation in C_i is related to photosynthetic capacity (A_{max})
3	No change in $\delta^{13}C$ over a wide range of $\delta^{18}O$	C_i remains constant
4	No change in $\delta^{13}C$ over a wide range of $\delta^{18}O$	As for #2 but can be distinguished

Scheidegger *et al*. (2000) Linking stable oxygen and carbon isotopes with stomatal conductance and photosynthetic capacity: a conceptual model. *Oecologia* 125: 350–357

Has control of stomatal conductance on PHS in *C. columellaris* varied through time in response to changes in climate?

Hypotheses

1. *Relative* stomatal control of photosynthesis = positive correlation between tree-ring $\delta^{13}C$ and $\delta^{18}O$ greater during wetter periods.

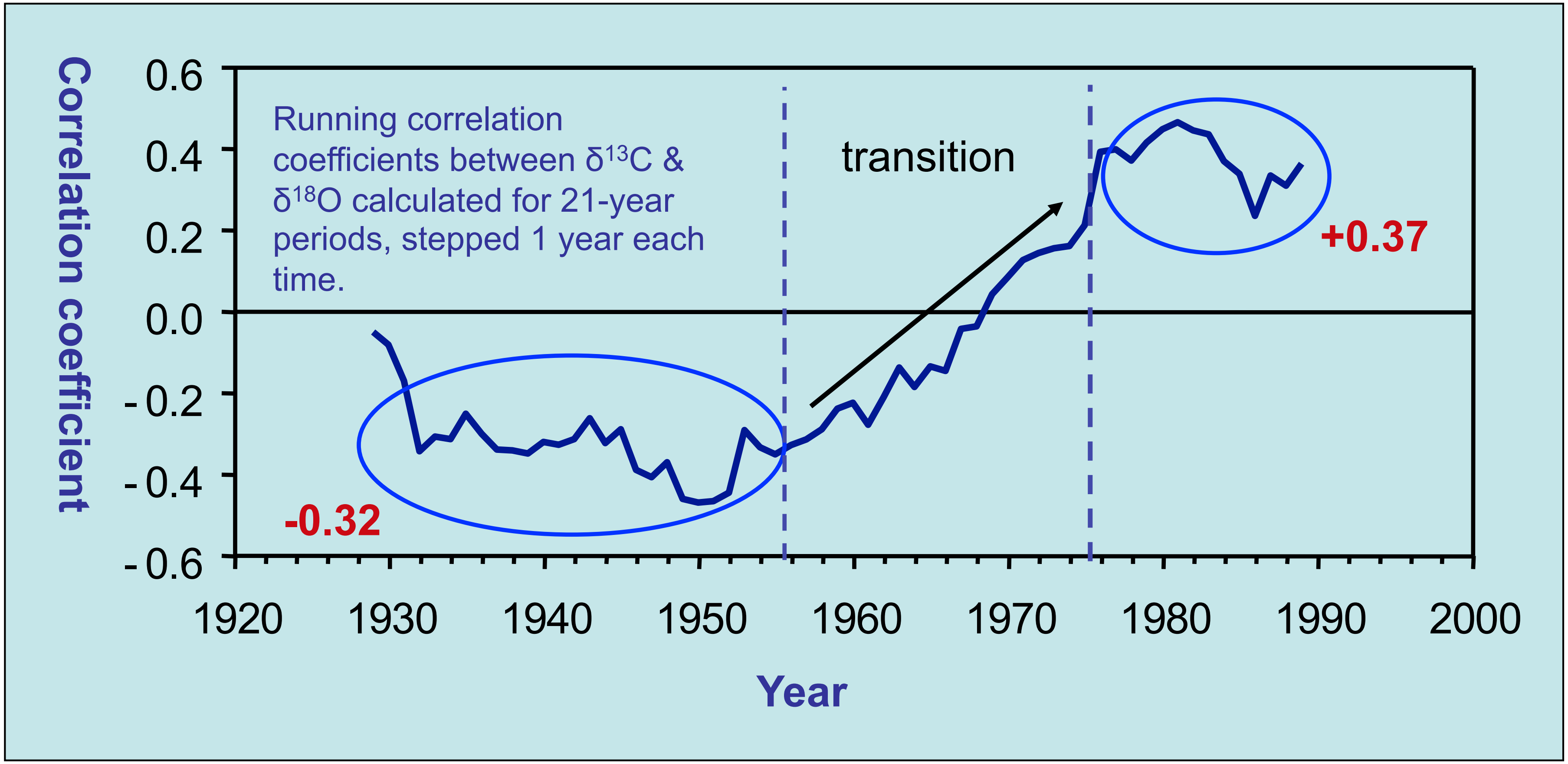
2. During dry periods, stomatal conductance will be suppressed and photosynthetic capacity more limiting, the result being that the two isotopes are either negatively correlated, or show no relationship.

→ correlations between $\delta^{13}C$ and $\delta^{18}O$ are

(i) positively related to rainfall and relative humidity

(ii) negatively related to temperature.

Relationships between $\delta^{13}C$ & $\delta^{18}O$ in tree rings (Pilbara)



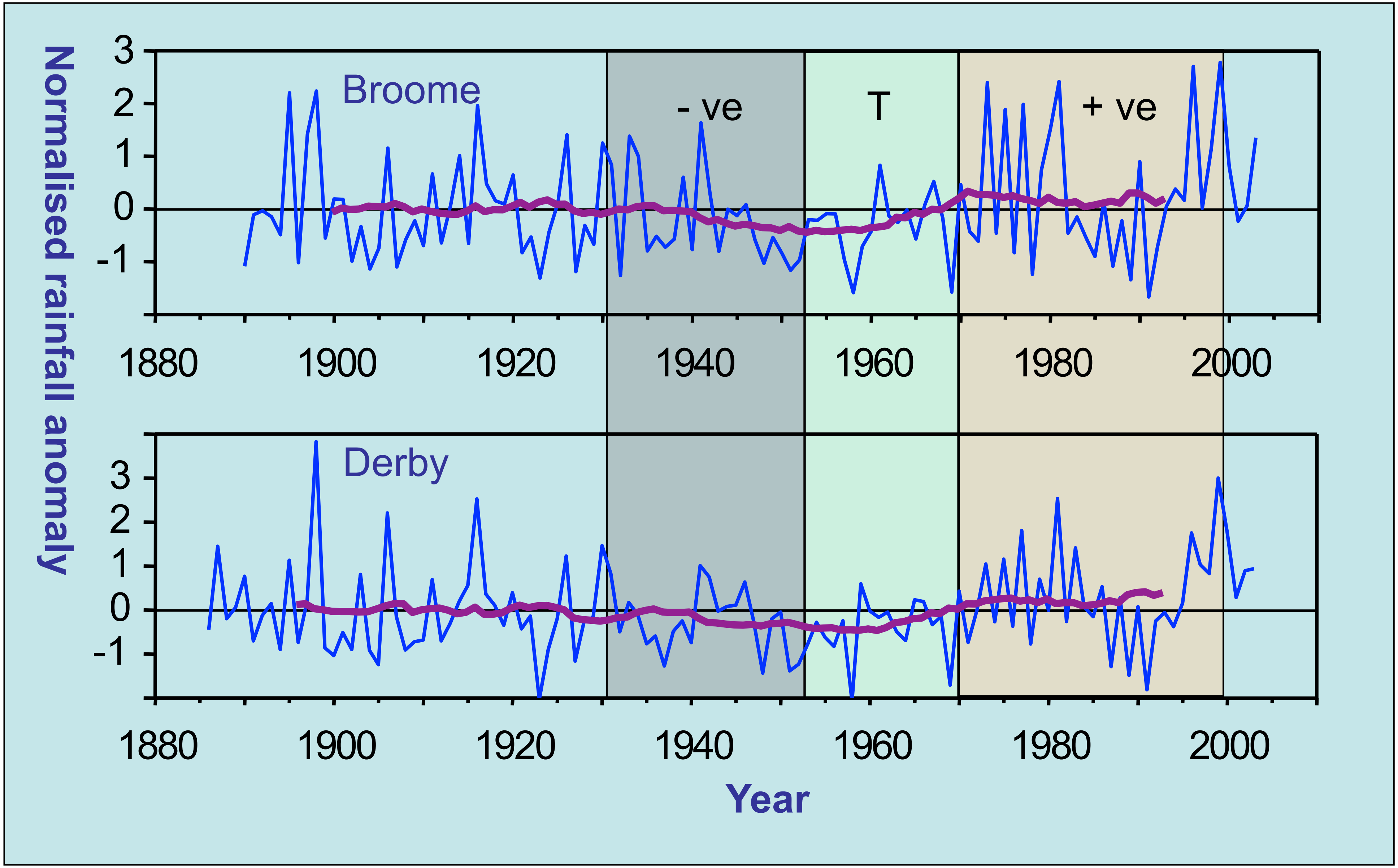
Negative correlation prior to 1955 = variation in C_i (intercellular atmospheric CO_2 concentrations) due to photosynthetic capacity & therefore biochemical factors = **drier climate?**

1955 - 1976, Transition = Increase in stomatal control

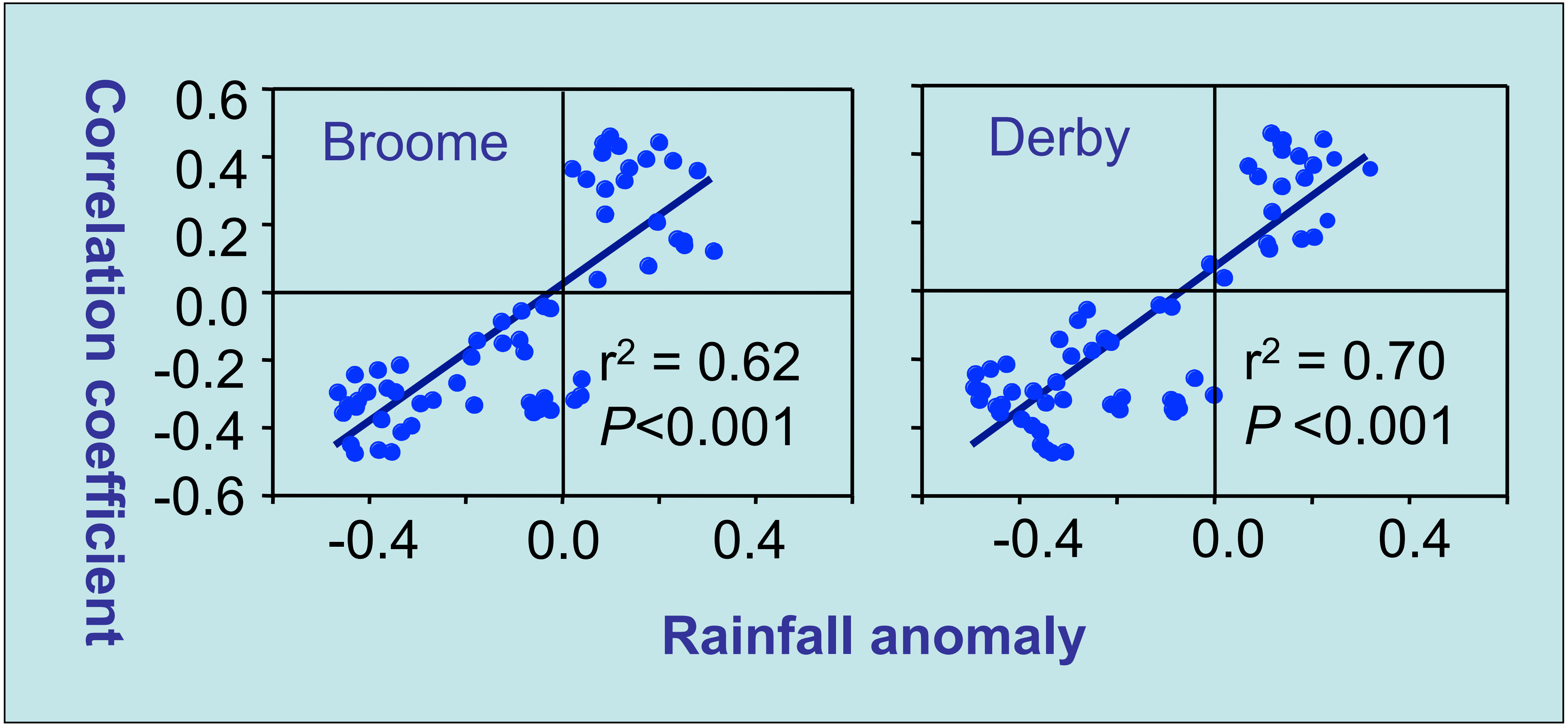
Positive correlation after 1976 = strong stomatal control of C_i and therefore photosynthesis = **wetter climate?**

Scheidegger *et al*. (2000). *Oecologia* 125: 350–357

Are rainfall trends in the region the main driver of changes in stomatal behaviour?



21-yr running correlation between the δ^{13}C and δ^{18}O residual series & rainfall anomalies in the region



δ^{13}C - δ^{18}O correlation was also negatively correlated with temperature (but much weaker)

Some evidence that temperature more important in driving ^{13}C variation during dry periods (influence on tree WUE)

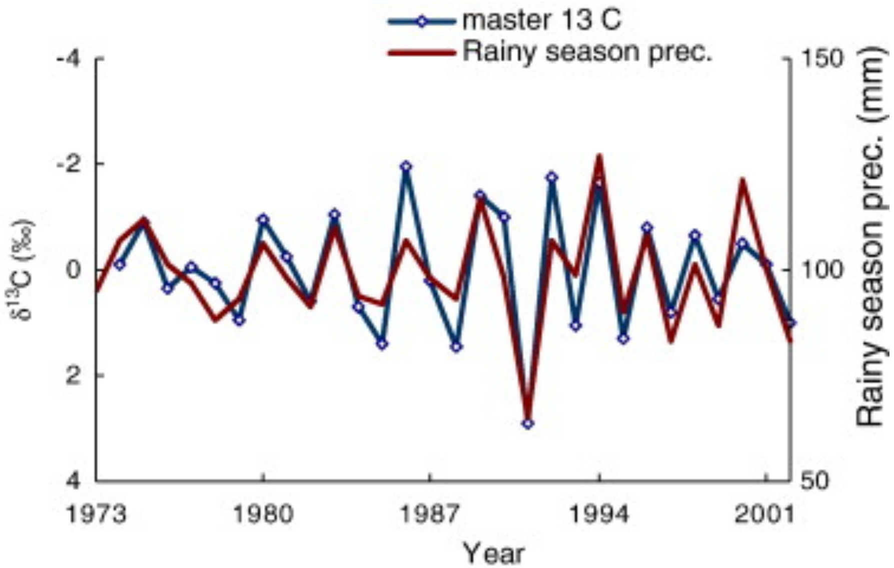
Interpretation - $\delta^{13}C$ and $\delta^{18}O$ residual series & rainfall anomalies

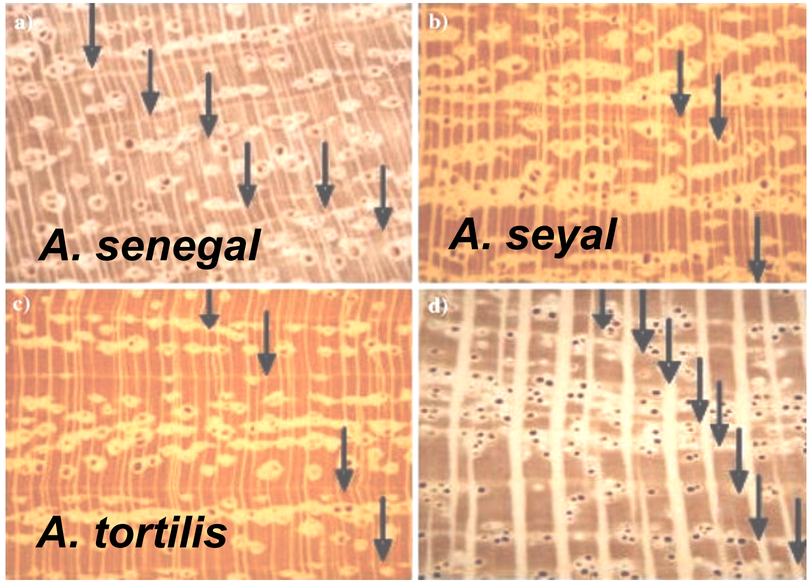
Lower rainfall and higher temperatures dampen stomatal conductance to limit water loss - a typical response of plants to water stress.

Change in $^{13}C/^{18}O$ relationship demonstrates significant adjustment of physiological characteristics **over decades** in response to region-wide changes in climate

Non-stomatal limitations to photosynthesis are likely to become increasingly important in areas where rainfall is expected to decrease i.e., in the south-west

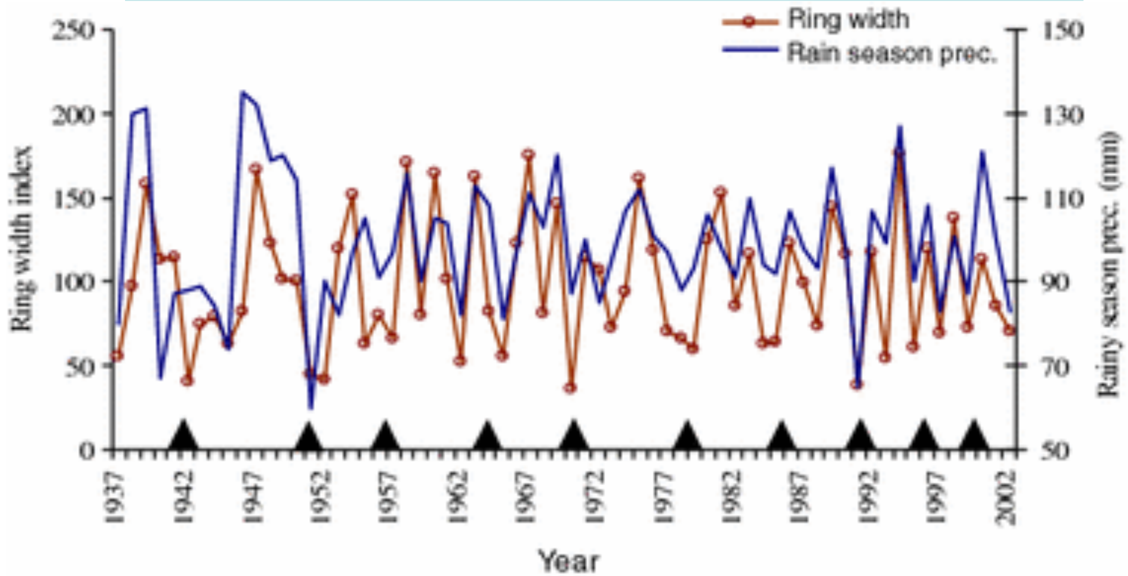
Other species with proxy potential in WA - Acacia





Annual patterns of δ^{13}*C series and rainy season precipitation (June–Sep) from 3 three Acacia species in Ethiopia*

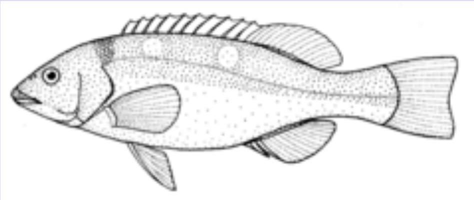
Annual patterns of *ring widths & ENSO events (drought/famine)*

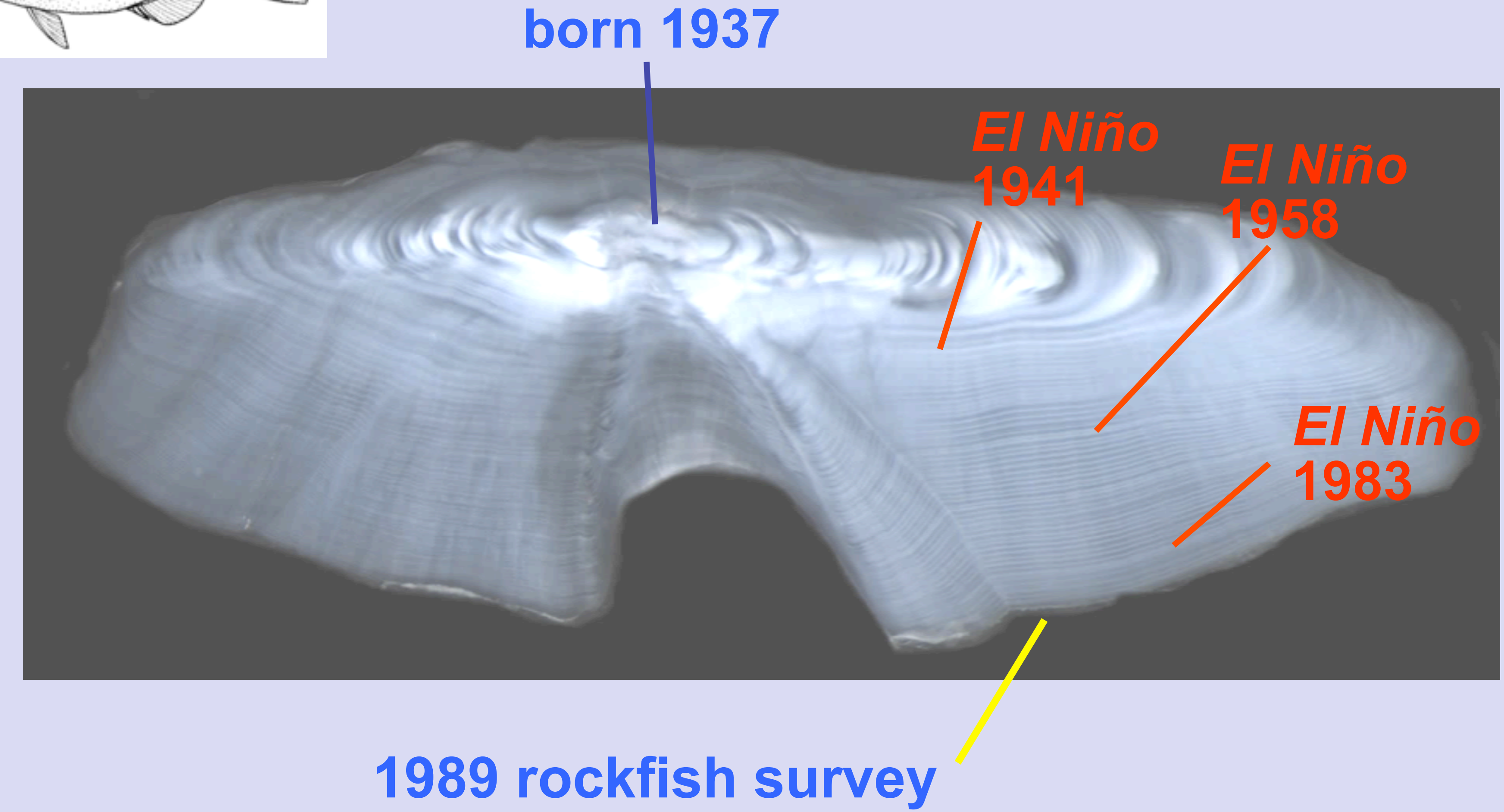


Gebrekirstos et al., 2008 *Trees 22 631–641*; Gebrekirstos et al., 2009. Global & Planetary Change 66, 253-260.

Otoliths of WA fish as environmental chronometers

April 2010 - foxfish (wrasse, Rottnest Island) & rock flathead (SW-WA) : preliminary crossdating good; strongly related to ENSO indices (La Niña is good for growth).





BA Black, GW Boehlert, MM Yoklavich. 2005. *Canadian Journal of Fisheries and Aquatic Sciences*

Louise Cullen

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Cullen LE and Grierson PF. (2006). *Palaeogeography, Palaeoclimatology, Palaeoecology* 236, 206-216.

Cullen LE and Grierson PF. (2007). *Climatic Change* 85, 213-229.

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