Impact of climate on trees: identification of proxies in trees for measuring climatic stress

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BACKGROUND

- Climatic records have indicated that average **surface temperatures** on the globe have **increased** by 0.74^{o}C between 1906 and 2005 (IPCC, 2007).
- Future climate projections based on GCM models and different GHG emission scenarios indicate a **further warming** of 1.1-6.4 ^{o}C by the end of the 21st century (IPCC, 2007).
- **Increasing incidence of summer droughts** may cause a decline in tree health. Innes (1993) hypothesized that severe soil water deficits in one summer may cause hydraulic and physiological responses that are carried over into subsequent years (**lag**).
- Tree-ring chronologies can provide high resolution (annual and seasonal), continuous, precisely-dated, well replicated and sensitive (accurate) **indicators of climate variability** across large areas.

INTRODUCTION

- Several studies have shown that Dendrochronology and more advanced methods such as isotope discrimination in tree rings are good surrogates for **marking climatic events**.
- Changing climatic conditions will **affect the future growth** of forest species currently grown in the UK and Ireland. However, the **amplitude and extent** of such effects are not well understood.
- This knowledge is a prerequisite for the **sustainability** of future forests and **adaptation** of forest management.
- Ireland's forest cover is about **10%** (principally with Sitka spruce), of which most was built up in the last century. Afforestation is essentially done by the **private sector** (forest owners and industry).

INTRODUCTION

- Scientists around the world have investigated disturbances caused by a possible future elevation of the temperature. The **adaptability and transfer** of such techniques important.
- A **methodology** was developed to single out climate variables affecting tree radial growth and isotope discrimination in early and latewood. A combination of statistical tools including PCA, CCorrA, linear regression analysis and Pearson's correlation, a detailed assessment of tree response was completed for 3 species.
- The present work in this context is an attempt to understand and assess physiological mechanisms governing growth in Britain and Ireland, and to examine **tree response to climatic stress** along a **climatic transect varying in moisture deficit** between Britain and Ireland.

OBJECTIVE

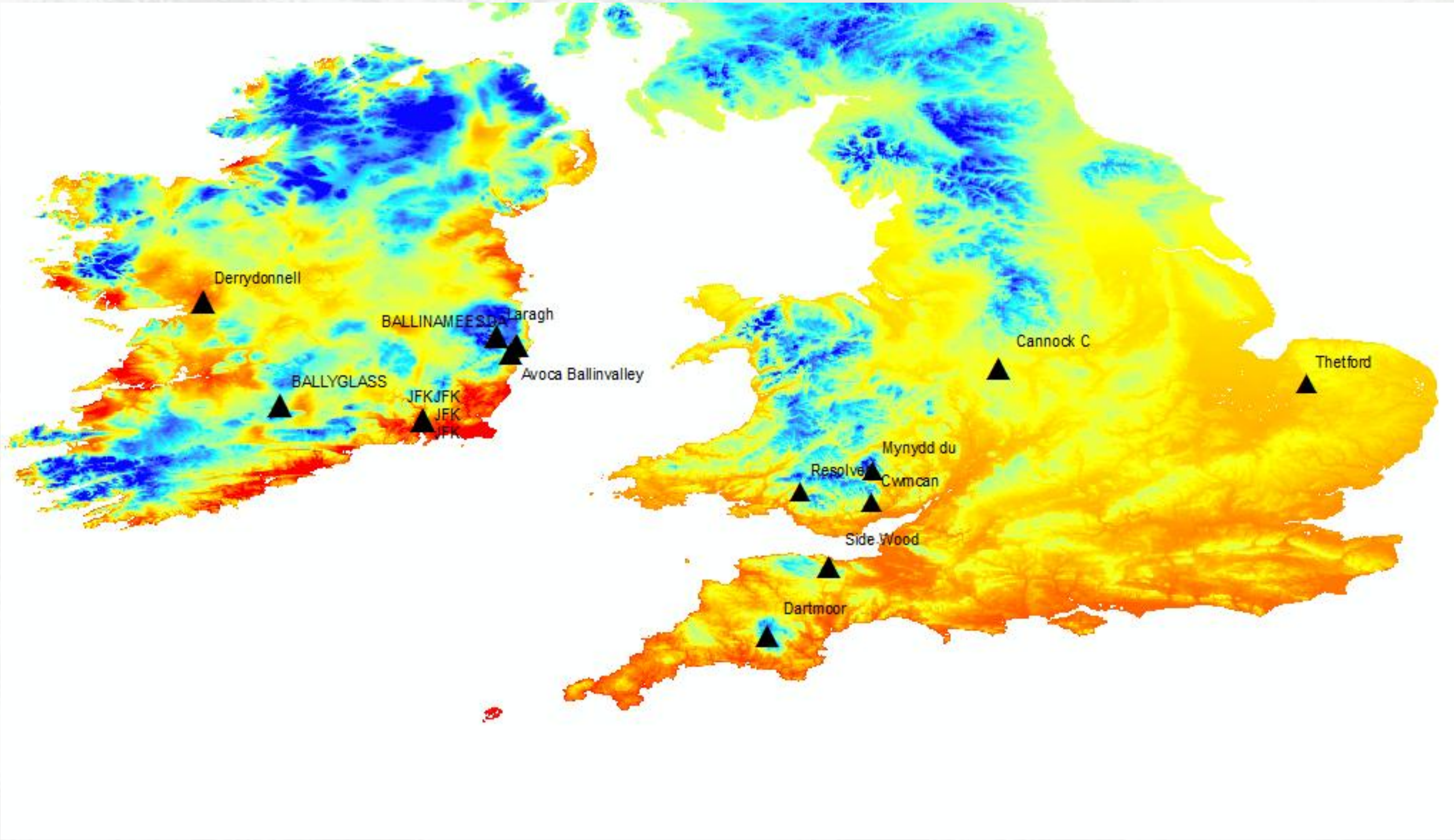
The aim of the study is to examine using dendrochonological procedures, and analysis of isotope concentrations, the adaptability of:

- **Sitka spruce** (*Picea sitchensis* Bong. (Carr.) – SS);
- **Scots pine** (*Pinus sylvestris* - SP);
- **Douglas fir** (*Pseudostuga menziesii* - DF);

to past severe climatic conditions across a climatic gradient (west to east). Allowing future adaptation strategies to be best anticipated and optimised by forest management.

Linking **tree reaction to past climatic stress** and **site classification with tree growth** and forest production will, not only **advise on species selection** in the future but also help modeling and **forecasting the production** of forest resources in the uncertainty triggered by climate change.

TRANSECT SITES



Studied transect: SS (JFK, Avoca, Derrydonnell, Dartmoor, Resolven); SP (JFK, Laragh, Thetford, Cannock, Cwmcan); DF (Ballinameesda, Ballyglass, JFK, Sidewood, Thetford, Myndd Du)

METHODOLOGY

- Analysis of tree growth over a time series, using stand and tree biometric data and dendroclimatology (ring width of earlywood latewood and whole ring).
- Local meteorological records were used for the analysis, and to select two localised drought periods for each site in the transect using moisture deficit and drought days index as criteria.
- Tree responses were measured by early- and latewood annual increment:
  - one year before,
  - the year of drought and
  - three years after each drought event (to spot any possible lag effect due to early or late occurrence of drought stress).
- Analysed in more detail using stable isotopes (C & O).

METHODOLOGY

Analyses:

- WinDendro Density was used for measurement of tree ring growth.
- Ring growth was analysed by the means of PCA and CCorA and, isotope concentration and relationship with environment was interpreted using the Barbour et al., model prediction (2002).
- Cellulose was extracted using the Brendel method, from earlywood and latewood of ring increments corresponding to a year before and three years after each drought year.
- Cellulose samples were sent to University of Göttingen for stable carbon and oxygen isotope analysis.

RESULTS

Sites	Species	Drought (DD yr^{-1})	AT (^{o}C)	Ew_MD (mm)	Lw_MD (mm)	Gs_MD (mm)	Gs_rainfall (ml)	Gs_PET (mm)
Avoca	SS	35.3	1865.11	50.8	-32.15	18.65	672.47	691.13
Dartmoor	SS	70.73	1581.47	56.79	-0.67	56.12	1191.05	1247.17
JFK	SS	41.91	1915.59	120.39	-22.48	97.9	631.59	729.5
Resolven	SS	79.34	1935.84	115.06	13.9	128.96	1139.67	1268.63
Derrydonnell	SS	34.05	2089.89	120.62	14.56	135.18	578.86	714.04
Laragh	SP	35.3	1865.11	50.8	-32.15	18.65	672.47	691.13
JFK	SP	41.91	1915.59	120.39	-22.48	97.9	631.59	729.5
Cwmcan	SP	119.32	1939.77	271.83	229.68	501.52	770.67	1272.18
Cannock	SP	171.27	1801.4	391.41	422.2	813.6	442.35	1255.95
Thetford	SP	171.27	1801.4	391.41	422.2	813.6	442.35	1255.95
Ballinameesda	DF	35.3	1865.11	50.8	-32.15	18.65	672.47	691.13
JFK	DF	41.91	1915.59	120.39	-22.48	97.9	631.59	729.5
Ballyglass	DF	34.05	2089.89	120.62	14.56	135.18	578.86	714.04
Sidewood	DF	111.25	1935.1	231.39	205.98	437.37	820.77	1258.14
Mynydd Du	DF	124.86	1874.13	273.07	281.4	554.46	707.44	1261.91
Thetford	DF	171.27	1801.4	391.41	422.2	813.6	442.35	1255.95

RESULTS

Climate analysis of the transect:

- Transect sites (per spp.) were defined according to MD (west – east / wet to drier gradation generally true!).
- DD (drought intensity) did increase eastwards (droughts in Wales and England 3 to 4 times greater than in Ireland).
- AT highest at 2 sites in Ireland (also lower than expected rainfall?)
- While rainfall values increased eastwards for most of the sites, with higher values at Dartmoor and Resolven.
- PET values were variable across the transect, with higher values observed on sites with an average of over 75 drought days (DD) per year over the study period.

RESULTS

- A total of 80 cores (16 sites with 5 cores per site) were collected for the study.
- Radial increments measured for period 1965 to 2008.
- Species chronologies with EPS values of 0.87 for SS, 0.90 for SP and 0.91 for DF showed similar variations between species.
- Within species, Sitka spruce chronology indices per site ranged between 3 units of the indices (from -1 to +2); however, Dartmoor (a moorland area) showed the highest growth response of all SS sites, especially between 1970 and 1980, and a greater variability (from +2 to -1 indices between 1980 and 1990).

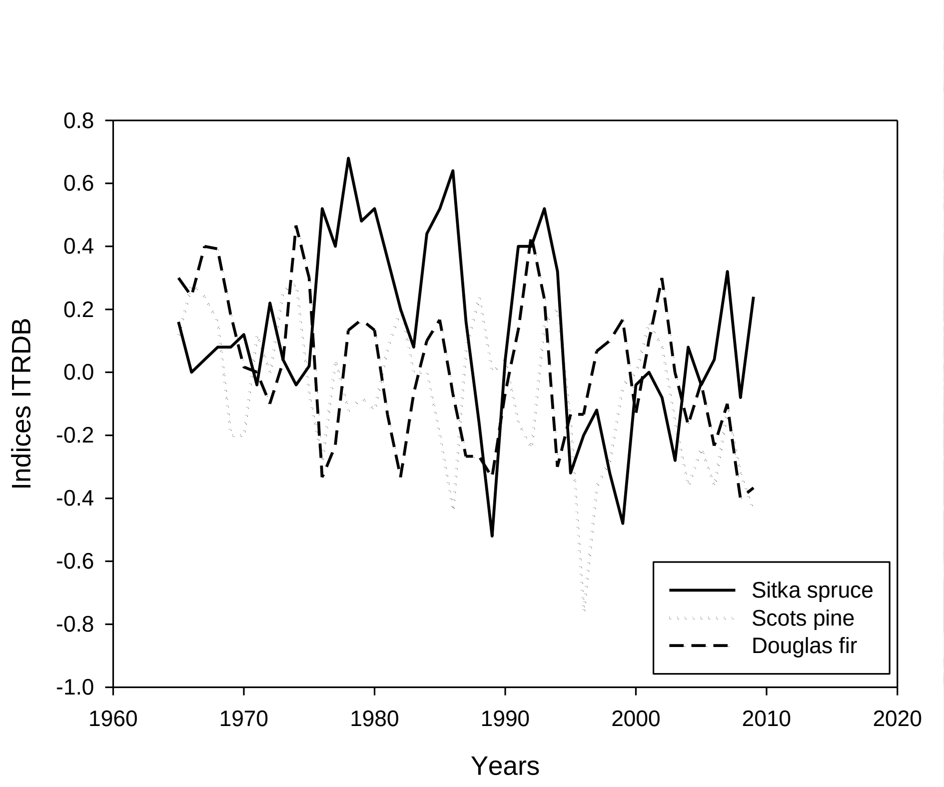


Figure: Species master chronologies

RESULTS

Statistics

Radial growth in most sites correlated significantly with MD, rainfall and AT. However, some differences were observed within and between species, and across sites.

Pearson's correlations showed a significant response of Sitka spruce to MD and rainfall during the growing season, especially during the latewood growth phase .

AT had the greatest effect on the growth of Scots pine, along with MD and rainfall .

Correlation analysis indicated that PET occurring during the growing season had a significant influence on growth of DF.

Site	Species	Country	Growth phase	Correlates	PCA	CCorA
Avoca	SS	Ireland	Whole ring Earlywood	AT	70.58%	100%
Dartmoor	SS	England	Whole ring Earlywood	Gs_MD EW_rain	77.08%	100%
JFK	SS	Ireland	Earlywood Latewood	Gs_MD Gs_rain Gs_PET	84.19%	100%
Resolven	SS	Wales	Whole ring Latewood	Gs_MD Gs_rain	90%	100%
Derrydonnell	SS	Ireland	Whole ring Latewood	Gs_MD Gs_rain	84.65%	100%
Laragh	SP	Ireland	Whole ring Latewood Earlywood	AT Gs_MD Gs_rain	78.75%	98.89%
JFK	SP	Ireland	Whole ring Latewood	AT PET_LW	64%	100%
Cwmcan	SP	Wales	n/a	n/a	n/a	n/a
Cannock	SP	England	Whole ring Earlywood Latewood	AT MD Gs_rain	84%	99.97%
Thetford	SP	England	Whole ring Earlywood	Gs_MD Gs_rain	82.87%	100%
Ballinameesda	DF	Ireland	Early wood Latewood	MD, Gs_rain, Gs_PET	73.91%	97.27%
JFK	DF	Ireland	n/a	n/a	n/a	n/a
Ballyglass	DF	Ireland	Latewood	AT Gs_PET	89.81%	100%
Sidewood	DF	England	Whole ring Latewood	MD Gs_rain	87.09%	100%
Mynydd Du	DF	Wales	Latewood	Gs_PET	89.85%	100%
Thetford	DF	England	Whole ring Earlywood	AT Gs_PET	87.15%	100%

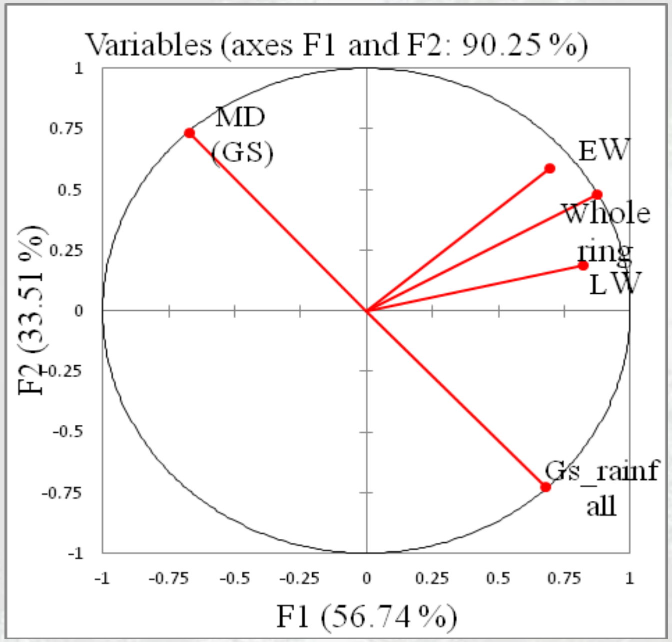
Table : Environmental variables identified as main influence on tree ring growth over the whole chronology. (n/a: no significant relationship was identified in the site)

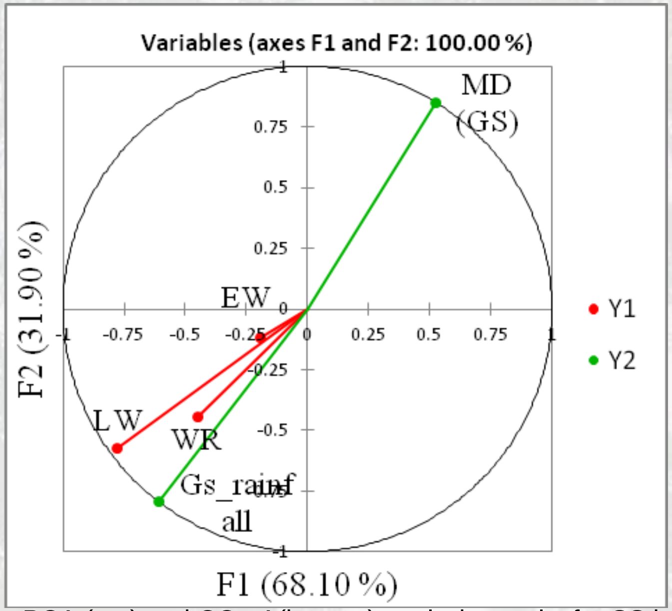
RESULTS

PCA and CCorA

PCA analysis produced the contribution of both tree and environmental parameters, with 90% of the variance explained, for SS site in Resolven for example, whilst CCorA for the same site provided the trend of the relationship. Growing season rainfall shortage affected latewood growth more than earlywood and, increased MD produced a similar effect, with 100% of the variation explained.

PCA grouped the proxies measured in the trees with environmental variables, and canonical correlation analysis showed that an increase in MD or a lack of rain were both limiting growth.





PCA (top) and CCorA(bottom) analysis results for SS in Resolven (MD(GS): moisture deficit growing season; Gs_rainfall: growing season rainfall; LW: latewood portion; EW: earlywood portion; WR: whole ring; Y1: proxies measured in trees; Y2: Environmental variables.)

RESULTS

- Regression analysis between associated variables gave a more detailed insight into the relationships between growth variables and the environment.
- Generally, for most species growing at most sites, for **radial growth**, analysis of variance confirmed a strong relationship with **moisture deficit**.

- In all DF sites (drought tolerant species), only the **latewood response** was predictable from environmental correlates.
- For SP, **all growth periods** demonstrated sensitivity to **MD, Rainfall and AT**.
- For SS, **all growth periods** were sensitive to **MD and Rainfall**.

Isotope Theory

$$\delta_{sample} = \frac{R_{sample}}{R_{standard}} - 1,$$

^{13}C discrimination is an alteration of the **ratio of internal CO_2 concentration within the sub-stomatal cavity and the external CO_2 concentration** in the atmosphere (C_i:C_a). C_a stays relatively constant ($\delta^{13}C$ = -8 ‰), C_i can change in C3 plant between -20 and -33 ‰ depending on:

$$A = \frac{V_{c\,max}(c_i - \Gamma)}{c_i + K'}$$

- A change in stomatal conductance (g_s) if maximal photosynthetic capacity (V_{cmax}) is constant.
- a change in V_{cmax}
- or both!

$$g_s = 269{\cdot}8 - 4{\cdot}4D_{ls}$$

Isotope Theory

- The fractionation of ^{18}O occurs from various sources including **ground water, water at sites of evaporation and the ^{18}O of CO_2 or O_2 during photosynthesis and respiration.**

- Analysis of both isotopes in ring tissue tells us if photosynthesis is limited by vapour pressure deficit: VPD, g_s or V_{cmax}.

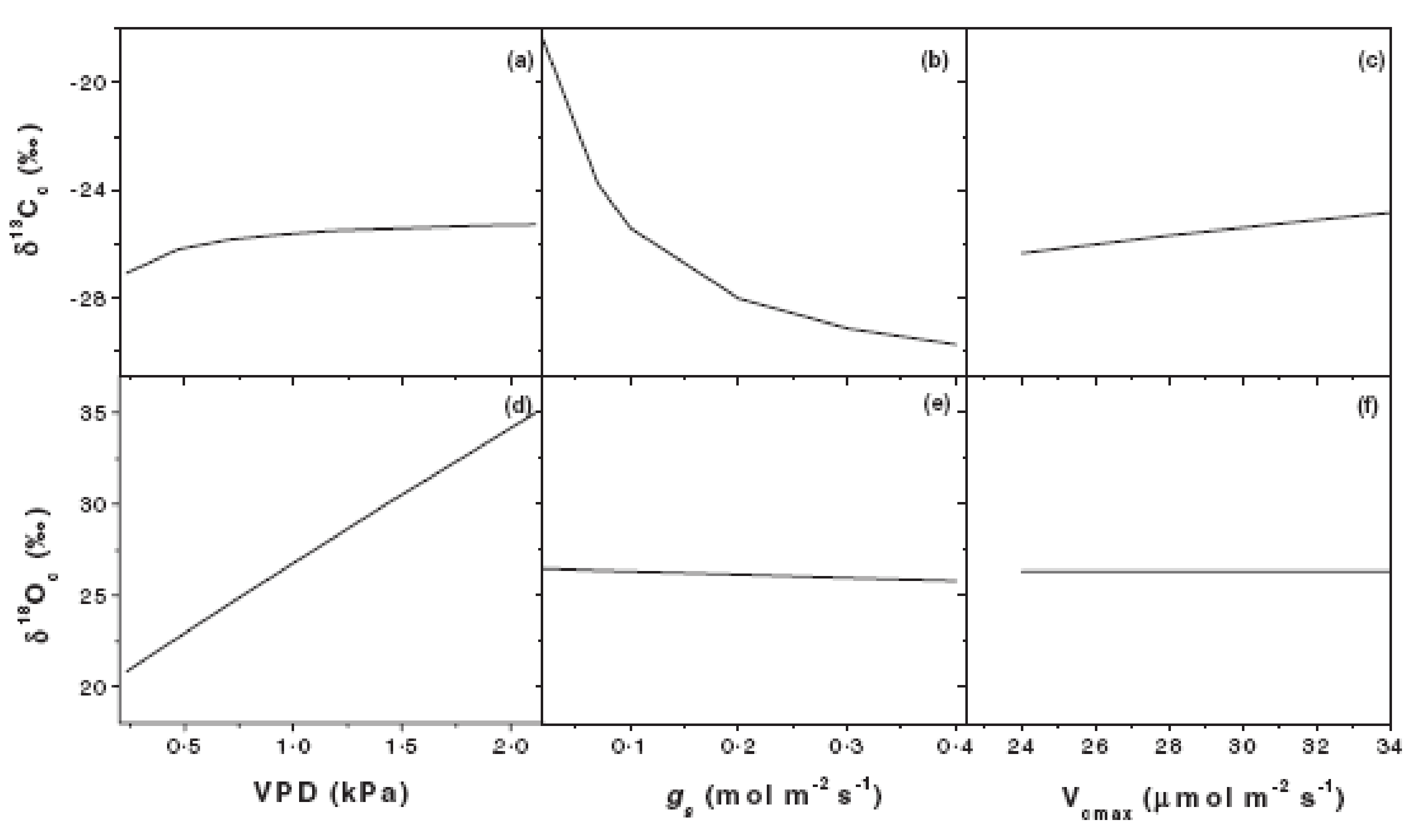
$$T_{\mathrm{dew}(i)} = \frac{237.3}{\left\{ \dfrac{1}{\left[\dfrac{\ln\left(\dfrac{RH_i}{100}\right)}{17.27}\right] + \left[\dfrac{T_i}{(237.3 + T_i)}\right]} - 1 \right\}}$$

$$VPD = \frac{\sum_{i=1}^{96} \left[e^*(T_i) \left(1 - \dfrac{RH_i}{100} \right) \right]}{96}$$

Isotope Theory

Changes are due to

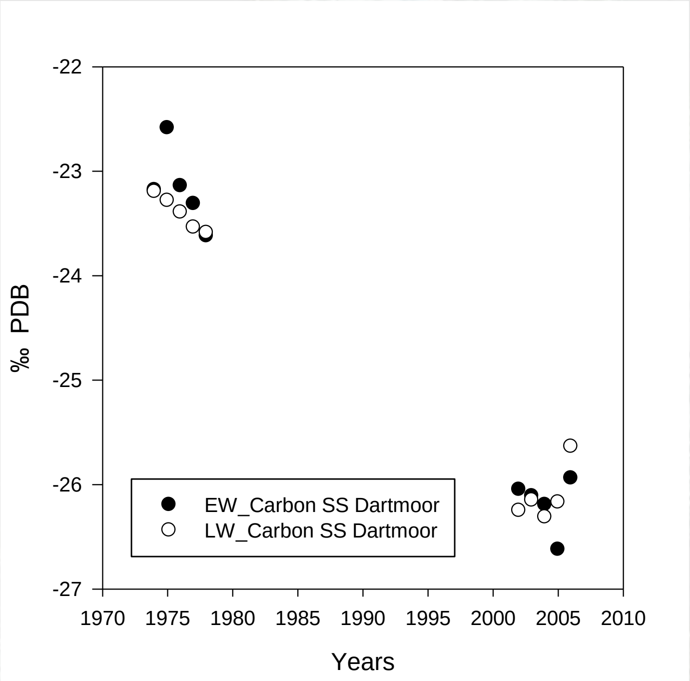
a) VPD, then only $\delta^{18}O_c$ should change .
b) There is no relationship between $\delta\ ^{18}O_c$ and $\delta^{13}C_c$ if only V_{cmax} changes.



Barbour, Walcroft and Farquar, 2002

RESULTS

- Discrimination of stable isotopes of ^{13}C were 1-3‰ higher in the first drought period than in the second on average, at most sites.
- ^{18}O concentration tended to be higher in the second drought period (up to 2‰ higher in Ballinameesda).
- Early and latewood isotope concentrations for the same drought in the same site were not significantly different.



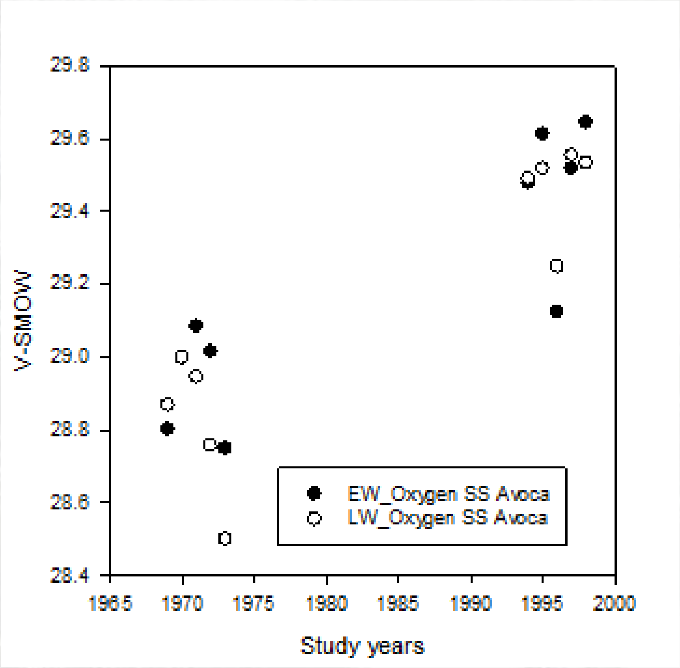
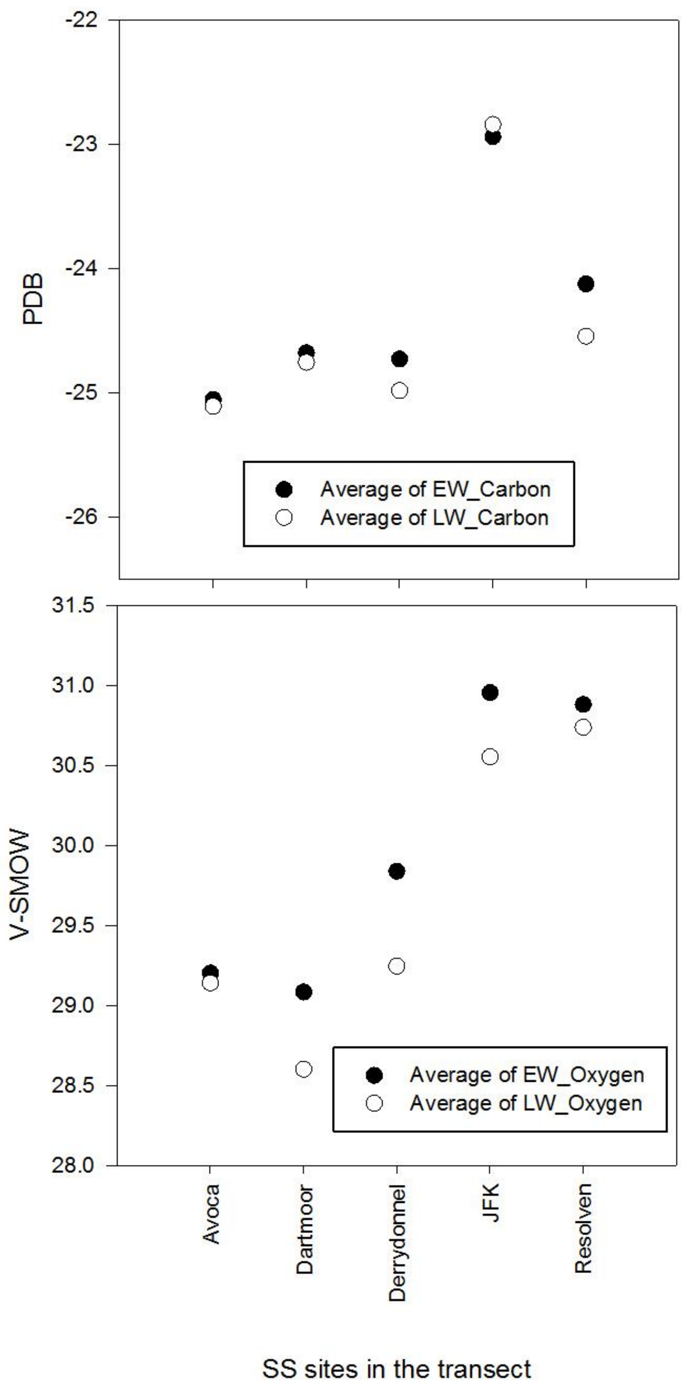
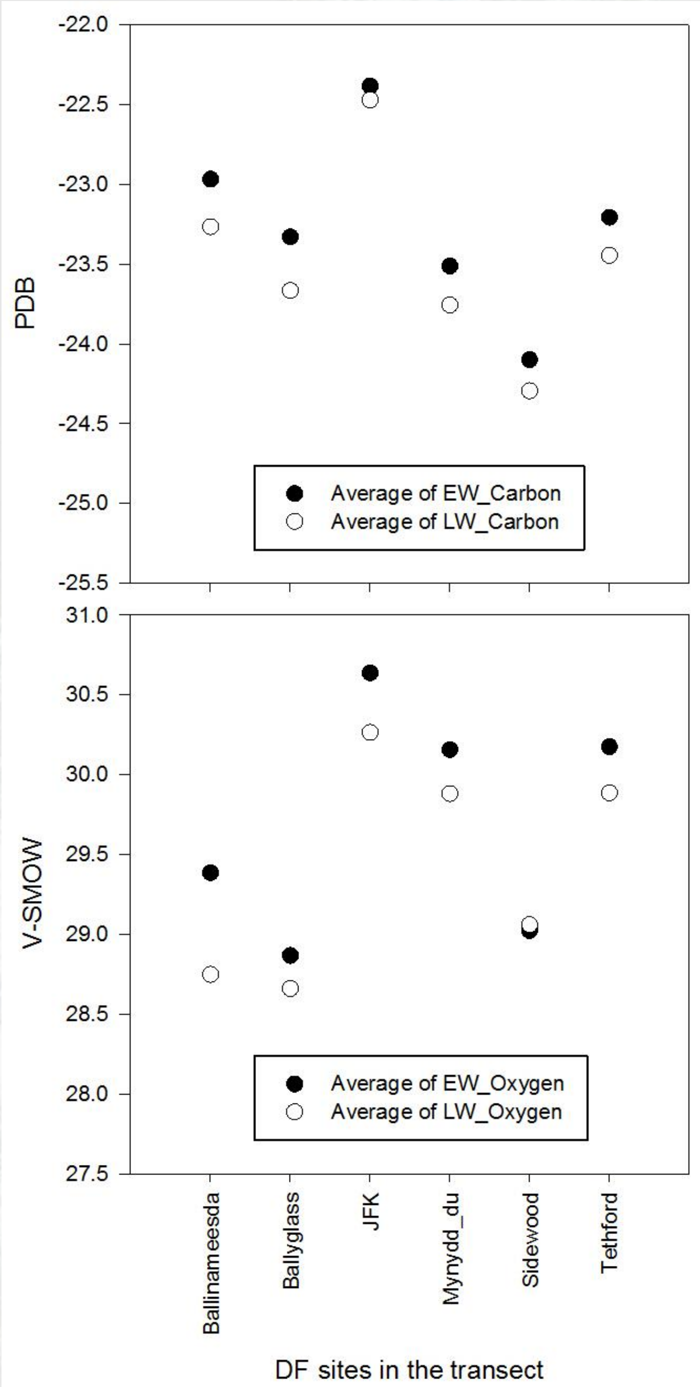


Figure Average isotope discrimination in Dartmoor ^{13}C (top) and Avoca ^{18}O (bottom). EW: earlywood; LW: latewood


-22
-23
-24
-25
-26
PDB
Average of EW_Carbon
Average of LW_Carbon
31.5
31.0
30.5
30.0
29.5
29.0
28.5
28.0
V-SMOW
Average of EW_Oxygen
Average of LW_Oxygen
Avoca
Dartmoor
Derrydonnel
JFK
Resolven
SS sites in the transect


-22.0
-22.5
-23.0
-23.5
-24.0
-24.5
-25.0
-25.5
PDB
Average of EW_Carbon
Average of LW_Carbon
31.0
30.5
30.0
29.5
29.0
28.5
28.0
27.5
V-SMOW
Average of EW_Oxygen
Average of LW_Oxygen
Ballinameesda
Ballyglass
JFK
Mynydd_du
Sidewood
Tethford
DF sites in the transect

RESULTS

- Pearson's correlation identified significant relationships between AT, PET, MD and rainfall with earlywood $\delta^{13}C$, $\delta^{18}O$ but only with latewood $\delta^{13}C$ at few sites.
- No significant difference was found between early and latewood values of $\delta^{13}C$ and $\delta^{18}O$ for the same tree in the same year.
- Fractionation of carbon was consistently higher during the first drought than during the second, conversely ^{18}O concentration was consistently lower during the first drought than the second
- Site averages of isotope concentration variation per species ranged from:

  SS: $\delta^{13}C$ (-25‰ to -23‰); $\delta^{18}O$ (28‰ to 31‰);

  SP: $\delta^{13}C$ (-25‰ to -24‰); $\delta^{18}O$ (30‰ to 31.7‰);

  DF: $\delta^{13}C$ (-24‰ to -22‰) $\delta^{18}O$ (28.5‰ to 30.7‰).

To be CONCLUDED…

- Within species, the site with **highest fractionation of carbon did not necessarily result from the highest values for δ^{18}O**. This is because the factor (VPD, V_{cmax} or gs) which affected the C and O fractionation (resulting in enrichment or depletion) causing variation at each site, changed according to growth period and source of drought.
- The study of stable isotope discrimination will provide more information than radial growth analysis, as analysis of δ^{13}C and δ^{18}O will be used to detect significant relationships with AT, MD, PET and Rainfall in both early and latewood; Enrichment or depletion of δ^{18}O for example may **arise due to changes in temperature or rainfall, but will relate better to VPD, gs or Vcmax**; this showed that isotopic signal should be used as an **indirect correlate of environmental variables**.
- Both δ^{13}C and δ^{18}O concentrations from cellulose of tree ring early and latewood showed similar values (*i.e.* not significantly different) supporting the idea of **pooling tree material from EW and LW** in the same analysis.
- Growth increment in the **EW** phase could be linked to changes in the environment in the **previous season** (Innes 1993), or related to the environmental occurrences during the **corresponding period**

CONCLUSIONS

- Drought periods resulted in reduced growth;
- Changes in radial growth were linked to specific environmental variables;
    - SS: All growth periods sensitive to MD & Rainfall;
    - SP: All growth periods sensitive to MD, Rainfall & AT;
    - DF: Only LW sensitive to MD, Rainfall, AT & PET.
- Effect on growth increased with intensity of drought;
- Isotopic discrimination to be used to investigate whether the reduced growth was carried into subsequent years (lag effect);
- No difference between C and O isotope values in EW and LW periods: simplify to GS;
- Significant relationships between EW $\delta^{13}C$ and $\delta^{18}O$ with AT, PET, Rainfall and MD.

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