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NON-STATIONARY SIMILARITY IN TRENDS OF MONTHLY RAINFALL IN THE TUSCAN APENNINE ALPS

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Purpose of Study

In 2010 Monash University (Australia) began a research program in collaboration with the "Corpo Forestale dello Stato, Uffici per la Tutela della Biodiversità" at Pratovecchio (province of Arezzo, Tuscany) and Vallombrosa (province of Florence, Tuscany). The aim was to investigate the relationships between recent and historical variability of climate, soil and site factors on the diffusion and severity of the 'butt rot' disease in silver fir (*Abies alba* Mill.) in the Tuscan Alps. Silver fir is susceptible to damage caused by drought or insufficient moisture availability. 'Butt rot' severely affects silver fir forests in the study area (Fig. 1), and how climate alterations may impact on intensity and diffusion of the complex disease is very important for the conservation and management of the species, and biodiversity. Therefore, one of our primary objectives was to ascertain if trends in rainfall show alterations during the 20th century in the Tuscan Apennine Alps, what kind of variability in rainfall occurs in the study area, and if alterations in trends of rainfall follow a similar pattern at all sites in the study area.

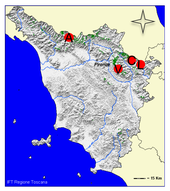


Fig. 1 – Location of the four meteorological stations on tops of the Tuscan Apennine Alps. Abetone is A, Camaldoli is C, La Verna is L, and Vallombrosa is V.

Table 1 – Elevation (m. asl), periods of precipitation data available, and distance between for the four meteorological stations.

	Elevation of the meteo station (m. asl)	Period available (year)	Distance (km)		
		(Precipitation)	LAV	CAM	VAL
ABE	1340	1931-2000	112.3	100.1	84.6
LAV	1120	1924-2006	-	13.2	30.4
CAM	1111	1885-1996	-	-	22.3
VAL	955	1872-2006	-	-	-

Some information about silver fir

- In the study area, a threshold for available soil water is ca. 39 mm
- Annual rainfall >1000 mm
- No water stagnation
- Normally, a temperature threshold for silver fir growth is at least 15 days with daily mean temperature >9ºC and never <0ºC
- Very shade tolerant
- Highly susceptive to climate variations
- 'Anastomosis' may keep trees alive once there are cut

'Butt rot'

Fig. 2 - A complex disease (or a disease complex?) that affects silver fir (*Abies alba* Mill.)

Research Question

Do alterations in trends of rainfall follow a similar pattern during the 20th century across all sites in the Tuscan Apennine Alps (Middle Italy)?

Methods

- EDA: annual, seasonal, and monthly rainfall
- Enhanced visualisation of medium-long term variability: smoothing by 7-years moving averages
- Variations in rainfall above and below the long-term mean: peaks and troughs in trends; upper and lower standard deviation
- Testing the presence of trends: Mann-Kendall trend tests
- Level of association in rainfall series among sites: matrix correlation (Pearson and Kendall)
- 'Proximity' in similarity of rainfall series: Agglomerative hierarchical clustering (AHC)

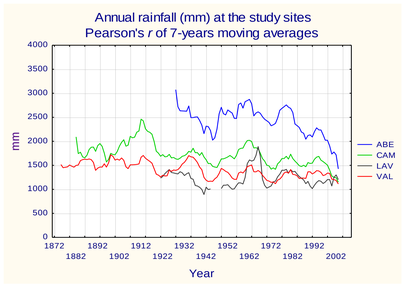
….. *but*

matrix correlation and AHC could not show if similarity in trends among sites is stationary over time; then

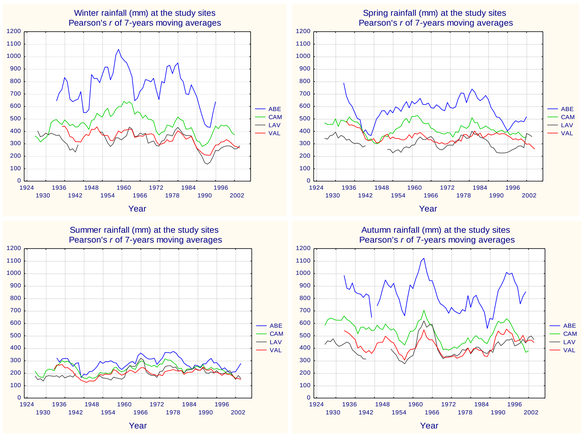
- Pearson's *r* correlation of 7-years moving averages to test whether similarity in rainfall series is non-stationary in the 20th century in the Tuscan Apennine Alps

Results

Trends in annual rainfall in the study area
7-years moving averages



Trends in seasonal rainfall in the study area
7-years moving averages



ABE is Abetone, CAM is Camaldoli, LAV is La Verna, and VAL is Vallombrosa

Association in seasonal rainfall in the study area
Matrix correlation, Pearson's *r* coefficients

The level of association in seasonal rainfall varies irregularly with season and site.
The lower variability within site is shown by ABE, the higher is shown by CAM and LAV.

Winter	ABE	CAM	LAV	VAL
ABE	1	0.77	0.66	0.70
CAM	0.77	1	0.64	0.81
LAV	0.66	0.64	1	0.76
VAL	0.70	0.82	0.76	1

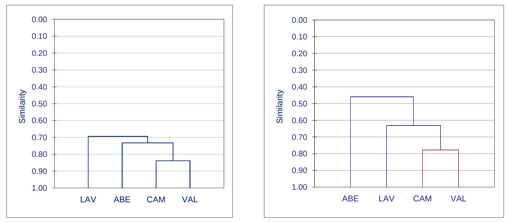
Spring	ABE	CAM	LAV	VAL
ABE	1	0.51	0.57	0.54
CAM	0.51	1	0.65	0.80
LAV	0.57	0.65	1	0.51
VAL	0.54	0.80	0.51	1

Summer	ABE	CAM	LAV	VAL
ABE	1	0.55	0.42	0.55
CAM	0.55	1	0.74	0.80
LAV	0.42	0.74	1	0.61
VAL	0.55	0.80	0.61	1

Autumn	ABE	CAM	LAV	VAL
ABE	1	0.57	0.53	0.63
CAM	0.57	1	0.76	0.78
LAV	0.53	0.76	1	0.71
VAL	0.63	0.78	0.71	1

Agglomerative hierarchical clustering

Dendrograms of similarity in the **winter** (left) and **summer** (right) **rainfall** series at the study sites as shown by agglomerative hierarchical clustering based on the Pearson's correlation coefficient, method 'complete linkage'. Results differ little when the 'unweighted pair-group average' method is applied. 'Distance' between sites changes with season and month.



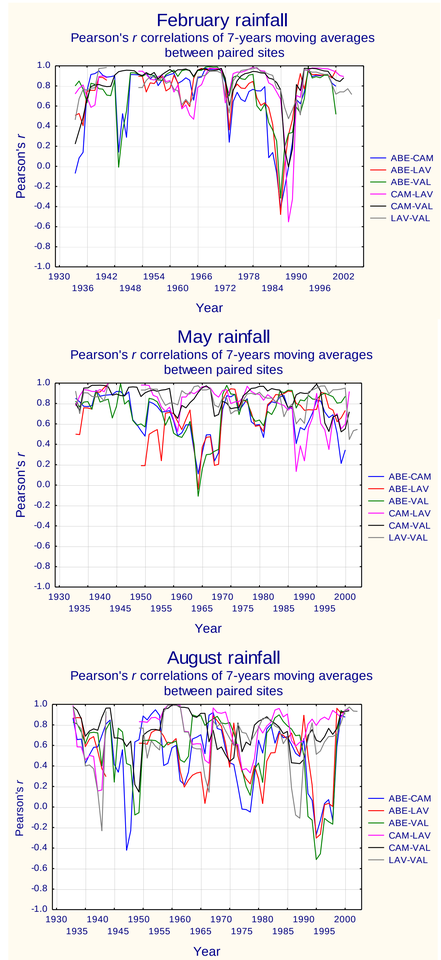
	1st order	2nd order	3rd order
Mar, Apr, Jun, Aug, Sep, Oct	CAM-VAL	LAV	ABE
Dec, Feb	CAM-VAL	ABE	LAV
Jan	CAM-LAV	ABE	VAL
Jul	CAM-LAV	VAL	ABE
May, Nov	LAV-VAL	CAM	ABE

Pearson's coefficients of matrix correlation of autumnal monthly rainfall among sites

Association in monthly rainfall tends to vary amongst sites within months although it is good in general. Instead, no significant correlation appears in the association of monthly rainfall between months.
None of the statistics provide insight into the variability in association over time.

		Sep				Oct				Nov			
		ABE	CAM	LAV	VAL	ABE	CAM	LAV	VAL	ABE	CAM	LAV	VAL
Sep	**ABE**	**1**	**0.71**	**0.56**	**0.64**	0.10	-0.02	0.02	0.09	-0.04	-0.19	-0.20	-0.12
	CAM	**0.71**	**1**	**0.81**	**0.92**	0.00	-0.09	-0.11	-0.03	-0.10	-0.22	-0.17	-0.07
	LAV	**0.56**	**0.81**	**1**	**0.81**	0.00	-0.05	-0.01	-0.02	-0.11	-0.10	-0.04	-0.03
	VAL	**0.64**	**0.92**	**0.81**	**1**	0.01	-0.06	-0.12	0.02	-0.09	-0.09	-0.10	-0.00
Oct	**ABE**	0.10	0.00	0.00	0.01	**1**	**0.78**	**0.73**	**0.82**	0.03	0.08	0.13	0.14
	CAM	-0.02	-0.09	-0.05	-0.06	**0.78**	**1**	**0.84**	**0.93**	-0.09	0.02	0.05	0.01
	LAV	0.02	-0.11	-0.01	-0.12	**0.73**	**0.84**	**1**	**0.81**	-0.05	0.01	0.18	0.04
	VAL	0.09	-0.03	-0.02	0.02	**0.82**	**0.93**	**0.81**	**1**	-0.11	-0.02	0.01	0.04
Nov	**ABE**	-0.04	-0.10	-0.11	-0.09	0.03	-0.09	-0.05	-0.11	**1**	**0.61**	**0.54**	**0.68**
	CAM	-0.19	-0.22	-0.10	-0.09	0.08	0.02	0.01	-0.02	**0.61**	**1**	**0.81**	**0.83**
	LAV	-0.20	-0.17	-0.04	-0.10	0.13	0.05	0.18	0.01	**0.54**	**0.81**	**1**	**0.86**
	VAL	-0.12	-0.07	-0.03	-0.00	0.14	0.01	0.04	0.04	**0.68**	**0.83**	**0.86**	**1**

Non-stationary association of monthly rainfall series amongst sites in the Tuscan Apennine Alps



Although variability in rainfall is likely to influence the real response of silver fir at the local level, none of the statistics used nor regression analyses provide insights into the variability of association in monthly rainfall series over time.
However, marked variability in similarity of seasonal and monthly rainfall amongst sites produces the likelihood of different effects on silver fir growth.

Conclusions

- Results of this research show that the trends in seasonal rainfall in the study area (Tuscan Apennine Alps) vary amongst site and with season during the 20th century
  ⇒ Master series of seasonal rainfall appear of little utility to analyze relationships with forest growth at the site level whereas the major and real effects of rainfall variability occur at the local level
- Variability in monthly rainfall throughout the season is normally high
  ⇒ Master series of seasonal rainfall are unlikely to show differences in rainfall that occur at/or within the monthly level and are important to silver fir growth

in particular...

- Similarity in trends of monthly rainfall from site to site varies irregularly with month and elevation in the study area
  ⇒ The influence of seasonal and monthly rainfall on forest growth can be inhomogeneous over time and amongst sites even at short distance and/or similar elevation

Therefore

The analysis of effects of changes in precipitation on silver fir growth needs to verify climate/tree-growth relationships at the local level in relation to the specific trends in precipitation.
The scope of this study is to verify whether,

- alterations in climate variables receive a similar response in silver fir growth at all sites in the study area

or

- silver fir growth is influenced by climate alterations in ways that vary with site – or elevation - even in relatively small areas