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RECONSTRUCTING THE LAST 3000 YEARS CLIMATE CHANGE IN N-ITALY FROM FOSSIL POLLEN ARCHIVES

Abstract: Vallé F., Furlanetto G., Pini R., Brunetti M., Maggi V. & Ravazzi C., *Recontructing the last 3000 years climate change in N-Italy from fossil pollen archive.* (IT ISSN 0391-9838, 2019).

We applied a newly established procedure to quantitatively estimate summer temperatures during two different time frames (the last 3 ka, the last 200 years) from selected fossil pollen records in northern Italy. The adopted procedure involved three steps: 1) the development of a specific calibration set (modern pollen data and site-specific climate data); 2) the application of numerical methods to the specific calibration set in order to create pollen-climate models based on the relationships between these variables; 3) the application of these models to fossil pollen records. The evaluation of pollen-climate calibration models and of the resulting past climate reconstructions is based on the comparison with instrumental series and with other independent climate proxies.

Key words: Pollen-climate models, Site-specific climate data, Instrumental series, Summer temperature, Late Holocene, N-Italy.

Riassunto: Vallé F., Furlanetto G., Pini R., Brunetti M., Maggi V. & Ravazzi C., *Ricostruzione del cambiamento climatico degli ultimi 3000 anni in N-Italia da archivi pollinici fossili.* (IT ISSN 0391-9838, 2019).

Per stimare in maniera quantitativa le temperature estive per diversi intervalli temporali (gli ultimi 3 mila anni e gli ultimi 200 anni) da record pollinici fossili selezionati in N-Italia è stata impiegata una procedura messa a punto in anni recenti. La procedura adottata si articola in tre fasi: 1) lo sviluppo di uno specifico dataset di calibrazione (dati pollinici moderni e dati climatici sito-specifici); 2) l'applicazione di metodi numerici a tale dataset per ottenere modelli polline-clima basati sulle relazioni tra queste variabili; 3) l'applicazione dei modelli sviluppati ai record pollinici fossili. La validazione dei modelli di calibrazione polline-clima e delle ricostruzioni ottenute si è basata sul confronto con le serie strumentali e con altri proxy climatici indipendenti.

Termini chiave: Modelli polline-clima, Dati climatici sito-specifici, Serie strumentali, Temperature estive, Olocene superiore, N-Italia.

INTRODUCTION

Pollen-climate calibration models based on modern relationships between pollen assemblages and associated climate data can be used to obtain quantitative reconstructions of past climate parameters from fossil pollen data (e.g. Brewer & *alii*; 2007; see Vallé & *alii* in this volume). In this work, we present the application of the so-called "three steps approach" procedure, described by Juggins & Birks (2012) and summarized in another contribution in this volume (Vallé & *alii*, this volume). We will hereby estimate climate parameters for selected fossil records spanning the last 3000 years in the alpine and pre-alpine regions of N-Italy. The diversity of modern pollen deposition sampled in northern Italy, responds most significantly to summer temperature, differently from the southern Italian regions, where modern pollen assemblages are more influenced by January and July temperatures and winter precipitation, as shown by Finsinger & *alii* (2007).

SELECTING A N-ITALY POLLEN-CLIMATE CALIBRATION SET PROVIDED WITH SITE-SPECIFIC CLIMATE DATA

The first requirement of the "three-steps" procedure mentioned in the previous paragraph is the development

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of a representative pollen-climate calibration set (see Vallé & *alii* in this volume). For this work, which focuses on the alpine and prealpine regions, 150 modern pollen samples (or assemblages) from this region (fig. 1) were selected from the larger European Modern Pollen Database (EMPD) (Davis & *alii*, 2013). The modern pollen data extracted from the EMPD were taxonomically harmonized to allow the comparison between modern pollen samples and fossil assemblages. To improve the quality of the calibration, we reconstructed site-specific climate information using the techniques provided in Brunetti & *alii* (2012, 2014) and Crespi & *alii* (2018), instead of the commonly used global climate dataset (e.g. Hijmans & *alii*, 2005). In fact, even the highest resolution global climatological datasets (reaching 1 km^2 of spatial resolution) fail in characterizing the local climate in complex mountain regions: here altitudinal gradients can be very steep and, within a 1 km^2 grid cell, elevation can vary up to 500 m, or even more. Given an average environmental lapse rate of about -0.67 °C/100 m (Furlanetto & *alii*, 2019a), and the well-known altitudinal and topographic effects on local climates, any mountain site-specific temperature estimation, based on a 1 km^2 grid cell, can suffer from an additional error of more than 1 °C.

Monthly instrumental temperature and precipitation series over the 1951-2015 period were first interpolated on each modern pollen sample site selected from the EMPD (see Vallé & *alii* in this volume). Finally, monthly temperature and precipitation mean values for the interval 1951-2000 were associated to each modern pollen assemblage. Summer temperatures were calculated by averaging June, July and August temperature values.

Multivariate analysis of the N-Italy calibration set

The representativeness of the calibration set was analyzed by means of multivariate analysis. The ecological and climate gradients of the selected calibration set were checked running a Canonical Correspondence Analysis (CCA) using as constraining variables the four climate parameters (summer temperature, Tsumm - January temperature, Tjan - spring temperature, Tspring - annual precipitation, Pann) suggested as most important for modern pollen samples in northern Italy in explaining most of their variance (Finsinger & *alii*, 2007). Fig. 2 shows the results of this initial analysis. Most sites from the western Alps (dark blue points in fig. 2A, and fig. 1) are distributed along the first axis (CCA1) thus are better described by temperatures than the samples from the eastern Alps (green dots, fig. 2A). Most pollen taxa close to the axes origin (fig. 2B) are shared between all calibration set samples. To check the importance of each variable in explaining the variance shown by the pollen assemblages calibration set, we run four CCA respectively with Tsumm, Tjan, Tspring and Pann as sole constraining variables. Tab. 1 reports the percentage of the total variance explained by each single variable and the ratio of first constrained (CCA1) to first unconstrained axis (CA1), indicated as λ1/λ2. This ratio represents the "relative explanatory power" of the variable considered in the calibration set; λ1/λ2 values greater than 1.0 indicate that the variable of interest represents an important ecological gradient in the calibration set (e.g. Juggins, 2013 and references therein). It appears that the most important variable for the selected N-Italy calibration set is Tsumm, followed by Tspring.

ACQUISITION OF FOSSIL POLLEN RECORDS COVERING THE LAST 3 KA FOR N-ITALY

All the available palynological records in the geographical and chronological contexts relevant to the NextData Project were considered. The first step of the analysis concerned an accurate bibliographic search that revealed 61 published palynological records from limnic/waterlogged stratigraphic successions partially or entirely covering the

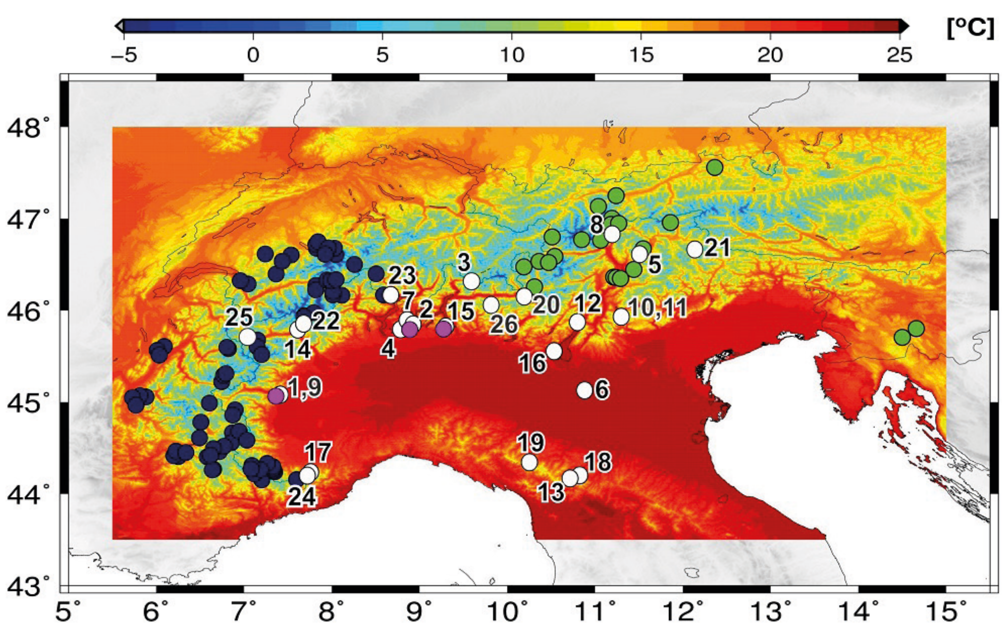


FIG. 1 - Map showing the 26 N-Italy best fossil pollen dataset covering the last 3000 years (white dots and corresponding numbers as listed in tab. 2) and the modern calibration set composed by 150 modern pollen assemblages (dark blue dots are from the western Alps, green dots indicate samples for the eastern Alps, fuchsia dots refer to modern samples from the foothills of the Alps) extracted from the European Modern Pollen Database (Davis & *alii*, 2013) for reconstructing temperatures in northern Italy. The base map presents July climatology obtained from high-resolution models (modified after Brunetti & *alii*, 2014).

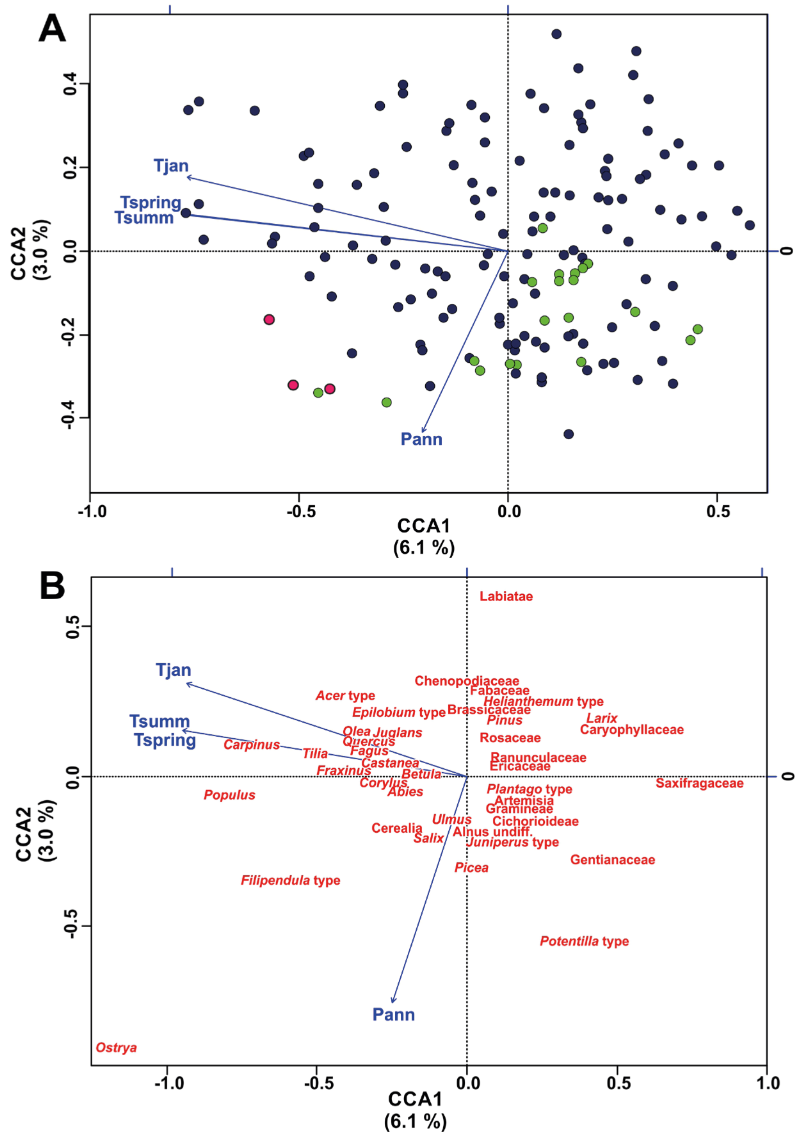


FIG. 2 - Canonical Correspondence Analysis (CCA) biplots of the modern assemblages included in the N-Italy calibration set in relation to 4 climate parameters [January temperature (Tjan), summer temperature (Tsumm), spring temperature (Tspring), and annual precipitation (Pann), blue arrows]. Sample sites and species are arranged in the ordination space with respect to the climate constrains. In A) the focus is on the calibration set sites distribution distinguished in dark blue dots (samples from western Alps, see fig. 1) and green dots (samples from eastern Alps). Fuchsia dots refer to modern samples from the foothills of the Alps. In B) the focus is on pollen taxa distribution (red names). There are several taxa that are in common to the different modern samples (taxa closer to the center of the axes). Pollen taxa with cold temperature optima are located towards higher scores of CCA1 (right edge of CCA axis 1), while taxa with warm temperature optima are arranged left of CCA axis 1.

last 3 thousand years. Those records have been then critically evaluated, with special attention to the quality and robustness of their chronologies – i.e. the number of absolute datings available for each record. The next step involved the acquisition of numerical data (pollen counts and percentages) selecting well-dated pollen records (provided with three or more absolute dates). Those records were included in the "*N-Italy best fossil pollen dataset*" (tab. 2 and fig. 1). Eleven fossil pollen records were obtained from the European Pollen Database (http://www.europeanpollendatabase.net/index.php); six published pollen records were digitized from the original publications. Nine additional fossil pollen records were provided by the Laboratory of Palynology and Palaeoecology of the Institute for the Dynamics of Environmental Processes (IDPA) of the Italian National Research Council. When necessary, the age-models of the selected records were re-processed with OxCal (Bronk Ramsey, 2009) or Tilia (Grimm, 2011) programs by using chronological information from the original publications.

POLLEN-CLIMATE MODELS APPLIED TO THE LAST 200 YEARS FOSSIL RECORDS: ARCHIVES LOCATION, PROPERTIES, AND MODEL EVALUATION BY COMPARISON WITH INSTRUMENTAL DATA

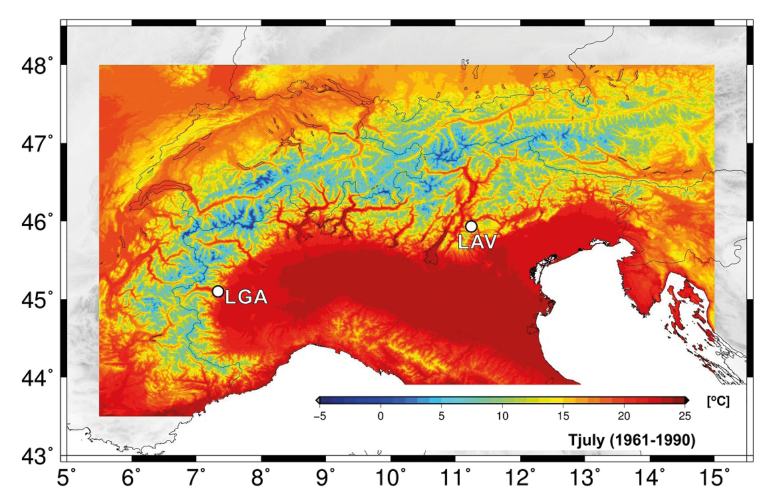
The pollen-climate models developed for past temperature reconstruction in northern Italy have been evaluated by comparing the pollen-inferred temperature series obtained from two pollen records covering the last 200 years with site-specific instrumental series interpolated on the specific site locations following the same procedure discussed above. This comparison allows a direct evaluation of the pollen-climate models developed, compared to the sole evaluation of the model performances in internal cross-validation. Hereinafter, we discuss the methodological approach and the possible bias by human activities in the pollen-inferred reconstructions.

TABLE 1 - Significance of each single climate variable used as constrained for the N Italy calibration set with 150 modern samples. Tsumm shows the highest value for ratio (λ1/λ2) of first constrained (CCA1) to first unconstrained axis (CA1).

	Tsumm			Tspring			Tjan			Pann		
N-Italian Calibration set	CCA1	CA 1	λ1/λ2	CCA1	CA 1	λ1/λ2	CCA1	CA 1	λ1/λ2	CCA1	CA1	λ1/λ2
Eigenvalue	0.058	0.054	1.07	0.057	0.054	1.05	0.057	0.058	0.98	0.025	0.089	0.3
Percentage variance (%)	7.7			7.7			7.6			3.3		
P-value	0.001 ***			0.001 ***			0.001***			0.001***		

These two high-resolution archives covering the last 200 years are located at different altitudes and show different mean climatological conditions. Lago Grande di Avigliana (LGA, 353 m a.s.l.) lies at the foothills of the western Alps: mean July temperature (reference period 1961-1990) is around 22 °C. Lago di Lavarone (LAV, 1115 m a.s.l.) is located in the pre-alpine region: mean July temperature is around 16 °C (fig. 3, modified from Vallé & *alii*, 2018). Sediment cores covering part of the Late Glacial and the whole Holocene were extracted from both lakes and studied for their pollen content to reconstruct the vegetation history, also including land-use changes in the relevant pollen source areas. Pollen records covering the last 200 years from Lago Grande di Avigliana and the last 2200 years from Lago di Lavarone are presented by Finsinger & *alii* (2006) and Arpenti & Filippi (2007), respectively. The sequence from Lago Grande di Avigliana has a good chronological control, based on varve counting, ^{210}Pb and ^{137}Cs dates: mean temporal resolution of the pollen record is ~4 years for the last 200 years. A good age control is available also for the Lago di Lavarone sequence (^{210}Pb and ^{137}Cs dates, for the last 200 years). Its pollen record has a mean sample resolution of ~9 years for the last 200 years with higher temporal resolution after ~1900 AD.

Site-specific monthly instrumental temperature series have been computed for Lago Grande di Avigliana (1833-2010) and Lago di Lavarone (1807-2010) with the methods presented by Brunetti & *alii* (2006, 2012, 2014). To highlight the temperature trends and to facilitate the comparison and the correlation between the instrumental records and the pollen-inferred reconstructions, the instrumental summer temperature series were smoothed with loess regression (for LGA span=0.05, for LAV span=0.1) following the pollen resolution using the PAST statistical software version 3.3 (Hammer & *alii*, 2001).



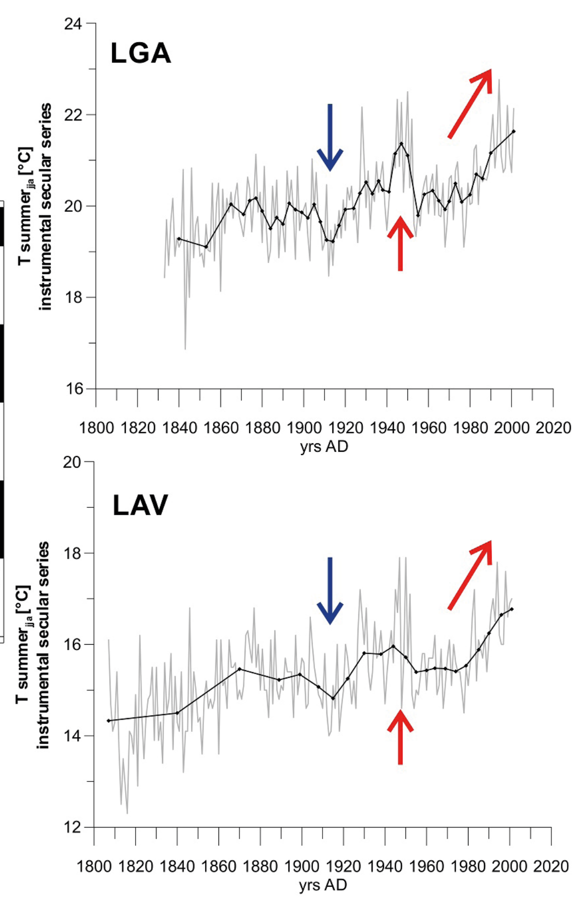


FIG. 3 - Left panel - Location of the study sites Lago Grande di Avigliana (LGA) and Lago di Lavarone (LAV). Right panels - The instrumental summer temperature series computed for these study sites are also shown; the light grey lines represent the annual records and the dark thick lines represent the smoothed records corresponding to the pollen sample resolutions. The warm intervals and the cold interval recorded during the last 200 years are indicated respectively with red and blue arrows (modified from Vallé & *alii*, 2018).

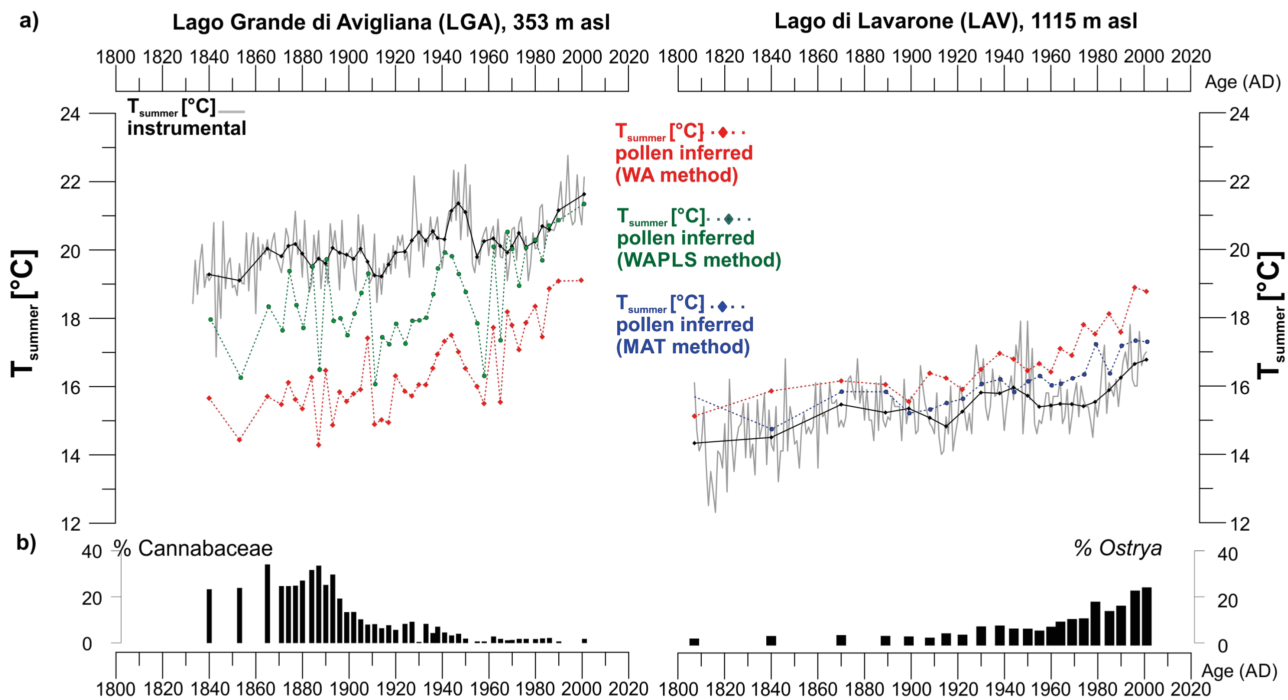


FIG. 4 - Pollen-inferred T summer series obtained with different numerical methods (WA: red dots and lines, WA-PLS: green dots and line, MAT: blue dots and line) compared with the instrumental series computed at LGA and LAV (modified from Vallé & *alii*, 2018).

Application of the numerical methods to the fossil records

The pollen-climate models (or transfer functions) obtained by Weighted Average (WA), Weighted Average Partial Least Square (WAPLS) and Modern Analogue Techique (MAT) methods (see methods description in Vallé & *alii*, this volume and reference therein) were applied to the fossil pollen records to estimate the summer temperature values for the last 200 years. The quality of the calibration set used in terms of availability of modern analogues for each fossil pollen sample was also evaluated using the MAT diagnostic. The "real" validation of the pollen-inferred temperature reconstructions has been obtained by comparing the pollen-based temperature series with the instrumental data. The development of WA, WAPLS and MAT models, the evaluation of their statistical performances, the temperature reconstructions and the MAT diagnostics were obtained using the software R (R Core Team, 2017) and the rioja R package (Juggins, 2017).

Pollen-inferred temperature series for the last 200 years. Comparison with instrumental series

Pollen-inferred summer temperature reconstructions obtained for Lago Grande di Avigliana and Lago di Lavarone are shown in fig. 4 along with their computed instrumental series. WA pollen-inferred summer temperature values obtained for LGA are almost constantly underestimated if compared to the instrumental series. Despite the shift in absolute values at LGA, the decadal variability and the long-term trend in summer temperature instrumental series are also detectable in the pollen-inferred reconstructions, and this is true for both sites. The relatively warmer interval recorded between 1940 and 1950 AD is very well recognized in the LGA pollen-inferred summer T reconstruction. The direct comparison of the WA pollen-inferred summer temperatures with the instrumental series yielded a moderate correlation for LGA (R^2=0.41, p-value <0.001) and a good correlation for LAV (R^2=0.7, p-value <0.001).

During the last two centuries mean air temperature in Italy recorded an increasing trend of 1 °C per century with an intensification in the last decades (Brunetti & *alii*, 2006, 2013). Beside this century-long temperature increase, negative trends over shorter periods have been observed at the beginning of the 19th century and between 1950-1970 AD (Brunetti & *alii*, 2006, 2013). Pollen-inferred summer temperature reconstructions capture the general warming over the last 170 years.

Fig. 4 also presents the pollen percentages of two important pollen producers, namely Cannabaceae from the pollen record of Lago Grande di Avigliana (Finsinger & *alii*, 2006) and *Ostrya* from the pollen record of Lago di Lavarone, which strongly reacted to land use changes in the last centuries. *Cannabis sativa* was in fact cultivated in northern Piedmont in the 19th century until ~1950 AD (Finsinger & *alii*, 2006 and references therein). Reconstructed absolute temperature values were significantly affected by this taxon, being lower than instrumental values, as shown by different solutions provided by a second test after removing Cannabaceae from the pollen sum (not presented in fig. 4). This issue needs to be

TABLE 2 - Metadata of the selected 26 fossil pollen records completely or partly covering the last 3 thousand years. Bold names indicate fossil records that have been used for reconstruction presented in this chapter.

Fossil pollen record	Site name	Lat, Long	Start date	End date	Temporal resolution (last 3ka)	Data type	Data source	Original publication
1) AVG07/02	**Lago Grande di Avigliana**	45° 03’ 54” N 7° 23’ 12” E	1828 AD	2001 AD	4 y	Pollen % calculated from original pollen counts. Age model from the original publication.	EPD (European Pollen Database)	Finsinger & *alii*, 2006
2) Bevera 2000	Lago di Bèvera	45° 51’ 07” N 8° 53’ 39” E	1940 AD	1990 AD	5 y	Pollen % calculated from original pollen counts. Age model from the original publication.	EPD (European Pollen Database)	van der Knaap & *alii*, 2000
3) Bo6-6b	Bondo	46° 20’ 10” N 9° 33’ 09” E	50 AD	1000 AD	35 y	Pollen % calculated from original pollen counts. Age model from the original publication.	CNR-IDPA Milano	Pini & *alii*, 2001
4) BOD5	Bodio	45° 47’ 46” N 8° 45’ 11”E	900 AD	1750 AD	57 y	Pollen % calculated from original pollen counts. Age model from the original publication.	CNR-IDPA Milano	Furlanetto & *alii*, 2015.
5) DuraMoor 1980	Dura Moor	46° 38’ 24” N 11° 27’ 32” E	11,400 BC	1980 AD	130 y	Pollen % calculated from original pollen counts. Age model revised from EPD.	EPD (European Pollen Database)	Seiwald, 1980
6) FOR6	Forcello	45° 06’ 39” N 10° 50’ 15”E	1300 BC	1150 AD	148 y	Pollen % calculated from original pollen counts. Age model from the original publication.	CNR-IDPA Milano	Ravazzi & *alii*, 2013
7) Ganna 2000	Lago di Ganna	45° 53’ 52” N 8° 49’ 33” E	1922 AD	1990 AD	3 y	Pollen % calculated from original pollen counts. Age model from the original publication.	EPD (European Pollen Database)	van der Knaap & *alii*, 2000
8) Kurzmoos 2000	Kurzmoos	46° 52’ 00” N 11° 09’ 00” E	15,000 BC	1960 AD	115 y	Pollen % digitized from the original publication. Age model revised.	Original publication	Stumböck, 2000
9) LagoPiccolo Avigliana 2006	Lago Piccolo di Avigliana	45° 03’ 17” N 7° 23’ 31” E	18,000 BC	1600 AD	61 y	Pollen % calculated from original pollen counts. Age model from the original publication.	EPD (European Pollen Database)	Finsinger & Tinner, 2006 Finsinger & *alii*, 2008
10) Lavarone P1P2	**Lago di Lavarone**	45° 56’ 11” N 11° 15’ 09” E	16,000 BC	1730 AD	125 y	Pollen % calculated from original pollen counts. Age model from the original publication.	CNR-IDPA Milano	Filippi & *alii*, 2007
11) Lavarone S5	**Lago di Lavarone**	45° 56’ 12” N 11° 15’ 08” E	200 BC	2000 AD	59 y	Pollen % calculated from original pollen counts. Age model from the original publication.	CNR-IDPA Milano	Arpenti & Filippi, 2007 Filippi & *alii*, 2007
12) LedroII coreL1	Lago di Ledro	45° 52’ 38” N 10° 45’ 59” E	3000 BC	2000 AD	70 y	Pollen % digitized from the original publication. Age model revised.	Original publication	Magny & *alii*, 2009
13) LGB	Lago del Greppo	44° 07’ 11”N 10° 40’25”E	12,000 BC	2000 AD	98 y	Pollen % digitized from the original publication. Age model revised.	Original publication	Vescovi & *alii*, 2010
14) Lod 1996	Lac de Lod	45° 48’ 9” N 7° 36’ 35” E	950 BC	1450 AD	68 y	Pollen % calculated from original pollen counts. Age model revised from EPD.	EPD (European Pollen Database)	Brugiapaglia, 1996
15) Ls-3a	Lago del Segrino	45° 49’ 40” N 9° 15’ 52” E	12,000 BC	1990 AD	60 y	Pollen % digitized from the original publication. Age model revised.	Original publication	Gobet & *alii*, 2000
16) LucDt1t2	Lucone	45° 32’ 53” N 10° 29’ 39” E	6000 BC	1450 AD	75 y	Pollen % calculated from original pollen counts. Age model from unpublished data.	CNR-IDPA Milano	Unpublished data
17) Mondovi 2003	Mondovì	44° 11’ 23” N 7° 43’ 58” E	10,000 BC	1350 AD	155 y	Pollen % calculated from original pollen counts.Age model revised from EPD.	EPD (European Pollen Database)	Ortu, 2008 Ortu, 2003
18) Ospitale 1996	Ospitale	44° 9’ 20” N 10° 46’ 48” E	4000 BC	1500 AD	80 y	Pollen % calculated from original pollen counts. Age model revised.	EPD (European Pollen Database)	Watson, 1996
19) Padule 1996	Padule	44° 17’ 55” N 10° 12’ 53” E	8500 BC	1970 AD	125 y	Pollen % calculated from original pollen counts. Age model from EPD.	EPD (European Pollen Database)	Watson, 1996
20) PGB1	Pian di Gembro	46° 09’ 53” N 10° 09’ 12” E	12,000 BC	1998 AD	60 y	Pollen % calculated from original pollen counts.Age model from the original publication.	CNR-IDPA Milano	Pini, 2002
21) PRKL01/01	Lago di Braies	46° 41’ 38” N 12° 05’ 08” E	2100 BC	2000 AD	40 y	Pollen % digitized from the original publication. Age model revised.	Original publication	Schneider & *alii*, 2010
22) SantAnna 1996	Tourbière de Santa Anna	45° 51’ 30” N 7° 39’ 15” E	8000 BC	1700 AD	250 Y	Pollen % calculated from original pollen counts.Age model revised.	EPD (European Pollen Database)	Brugiapaglia, 1996
23) SEG1	Segna	46° 10’ 50” N 8° 38’ 23” E	850 BC	2000 AD	95 y	Pollen % digitized from original publication. Age model revised.	Original publication	Valsecchi & *alii*, 2010
24)Selle Carnino1977	Selle di Carnino	44° 9’ 0” N 7° 41’ 40” E	14,000 BC	1550 AD	132 y	Available pollen percentages_calculated from original pollen counts. Age model revised from EPD.	EPD (European Pollen Database)	de Beaulieu, 1977
25) Rutor composite record	**Rutor (TbValter)**	45° 40’ 20.3” N 6° 59’ 45.61” E	Covers last 8800 years		120 y	Pollen % calculated from original pollen counts.Age model from the original publication.	CNR-IDPA Milano	Badino & *alii*, 2018
26) Arma	**Armentarga**	46° 02’2 6.64” N 9° 52' 44.26" E	Covers last 10,000 years		100 y	Pollen % calculated from original pollen counts.Age model from the original publication.	CNR-IDPA Milano	Furlanetto & *alii*, 2018

carefully considered because this pollen *taxon* is not well represented in the used calibration set. Concerning *Ostrya*, today this tree species is the main component of forest vegetation in the pollen source area of Lago di Lavarone. Its expansion started around 1965 AD, favored by a declining intensity of livestock husbandry in the area (Arpenti & Filippi, 2007). The overestimation of WA pollen-inferred temperatures compared to the instrumental series after 1965 AD at Lavarone (fig. 4) is related to the high percentages of *Ostrya* in those samples. This overestimation is reduced when using a MAT model solution (fig. 4).

We are aware that WA methods are able to solve the "non-analogues" problem (i.e. the absence of good modern analogues in the calibration set, for each fossil pollen sample) but suffer from the "edge effects" (that is due to the difficult estimation of the climate parameters at the edges of the calibration set climate gradient) (e.g. Juggins & Birks, 2012 and reference therein). The constant underestimation of the Lago Grande di Avigliana pollen-inferred summer temperature might be also due to the fact that this site shows summer temperature values at the end of the gradient of the calibration set. This shift in absolute values (which does not affect the long-term variability) is reduced by using the WAPLS model (fig. 4).

TEMPERATURE RECONSTRUCTIONS FOR THE LAST 3000 YEARS AND THEIR EVALUATION BY COMPARISON WITH OTHER CLIMATE PROXIES

Pollen-climate models were applied to four fossil records at different elevations, namely the Rutor record (2500 m a.s.l.; Badino & *alii*, 2018), Armentarga (2345

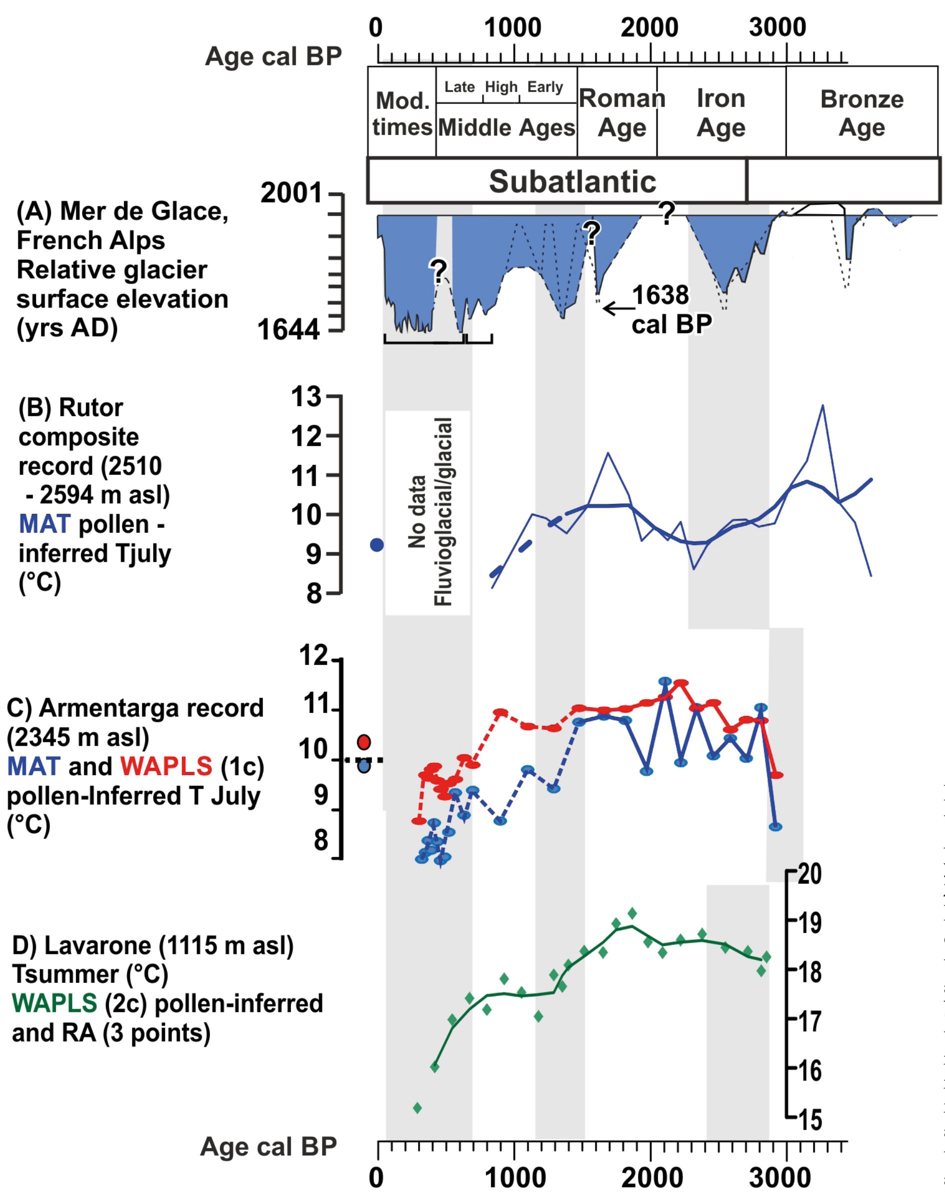


FIG. 5 - Summer temperature reconstructions obtained from fossil sites from the Alpine region covering the last 3000 years [Rutor (B) (from Badino & *alii*, 2018), Armentarga (C) (redrawn from Furlanetto & *alii*, 2018), Lavarone (D) compared with A] glacier surface elevation (redrawn from Le Roy & *alii*, 2015) as independent climate proxies. Grey bands indicate colder periods characterized by glacier advances. RA = Running Average. Green curve and rhombi mean that reconstruction method used is WAPLS 2 components (2c), blue curve and dots represent reconstruction obtained with MAT method while red lines and dots indicate the use of WAPLS 1 component (1c).

m a.l.s.; Furlanetto & *alii*, 2018) and Lago di Lavarone (1115 m a.s.l.; Arpenti & Filippi, 2007). Fig. 5 presents the reconstructions compared with the glacier advances record from the French Alps (Le Roy & *alii*, 2015), which is used here as independent proxy for summer temperatures. Colder intervals indicated by glacier advances are reconstructed from the pollen records as relatively colder temperature. A warmer phase chronologically set into the Roman age is mirrored by warmer temperatures reconstructed in all the four pollen-inferred temperature records. Furthermore, the temperature series reconstructed at the Armentarga and Lavarone sites (C and D in fig. 5) show similar patterns, especially during the last 2000 years, despite their different elevations. A warmer phase around 2 ka, chronologically constrained during the Roman Age, is identified in both records, and followed by a general trend of decreasing temperatures, marked by two steps, the first around 1500-1200 yrs cal BP, and the second around 500 yrs cal BP.

CONCLUSIONS AND OUTLOOK

Our results show that pollen records obtained from lacustrine/palustrine archives can be used to obtain pollen-inferred reconstructions of temperatures revealing trends comparable to instrumental data over the last 200 years. Some requirements need to be fulfilled: 1) pollen records must have a robust age control and high sample resolution (ideally less than a decade), 2) proper calibration sets and adequate numerical techniques must be used to develop pollen-climate models and transfer functions to be applied to fossil pollen records. The human activities and their effects in the pollen relative abundances must be considered and evaluated in the process of taxa selection before applying quantitative methods. Reconstructions obtained for the last 3000 years are comparable with other climate proxies such as glacier front advances and temperatures reconstructed from tree-rings series.

Holocene precipitation reconstructions based on pollen data were obtained using a fossil pollen record from a high-elevation site located in the oceanic external alpine chains of Lombardy (Furlanetto & *alii*, 2018). The modern calibration dataset used in Furlanetto & *alii* (2018) was designed to increase the percentage of variance of the modern pollen data explained by the precipitation. The resulted Holocene precipitation reconstruction was found statistically significant and the inferred changes were in agreement with the fluctuations of lake levels (Furlanetto & *alii*, 2018).

As a future perspective, it is worth experimenting the use of climate indexes that combine different climate parameters, e.g. summer temperature and precipitation in the Alps, or annual precipitation and T winter in regions affected by Mediterranean climates. This would increase the variance explained in modern pollen assemblages from different geographical regions and will improve the potential of pollen data as quantitative climate predictors.

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