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QUANTITATIVE RECONSTRUCTIONS OF QUATERNARY CLIMATES USING POLLEN: ASSUMPTIONS, NUMERICAL TECHNIQUES AND CALIBRATION DATASETS

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ABSTRACT: Pollen assemblages are increasingly used for quantitative reconstructions of past climate parameters. Estimated temperatures and precipitations can be coupled with palaeoecological records to make their interpretation more robust. Although the potential of numerical techniques is suggested by published and ongoing researches, improvements in the calibration datasets used to compare fossil and modern pollen spectra are needed. Current limitations within the European Modern Pollen Database concerning data quality and density are discussed. Attention is given to altitudinal training sets of modern pollen rain - vegetation - climate - terrain parameters, allowing a better understanding of pollen dispersal and deposition across elevational gradients.

KEYWORDS: Quaternary, northern Italy, climate, pollen, quantitative reconstructions, altitudinal training sets

1. INTRODUCTION

Pollen is used since the early XXth century as a tool to reconstruct vegetation and environments and their reaction to climate change and human pressure. The potential of pollen spectra as descriptors of past climate conditions is gaining increasing interest in the Quaternary community (Juggins and Birks, 2012). New pollen records are produced every year from different ecological and climatic regions, thanks to the exceptional fossilization potential of palynomorphs and to the possibility of identifying them with high taxonomic resolution. Coupling traditional pollen-stratigraphical researches with quantitative climate reconstructions based on the same compilation of data can indeed provide new hints for the interpretation of palaeoecological records and improve our understanding of man-environment interactions.

Statistical approaches based on regression - calibration and modern analogues were developed for different types of microscopic biological remains (chironomid: Eggermont and Heiri, 2011; chrysophytes: Kamenik and Schmidt, 2005; cladocera: Brodersen et al., 1998; diatoms: Birks et al., 1990; pollen: see references cited in Seppä et al., 2004) and they are currently used for quantitative estimations of past temperatures, precipitation, chemical and trophic state of water bodies. To do so, the development of transfer functions connecting modern calibration data sets and fossil ones is needed. As far as pollen is concerned, the European Modern Pollen Database (EMPD; Davis et al., 2013) is used as source for statistically-based comparisons between fossil and modern pollen spectra. Although the relevance of this dataset is undeniable, several points need to be fixed in order to provide the Eurasian pollen-community with an ecologically sound and complete tool for palaeoclimate reconstructions.

This contribution will focus on principles and techniques of quantitative climate reconstructions using pollen, the relevance of such reconstructions for our understanding of past ecological systems and on advantages/ disadvantages of current calibration datasets.

2. METHODS: A SHORT REVIEW ON PRINCIPLES AND TECHNIQUES OF QUANTITATIVE CLIMATE RECONSTRUCTIONS BASED ON POLLEN

Some biological assumptions support the use of pollen as a proxy of climate. As regional vegetation is influenced by climate, we might expect that the climate variability plays a relevant role not only in the extent of vegetation communities and their composition, but also on pollen productivity and deposition modes. The validity of this hypothesis was checked by several authors (Sjögren et al., 2006 and references therein). Pollen proportions and Pollen Accumulation Rates (PAR) can indeed be considered as a response of vegetation and depositional processes to climate conditions. Before using pollen as climate descriptor, a few requirements need to be met: **(1)** a calibration training set of pollen deposition and associated temperature/precipitation data must be available for a given climate gradient; **(2)** the relationships between pollen descriptors and modern climate parameters must be modelled; **(3)** quantitative climate parameters can be estimated through the application of the model (transfer function) to fossil pollen data.

Requirement #1 may be fulfilled by subsets extracted from the European Modern Pollen Database (Fig. 1). Requirements #2 and #3 are tackled through numerical techniques of regression-calibration and search for modern analogues, namely WA (Weighted Averaging), WA-PLS (Weighted-Averaging Partial Least Square) and MAT (Modern Analogue Technique) (Fig. 2).

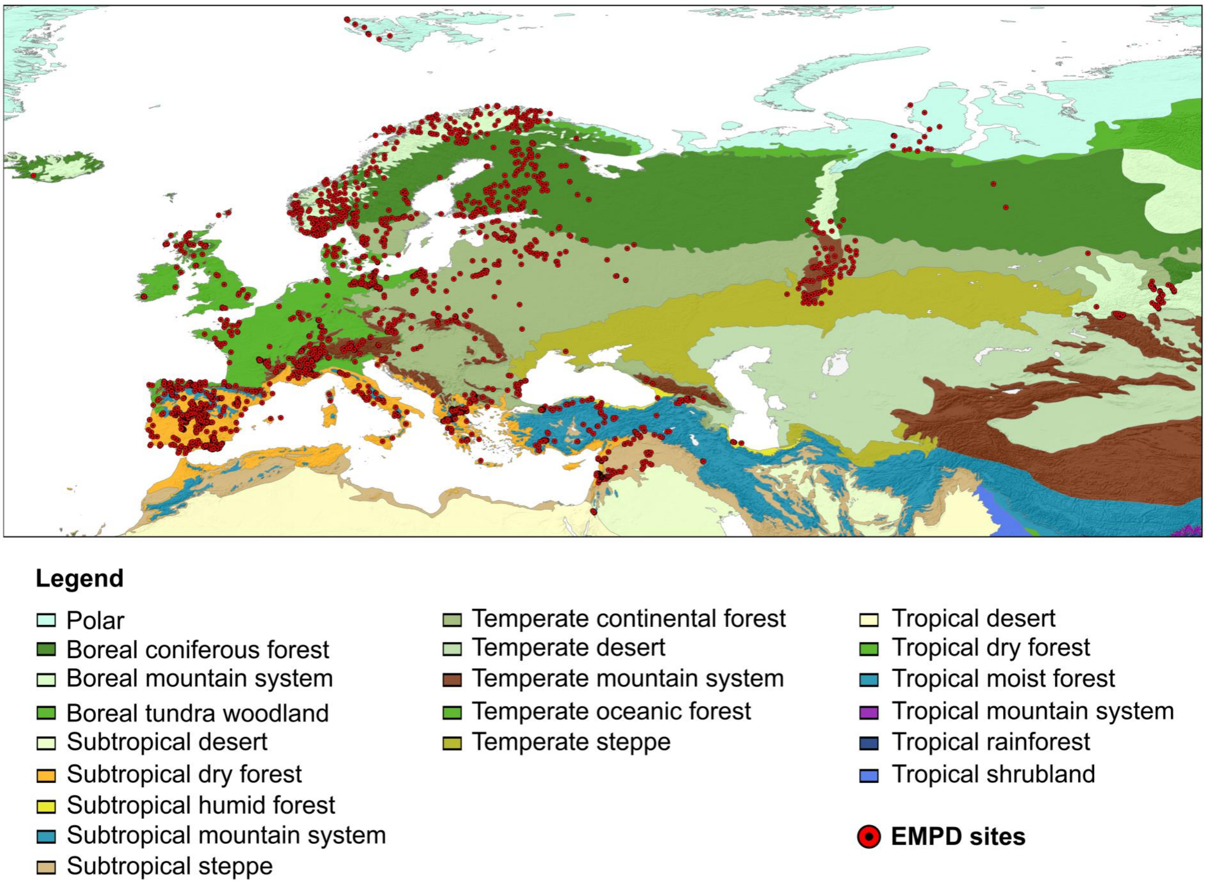

Fig. 1 - geographical extent of the European Modern Pollen Database (EMPD: Davis et al., 2013). Red dots indicate the location of the 4270 sampling sites superimposed on the spatial distribution of global ecological zones (GEZ) proposed by the Global Forest Resources Assessments (GRFA) of FAO (http://www.fao.org/forest-resources-assessment/remote-sensing/global-ecological-zones-gez/en/). Metadata, as well as pollen and climate data associated to each EMPD site shown in the map can be downloaded at http://www.europeanpollendatabase.net/wiki/doku.php?id=empd_download_database

3. THE EUROPEAN MODERN POLLEN DATABASE: ITS CONTENT AND SOME MAIN LIMITATIONS

More than 4200 modern pollen samples with associated climate data are stored in the current EMPD version (Fig. 1). Samples cover a large part of Eurasia, from Portugal to Siberia, from Fennoscandia to the Near East; a large variety of ecosystems is represented. The effort done by Davis et al. (2013) to make this database available to the scientific community is impressive and no progresses in the direction of using pollen as a proxy of climate could be possible without this calibration set. Nevertheless, the EMPD has some limitations; they do not hamper its use, although refinements would greatly increase its potential. The main disadvantages are here listed:

1) uneven quality of the taxonomic identification of pollen grains. Unfortunately there is no common rule on the degree to which palynologists identify pollen grains; this results in a great issue when pollen spectra counted by hundreds of different analysts are gathered in a common dataset. Just two examples: keeping the pollen of climate-sensitive timberline species such as *Pinus cembra* separated from *Pinus sylvestris/mugo* and *Alnus viridis* from *Alnus glutinosa/incana* can greatly enhance the quality of pollen-reconstructed climate series in the high-altitude Alps (Furlanetto et al., unpublished data). At an alpine scale, only 68 modern pollen spectra out of the available 270 comply these rules.

2) uneven spatial and temporal distribution of the sampling sites. Fig. 1 shows that, despite the wide latitudinal and longitudinal extents covered by the EMPD, large areas still have poor or no sample coverage. This is the case, for example, of the area between the Balkans and the Carpathians, the Ukrainian Plains, Western Siberia, the Mediterranean islands and the Po Plain. Some of the ecosystems represented in these areas (garrigue, steppes, forest-steppe ecotones and taiga) are not sufficiently sampled in the EMPD, resulting in an incomplete representation of the ecological gradient of several plant species.

3) data stored in the EMPD do not provide a consistent picture of pollen dispersal along mountain altitudinal

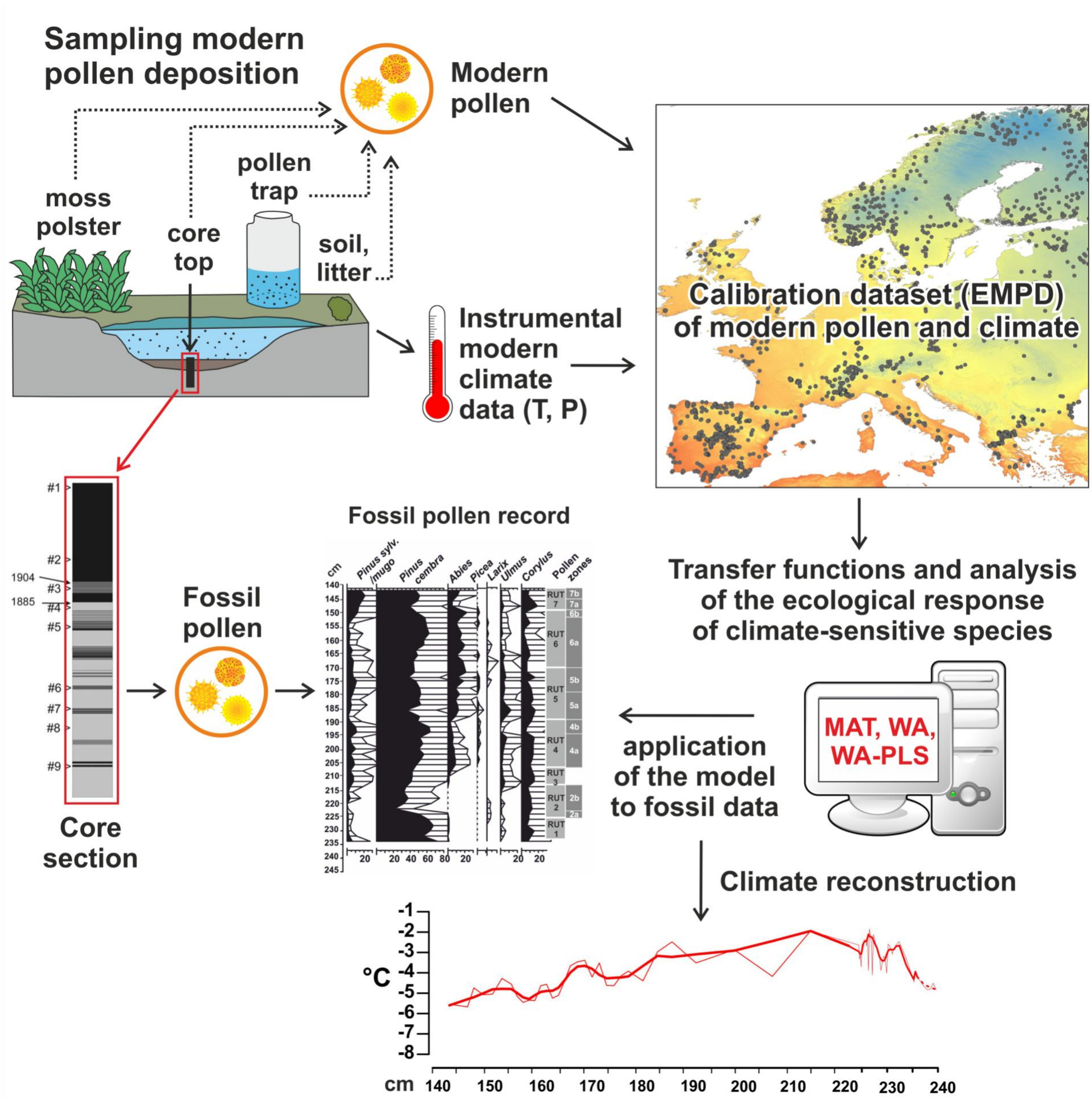

Fig. 2 - schematic representations of the materials and methods involved in a quantitative climate reconstruction based on pollen grains (redrawn and modified after Juggins and Birks 2012). Modern pollen deposition can be analyzed in different typologies of samples (mosses, core tops, artificial pollen traps, soil, litter): these data are accompanied by information on site-specific temperature and precipitation. The calibration dataset used for the development of paleoclimate transfer functions is composed by thousand of modern sites. Transfer functions are then applied to fossil pollen spectra for the reconstruction of past climate parameters.

gradients of Eurasia, given the limited number of samples collected from the same catchment trunk. The issue of long-distance transport of pollen is well known to researchers working in mountain areas and it must be carefully considered when using pollen data for palaeoenvironmental reconstruction and inferences on past climate. To overcome this issue, the development of local altitudinal training sets is needed (see section 4).

4) variations of pollen deposition throughout sedimentary processes and the effects of human activities on the accumulation of microbiological particles are poorly accounted by EMPD sampling. Long-distance floated and airborne associations of alluvial, marine and aeolian environments are almost not represented in the EMPD. Those issues have to be carefully considered when working in archaeological sites and cultural landscapes.

4. ALTITUDINAL TRAINING SETS OF MODERN POLLEN AND CLIMATE FOR PROXY CALIBRATION ALONG MOUNTAIN VALLEYS

We recently developed two calibration sets of modern pollen rain - vegetation cover - climate data - terrain parameters in the western and central Alps (La Thuile and Brembana Valleys, respectively; Badino, 2016 and Furlanetto et al., submitted); in the same valleys palaeoecological researches on high-altitude mires were in progress. At each sampling site we carried out vegetation surveys and monitoring of modern pollen deposition through the analysis of moss samples. Site-specific temperature and precipitation series, covering the 1951-2015 period, were reconstructed for each sampling site by means of the anomaly method (New et al., 2000; Mitchell and Jones, 2005) as described in Brunetti et al. (2012). The aim of such big efforts was to obtain valley-specific proxies' calibration along altitudinal transects and to improve our knowledge on the relationships between the selected parameters.

Data collected with our two alpine calibration sets were used, along with the EMPD data, for temperature and precipitation reconstructions of Holocene pollen records from two high-altitude sites in the continental western Alps (Badino et al., 2018) and in the oceanic external alpine chains of Lombardy (Furlanetto et al., in progress). Pollen-inferred climate reconstructions show a significant comparison with independent proxies of climate such as the extent of some alpine glaciers (Holzhauser et al., 2005; Le Roy et al., 2015), pollen and chironomid-inferred temperature records from the swiss and Austrian Alps (Wick et al., 2003; Ilyashuk et al., 2011), isotopic records from alpine speleothems (Luetscher et al., 2011; Fohlmeister et al., 2013) and the sequence of cold periods in the Alps (Zoller et al., 1966; Patzelt and Bortenschlager, 1973).

5. CONCLUSION

Similarly to other biological remains, pollen can be used for quantitative reconstructions of past temperatures and precipitations. In the past decade, progresses were recorded in the numerical techniques employed for this purpose and in the digital platforms where specific software packages are executed. For robust climate reconstructions, a thorough knowledge of the relationships between modern pollen deposition, temperature and precipitation is mandatory. The availability of continental-wide calibration sets (European Modern Pollen Database - EMPD, North American Pollen Database - NAPD, East Asian Pollen Database - EAPD, African Pollen Database - APD, etc.) is acknowledged. Improvements in the quality and quantity of data stored in these datasets are needed, to increase the performance of the modern-to-fossil transfer functions for past climate reconstructions.

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