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Cenozoic paleotemperatures and leaf physiognomy — A European perspective

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Abstract

For 21 European leaf-floras (with a focus on Central Europe), which span a stratigraphic range from the Late Eocene to the Pliocene, paleoclimate estimates have been calculated using five different quantitative techniques: (a) leaf margin analysis (LMA_1), using a regression model based on data from East Asia, (b) the multivariate Climate Leaf Analysis Multivariate Programm (CLAMP) technique, based on data from East Asia and N.-America, (c) a recently developed multivariate technique based on modern European vegetation (ELPA), (d) a provisional LMA regression model based on the vegetation of several wet localities from N.-America (LMA_2), and e) the Coexistence Approach (CA), a technique based on comparisons with the nearest living relatives (NLRs) of fossil taxa. According to our results there seems to be certain discrepancies where the different techniques are compared for paleotemperatures estimates, depending mainly on the stratigraphic age of the floras. For Paleogene floras, both multivariate leaf physiognomic techniques are in rather good agreement with CA, although both techniques may differ considerably from each other. In contrast, for the Neogene, CLAMP shows a tendency to produce estimates that are considerably colder than CA, whereas ELPA, provides generally warmer estimates, and is in better agreement with CA and other independent evidence. Our results and interpretations add some *caveats* to temperature reconstructions based on leaf physiognomy, especially when applied to European floras from older periods (i.e. Paleogene, Cretaceous). Possible changes of the relationship between climate and leaf physiognomy over time should be taken into account as a possible source of error whenever such techniques are used. There is the possibility that the actual correlation between climate and leaf form may be modified by long-time evolutionary responses or floral changes, leading to erroneous paleoclimate estimates, if a calibration data-set is used, which is not suited for the region and time-interval in question. However, further research will be needed to test whether such changes in the relationship between climate and leaf physiognomy over time can also be detected on other continents, or whether this is a problem restricted to Europe.

Keywords: Paleotemperatures; Cenozoic; Nearest living relatives; Leaf physiognomy; Europe

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1. Introduction

Understanding paleoclimate may be essential for our understanding of future climatic situations evolving during contemporary and future global climate change. For the terrestrial realm, fossil plants are generally considered to represent excellent paleoclimatic proxies. Consequently, in recent decades a number of different techniques have been developed for the estimation of paleoclimate parameters relying on fossil plant remains. Unlike taxonomically based techniques established by comparisons with the nearest living relatives (NLRs) of fossil plants (e.g., Kershaw and Nix, 1988; Mosbrugger and Utescher, 1997; Mosbrugger, 1999), non-taxonomically based techniques depending on correlations between certain climatic parameters and leaf physiognomy are considered by many authors to represent powerful and reliable tools for the estimation of paleoclimatic parameters. This is because such methods are considered to be independent of the correct identification of fossil leaves (e.g., Wolfe, 1979, 1993; Wing and Greenwood, 1993; Wolfe, 1995; Wilf, 1997; Wolfe and Spicer, 1999; Roth-Nebelsick et al., 2004). Despite the general acceptance of leaf physiognomic methods by many authors, there is still intense debate on the applicability of certain leaf physiognomic techniques for the reconstruction of Cenozoic paleotemperatures (e.g. Boyd, 1994; Mosbrugger and Utescher, 1997; McIver and Basinger, 1999). For example, several applications of leaf physiognomic techniques to paleofloras of the European and Asian Neogene yielded mean annual temperatures (MAT) which were considerably lower than those derived by other paleobotanical techniques (e.g. NLR techniques), and also than those indicated by independent geological and paleontological evidence (e.g. Mosbrugger and Utescher, 1997; Utescher et al., 2000; Kvaček et al., 2002; Liang et al., 2003; Kowalski and Dilcher, 2003; Uhl et al., 2006).

Kowalski and Dilcher (2003) suggested that leaf physiognomic reconstruction techniques may tend to underestimate paleotemperatures since paleofloras are dominated by leaves from wet environments, which show a greater proportion of toothed leaves in modern vegetation than has been documented from “standard” correlations between climate and leaves from less mesic habitats, a fact first recognized by Burnham et al. (2001). To overcome such a bias, Kowalski and Dilcher (2003) proposed an alternative, though provisional, regression model for these floras, based on a modern calibration data-set derived from wet environments. Although this approach yielded temperature estimates for both fossil and modern assemblages that were closer to other (independent) evidence, persistent lower paleotemperature estimates for a number of European Neogene paleofloras left the discussion still open (e.g. Mosbrugger and Utescher, 1997; Utescher et al., 2000; Kvaček et al., 2002; Liang et al., 2003; Kowalski and Dilcher, 2003; Uhl et al., in press). Further, considering paleotemperature reconstructions not only from the Neogene, but also from the Paleogene of Europe, it is evident that in many cases the estimates derived from leaf physiognomic techniques are actually in good agreement with other paleoclimatic evidence, despite the fact that at least some of these Paleogene floras certainly also originated from wet environments (e.g. Uhl et al., 2003; Roth-Nebelsick et al., 2004; Kvaček and Walther, 2004). To elucidate whether these observations can be generalized or not, we compared the paleotemperature estimates derived from several quantitative techniques for thirteen Neogene and eight Paleogene floras from Europe. For this purpose, we used methods based on different modern calibration data sets originating from different continents, to see whether there are any systematic patterns.

2. Material and methods

2.1. Material

For this meta-analysis we have chosen 21 European leaf-floras (with a focus on Central Europe) which span a stratigraphic range from the Late Eocene to the Pliocene (cf. Table 1). The floras have been selected based on the following criteria:

1) diversity of the flora, with well known taxonomic composition
2) extremely good preservation and documentation of leaf physiognomy
3) coverage of a wide area of depositional environments by individual floras.

Stratigraphic and taxonomic details for the individual floras, as well as their depositional settings can be found in the citations given in Table 1 and will not be repeated here.

2.2. Methods

We applied several frequently used leaf physiognomic techniques including (a): leaf margin analysis (LMA_1) (using a regression model established by Wing and Greenwood (1993); based on data from East Asia from Wolfe (1979)) and (b) the multivariate Climate Leaf Analysis Multivariate Program (CLAMP) technique (based on data from East Asia and N.-America;