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Climate changes in the central Mediterranean and Italian vegetation dynamics since the Pliocene

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ABSTRACT

Pollen records and pollen-based climate reconstructions from the Italian peninsula (central Mediterranean) show clear signals of vegetation change linked to variations in water availability in the Mediterranean basin over the past 5 million years. Profound vegetation changes occurred in four major steps from the Pliocene to the present. The subtropical taxa that dominate Pliocene assemblages declined and then disappeared between 3–2.8 and 1.66 Ma (at around 2.8 Ma in the North and later in the South), progressively being replaced by temperate *Quercus* forests at mid altitude. In the south Italy, *Quercus* expanded more at around 1.4–1.3 Ma and *Fagus* proportions increased after 0.5 Ma. Conifer forest (first mainly composed of *Tsuga* then by *Abies* and *Picea)* began to expand at 2.8 Ma, probably rather at high altitude, beginning at 2.8 Ma. Mediterranean-type forest, rare during the Early Pleistocene, developed and increased in diversity during the Middle Pleistocene. Open landscapes, with higher abundances of steppic taxa, became more frequent and extensive at the onset of Glacial/Interglacial (G/I) cyclicity around 2.6 Ma and gradually expanded with more and more marked glacials. Climate reconstructions done on selected pollen records from southern Italy suggest a decline in winter temperature and annual precipitation from the early Pleistocene to the Holocene. Specifically, both precipitation and winter temperature reconstructions show changes in interglacial maxima and glacial minima at around 3–2.8 Ma, 2 Ma, 1.3–1.4 Ma and 0.5 Ma.
This critical review provides evidence that the North–South precipitation gradient, with drier conditions in the South, has been a consistent feature of the Italian peninsula since the beginning of the Pleistocene.

1. Introduction

The Mediterranean basin is considered a global biodiversity hotspot (e.g. Médail and Quézel, 1997, 1999; Giorgi, 2006; Christensen et al., 2007). Given projections of future regional climate change, growing demographic pressures in coastal zones, and the particular importance of water resources in the region, the preservation of ecosystems within the basin is considered a key goal for governments (IPCC, 2007). Water availability is a key factor limiting plant growth and is an important driver of vegetation composition (Daget, 1977; Venetier et al., 2010). The future composition of Mediterranean ecosystems is thus clearly tied to water availability. While modern vegetation data from the region provide a baseline for understanding relationships between aridity and vegetation composition, paleoecological records provide support for

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understanding vegetation responses at longer time scales (e.g. Bertini, 2010; Joannin et al., 2012; Combourieu-Nebout et al., 2013; Peyron et al., 2013 and references therein). Paleoecological records show that aridity, as a feature of the Mediterranean basin, appeared recently, gradually increasing up to the present time (Pons et al., 1995). Even during the Messinian salinity crisis (MSC, 5.9–5.3 Ma), aridity did not play a major role in restructuring vegetation (Suc and Bessais, 1990; Bertini, 2006; Fauquette et al., 2006 and references therein). What we now call Mediterranean-type taxa have been present in the basin since the Paleocene, but only sporadically until they increased in importance during the last several thousand years. The development of modern Mediterranean ecosystems seems to be linked to increasing dryness and seasonality, with increasingly dry summers focusing moisture deficiency during the summer months (Pons et al., 1995; Quézel and Médail, 2003).

Researchers have documented a stepwise Pliocene–Pleistocene development of modern Mediterranean ecosystems and climate, although the rarity of records has hindered basin-wide reconstructions (Pons et al., 1995; Sadori et al., 2013a). Given the limited number of Mediterranean available records, reconstructing long-term (5 Myr) vegetation changes on the Italian peninsula will help to identify links between vegetation changes and increasing aridity in the region. The Italian peninsula stretches across the centre of the north Mediterranean basin, running in a northwest to southeast direction. The Apennine Chain forms the backbone of the peninsula, and within the peninsula generate heterogenous environmental conditions that support vegetation that varies with elevation and latitude. Several distinct climatic systems influence the Italian climate: polar air masses from the North; tropical air masses from the South; Atlantic Westerlies; and a monsoon system from the East (Lionello et al., 2006). This results in a climate gradient from north to south with a mosaic of local/regional situations, with usually higher humidity in the north and increasing aridity to the south. Italy thus represents one of the most informative Mediterranean areas to: (i) reconstruct the response of vegetation to various climatic stresses; and (ii) assess the likely future behaviour of Mediterranean plants. Furthermore, the Italy's rich geological and stratigraphical record makes it a significant source of information on the history of Mediterranean vegetation.

In this paper we describe vegetation reconstructions grouped in two areas: Northern and Southern Italy, placing the boundary between the two at 42.5°N. This latitude approximately splits the Italian peninsula according to the present duration of the dry season between areas to the south where this exceeds three months and those to the north where it is shorter. This division allows us to describe continuous long- and short-term climate and vegetation changes in the Mediterranean basin during the last 5 million years.

2. Present day Italian climate and vegetation

Italy is a mountainous country, bounded in the North by the Alps, and with the Apennines running as a backbone from northwest to southeast.

Located at mid-latitude (47°N to 37°N) and towards the western margin of the Eurasian landmass, the Italian peninsula exhibits a classic Mediterranean climate, with mild winters (especially in the hilly and coastal areas) and pronounced summer drought (Fig. 1). The influence of the Mediterranean climate on vegetation is most evident at lower altitudes and on the coasts, becoming attenuated with increasing altitude on the pre-Alpine chains and in the Apennines. In the Apennines, summers are cooler and moister with increasing altitude, whereas continentality increases towards and into the Alpine mountains, leading to increased annual temperature range, with colder winters and summers that are hot but not markedly dry. The Po Valley, a large plain situated in the north between the western Ligurian Alps and the Adriatic Sea, is relatively continental in climate. This is principally due to its proximity to the Alps and its separation from the Mediterranean proper by the Apennines. The Italian peninsula thus spans a clear and complex gradient from the southern warm-temperate Mediterranean climate, through the cool-temperate climate of the Apennines and pre-Alpine ranges, to the continental climate of the innermost Alps with its strong temperature seasonality. This complex topographic and climatic landscape has deeply affected the flora of the peninsula. The Italian vegetation is well documented (e.g. Tomaselli et al., 1973; Ozenda, 1975; Bonin, 1981; Ozenda, 1994; Pignatti, 1998; Quézel and Médail, 2003; Blasi, 2010). The European potential natural vegetation zones and the main physiognomic–ecological units for the Italian peninsula are summarised in Fig. 1 (modified from Pignatti, 2011).

3. Materials and methods

3.1. Pollen records

We use vegetation reconstructions based on palynology and paleobotanical information available from the Italian peninsula (Fig. 2, Table 1). These data help to reconstruct vegetation changes in Italy, and their links to increasing aridity since the Pliocene. The pollen records presented here are distributed unevenly across the region, and so each site has been assigned to either "Northern" or "Southern" Italy relative to latitude 42.5°N, the isocline for current dry season duration (longer or shorter than 3 months) (Figs. 1 and 2). Vegetation types inferred from pollen records and the literature are plotted for glacial and interglacial within six key geological intervals during the last 5 Myr: Pliocene (Zanclean, 5.332–3.600 Ma, and Piacenzian, 3.600–2.588 Ma); Early Pleistocene (Gelasian, 2.588–1.806 Ma, and Calabrian, 1.806–0.781 Ma); Middle Pleistocene ("*Ionian*", 0.781–0.126 Ma); Late Pleistocene ("*Tarantian*", 0.126–0.01 Ma); and Holocene (last 0.01 Ma) (Fig. 3a and b). Sixteen sites that combine long time series, coverage for key time intervals and consistent age models (Table 1 and Fig. 2 in red), provide the opportunity to develop a model of continuous vegetation change throughout Italy. Pollen diagrams for these sites have been plotted using Psimpoll (Bennett, 2008) for a subset of taxa selected to illustrate the major changes in Italian vegetation since the Pliocene (Fig. 4a and b).

The taxon "Taxodiaceae" is referred to in quotation marks throughout because many genera formerly assigned to this family are now placed in subfamilies of Cupressaceae, for example, Taxodioideae Endl. ex K. Koch (*Taxodium*, *Glyptostrobus* and *Cryptomeria*) and Sequoioideae (Luerss.) Quinn (*Sequoia*, *Sequoiadendron* and *Metasequoia*). The genus *Sciadopitys* is now generally placed in Sciadopityaceae (Brunsfeld et al., 1994; Farjon, 1998, 2005). However, the term "Taxodiaceae" has been commonly used in Italian records where it is generally assumed to represent *Sciadopitys*, *Taxodium* type (which includes *Taxodium* cf. *distichum* and *Glyptostrobus*) and *Sequoia* type (which includes *Cryptomeria*, *Cunninghamia*, *Metasequoia glyptostroboides*, *Sequoiadendron giganteum* and *Sequoia sempervirens*). Because of the ecological diversity of taxa represented by the term "Taxodiaceae" it is difficult to revisit the records and apply the new taxonomy; we have therefore chosen to keep the term "Taxodiaceae", as used in older publications, although providing greater clarity where possible.

3.2. Climate reconstructions

Climate reconstructions from pollen records allow us to understand the climate trends that have driven changes in Italian vegetation over the last 5 Ma. Depending on the period of interest we have used different methods for reconstructing climate. Annual precipitation and temperature have been reconstructed using: (1) probability mutual climatic spheres (PCS); and (2) the Modern Analogue Technique (MAT). The PCS method uses the modern climatic requirements of plant taxa, transposed to plant assemblages (Klotz, 1999; Klotz et al., 2006) and has been applied using 60 of the 110 taxa identified in fossil pollen floras from the Pliocene to Early Pleistocene (e.g. Fauquette et al., 1999; Klotz et al., 2006; Fauquette et al., 2007). The PCS method is