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Late Holocene forest dynamics in the Gulf of Gaeta (central Mediterranean) in relation to NAO variability and human impact

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A R T I C L E I N F O

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A B S T R A C T

A new high-resolution pollen record, spanning the last five millennia, is presented from the Gulf of Gaeta (Tyrrhenian Sea, central Italy), with the aim of verifying if any vegetation change occurred in the central Mediterranean region in relation to specific well-known global and/or regional climate events, including the 4.2 ka event, the Medieval Climate Anomaly (MCA) and the Little Ice Age (LIA), and to detect possible vegetation changes related to still under-investigated climate signals, for example the so-called "Bond 2" cold event around 2.8 ka BP. The vegetation dynamics of the Gaeta record shows a recurrent pattern of forest increase and decline punctuating the mid- and late Holocene. When the timing of these patterns is compared with the climate proxy data available from the same core (planktonic foraminifera assemblages and oxygen stable isotope record) and with the NAO (North Atlantic Oscillation) index, it clearly appears that the main driver for the forest fluctuations is climate, which may even overshadow the effects of human activity. We have found a clear correspondence between phases with negative NAO index and forest declines. In particular, around 4200 cal BP, a drop in AP (Arboreal Pollen) confirms the clearance recorded in many sites in Italy south of 43°N. Around 2800 cal BP, a vegetation change towards open conditions is found at a time when the NAO index clearly shows negative values. Between 800 and 1000 AD, a remarkable forest decline, coeval with a decrease in the frequencies of both *Castanea* and *Olea*, matches a shift in the oxygen isotope record towards positive values, indicating cooler temperatures, and a negative NAO. Between 1400–1850 AD, in the time period chronologically corresponding to the LIA (Little Ice Age), the Gaeta record shows a clear decline of the forest cover, particularly evident after 1550 AD, once again in correspondence with negative NAO index.

1. Introduction

The vegetation of the central Mediterranean Basin, at the interface between the two continents of Europe and Africa, is especially sensitive to the climate forcing from both the North Atlantic Oscillation (NAO) and the high-pressure conditions that dominate the Sahara. The balance between these two patterns of atmospheric circulation determines the amount and seasonality of moisture availability, and consequently the development of forest vegetation. Recent paleoclimate reconstructions agree that during the entire Holocene the climate evolution of the Mediterranean

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region exhibits a strong spatial and temporal precipitation variability, often linked to seasonal mid-latitude and sub-tropical climate dynamics (Fletcher et al., 2013; Magny et al., 2013; Peyron et al., 2017).

The most prominent mode of climate variability influencing winter precipitations in the North Atlantic and Mediterranean regions is the NAO, coupled with the Arctic Oscillation (Hurrell, 1995; Wanner et al., 2001; Xoplaki et al., 2012). According to Olsen et al. (2012), when the NAO index is positive Northern Europe and the Eastern United States are mild and wet, while a negative index is associated with the reverse pattern. Regarding the Mediterranean area, the NAO index signal often appears associated with regional hydrological regimes showing opposite patterns in different areas, and in turn opposite vegetation responses: under a positive NAO, the Mediterranean northern borderlands experience dry conditions, while the southern Mediterranean regions benefit from increasing precipitation as in NW Europe (Marshall et al., 2001; Dünkeloh and Jacobeit, 2003; Magny et al., 2013). Opposite patterns develop under negative NAO conditions. According to Magny et al. (2013), the boundary between the two opposite hydrological sectors of the Mediterranean may be affected by latitudinal fluctuations.

A further factor of climate variability is represented by orbitally-driven changes in insolation, producing latitudinal migrations of the Intertropical Convergence Zone (ITCZ), thus influencing the global-scale climate variability (Wanner et al., 2011). Latitudinal migrations of the ITCZ may affect the precipitation in the Northern Hemisphere summer monsoon area (Yan et al., 2015) and contribute to a reorganization of the atmospheric systems at middle latitudes (Wirth et al., 2013), possibly influencing the distribution of the vegetation in the central Mediterranean (Di Rita, 2013; Zanchetta et al., 2016).

The vegetation of southern Italy is particularly exposed to these different climatic signals and can rapidly respond to climate change, being developed in a complex physiographic system, determining high floristic richness and admixtures of xerophilous and mesophilous plant assemblages, often located close to each other (Magri et al., 2015). This pattern is the result of a long-term persistence of temperate, mediterranean and steppe plant communities, which coexisted throughout the glacial-interglacial cycles of the Quaternary (Magri et al., 2017).

This climatic, physiographic and vegetational complexity is well expressed in the Tyrrhenian coast of the Campania region (Fig. 1). We present a new detailed palaeovegetational reconstruction, extending back to 5.5 ka, from a shallow water marine core, recovered in the Gulf of Gaeta at the mouth of the Volturno river.

A previous study on this core (Margaritelli et al., 2016) provided a detailed reconstruction of the main climate oscillations over the last 4.5 ka, identifying nine time intervals associated with archaeological/cultural periods (top of Eneolithic ca. 2410 BC, Early Bronze Age ca. 2410 BC ca. 1900 BC, Middle Bronze Age Iron Age ca. 1900–500 BC, Roman Period ca. 500 BC - 550 AD, Dark Age ca. 550–860 AD, Medieval Climate Anomaly ca. 860–1250 AD, Little Ice Age ca. 1250–1850 AD, Industrial Period ca. 1850–1950 AD, Modern Warm Period ca. 1950 AD - present day). The good correspondence between climate oscillations and archaeological intervals underlines the role exerted by climate change in determining rises and declines of civilizations. Within these time intervals, planktonic foraminifera and oxygen stable isotope data have allowed us to detect a series of past climate changes on decadal to millennial time scale, linked to dynamics of ocean-atmospheric coupling or to solar activity, such as the 4.2 ka event, four Roman solar minima, the Medieval Cold Period and the Maunder event. In addition, Margaritelli et al. (2016) suggest a strong modification in the climate system from the onset of the Roman Period up to the present-day documented by long-term trend and amplitude oscillations in the $\delta^{18}O_{G.\ ruber}$ signal, by the onset of main planktonic foraminiferal turnovers from carnivorous to herbivorous opportunistic species, and by consistent forest fluctuations in the pollen record. Moreover, the correlation between the NAO index and $\delta^{18}O_{G.\ ruber}$ signal suggests a global climate signature in the shallow water marine study record, pointing to a hemispheric scale atmospheric connection.

Climate reconstructions from planktonic foraminifera and oxygen stable isotopes offer the possibility to avoid circular argumentations when evaluating the responses of vegetation to climate change, and to disentangle the effects of human activity from changes in temperature and precipitation. For the same reason, special attention has been paid to independent evidence of the NAO index oscillations, which – as discussed above – undoubtedly influenced the regional vegetation dynamics (Gouveia et al., 2008).

Based on these premises, the present study is aimed not only at providing a high-resolution vegetation record for the last five millennia, which is missing for this region, but also at defining possible responses of vegetation in the central Mediterranean to specific climate events detected in Margaritelli et al. (2016), which are in some cases relatively well known, for example the 4.2 ka event, but in other cases are still unclear, for example the 2.8 ka event, corresponding to the so-called “Bond 2” event (Bond et al., 2001), the Medieval Climate Anomaly (MCA) and the Little Ice Age (LIA). In this paper, we discuss the role of human activities in the vegetation changes recorded at Gaeta in more detail with respect to Margaritelli et al. (2016), considering both pollen indicators and historical/archaeological sources, although a marine pollen record >10 km away from the shore may not be the best place to analyse local vegetation dynamics, including human impact related to crops and land use, which may be mitigated by the distance. On the whole, our pollen record appears especially suitable for tracing changes in the regional vegetation.

2. Study area

The Gulf of Gaeta borderland has a typical Mediterranean climate, with annual precipitations of up to 1200 mm on the reliefs and ca. 850 mm along the coastal plains. The mean annual temperature varies between 9 °C and 16 °C. This area is characterized by the Garigliano and Volturno floodplains and the Campania Plain more inland; it is bordered on the North by the Aurunci mountains, on the East by the volcanic district of Roccamonfina and the limestone Southern Apennines, and on the South by the volcanic districts of Mt. Somma-Vesuvius and Phlegraean Fields (Fig. 1). This region represents the main source area of the pollen recorded in the Gulf of Gaeta pollen record.

A recent classification of Italy based on vegetational aspects includes this territory in the Southern Lazio and Western Campania ecoregion subsections (Blasi et al., 2014), which are mostly characterized by central Tyrrhenian pre-Apennine coastal subacidophilous *Quercus frainetto* series (*Mespilo germanicae-Querco frainetto* sigmetum), central Tyrrhenian pre-Apennine neutro-basophilous *Ostrya carpinifolia* series (*Mespilo germanicae-Ostryo carpinifoliae* sigmetum), Adriatic neutro-basophilous *Quercus cerris* and *Q. pubescens* series (*Daphno laureolae-Querco cerridis* sigmetum), peninsular neutro-basophilous *Quercus ilex* (*Cyclamino hederifolii-Querco ilicis* sigmetum), and peninsular hygrophilous chain of series of the riparian zone (*Salicion albae*, *Populion albae*, *Alno-Ulmion*).

Both the climate and the modern vegetation of the Gulf of Gaeta borderlands appear to be strongly related to the inland orographic complexity and the proximity of the sea (Filesi et al., 2010). Sclerophyllous shrublands and *Quercus ilex* woodlands generally