The 4.2 ka BP event in the vegetation record of the central Mediterranean

Federico Di Rita[1], Donatella Magri[1]

[1]Department of Environmental Biology, Sapienza University of Rome, Rome, 00185, Italy

5 *Correspondence to*: Federico Di Rita (federico.dirita@uniroma1.it)

Abstract.

In this paper, the variation in forest cover in the central Mediterranean region, reflected by percentage changes of the arboreal pollen record, has been examined in relation to the 4.2 ka BP event. A number of 36 well-dated and detailed pollen records from latitudes between 45° and 36° N were selected and their vegetation dynamics between 5 and 3 ka examined in relation

10 to the physiographic and climatic features of the study area and to the influence of human activity on past vegetation, as suggested by anthropogenic pollen indicators. We have found that the sites located between 43° and 45°N do not show any significant vegetation change in correspondence with the 4.2 ka event. Several sites located in the Italian Peninsula between 39°-43°N show a marked opening of the forest, suggesting ~~that a lowering of rainfall occurred during the 4.2 ka BP event, sufficiently strong to determine a forest decline~~a vegetation response to the climate instability of the 4.2 ka BP event. Between

15 36°-39°N, a forest decline is always visible around 4.2 ka BP, and in some cases it is dramatic. This indicates that this region was severely affected by a climate change towards arid conditions that lasted a few hundreds of years and was followed by a recovery of forest vegetation in the ~~middle~~ Middle Bronze ~~age~~ Age. Human activity, especially intense in southern Italy, may have been favored by this natural opening of vegetation. In Sardinia and Corsica, no clear change in vegetation is observed at the same time. We suggest that during the 4.2 ka BP event southern Italy and Tunisia were under the prevalent influence of a

20 north African climate system, characterized by a persistent high-pressure cell.

1 Introduction

The so-called '4.2 ka BP event' has so far been observed in several pollen records from the central Mediterranean, where it has been described as a phase of temporary decline of Arboreal Pollen (AP) percentages, interpreted as an opening of the

25 forest vegetation (Di Rita and Magri, 2009, 2012; Di Rita et al., 2018b). This palaeovegetational event is more or less coeval to the drought event that has been recognized in the eastern Mediterranean regions (Kaniewski et al., 2018), in the Middle East (e.g., Weiss et al., 1993; Cullen et al., 2000; Staubwasser et al., 2003; Weiss, 2017), Africa (e.g., Marshall et. al., 2011), and South and East Asia (Liu and Feng, 2012; Dixit et al., 2014, 2018), and to widespread climate anomalies recorded at a global scale (e.g., Walker et al., 2012), including wetter climate conditions in the south-western Mediterranean regions (Di

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Rita et al., 2018a; Zielhofer et al., 2018). A detailed review of pollen-independent key-studies concerning the climatic and environmental changes occurred in the Mediterranean Basin between 4.3 and 3.8 cal. ka BP is available in this volume of Climate of the Past (Bini et al., 2018), to which we refer. For this reason, dDefining the temporal and geographical limits of this environmental change in the central Mediterranean, as well as its overall intensity and effects, may help to a better understanding of the causes and climate processes underlying the establishment and distribution of this event at a wider scale.

The interest of studying the 4.2 ka BP event in the central Mediterranean is further increased by the climate-sensitive position of this region, located at the interface between two large continents (Europe and Africa) and subject to climate forcing influence from both the North Atlantic Oscillation (NAO) and the high-pressures that dominate the Sahara. The balance and complex interplay between these two patterns of atmospheric circulation determines the amount and seasonality of moisture availability in the region, and consequently the development or contraction of the forest vegetation. Recent studies have recognized that during the Holocene the northern and southern regions in the central Mediterranean have been under the prevalent influence of different climate forcingpatterns, producing opposite hydrological regimes and consequent vegetation dynamics (Magny et al., 2013; Di Rita et al., 2018a). The geographical distribution of rainfall, depending partly on the prevalent climate mode and partly on physiographical features, appears particularly important for the effects it may have on the vegetational landscape at middle latitudes. In case of a climate shift towards aridity, the response of forest vegetation may be modest in areas with abundant water availability, while marked deforestation effectsforest declines are expected in areas that suffer for water deficit. Considering that the modern mean annual precipitation in the central Mediterranean, ranging from <300 mm to >2500 mm (Fig. 1), is largely conditioned by the orography of the region, it is reasonable to assume that also in the past similarly different pluviometric regimes from one region to the other could determine different responses of the forest vegetation to climate change.

Another feature peculiar to the central Mediterranean is the ability of vegetation to rapidly respond to climate change, being developed in a complex physiographic system, that enhances a high floristic diversity and admixtures of xerophilous and mesophilous plant assemblages, often located in ecological niches 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, ready to alternately develop following climate oscillations (Magri et al., 2017).

The vegetation history of the central Mediterranean is further complicated by a long-lasting and intense human impact on the landscape through agro-pastoral and silvicultural practices, forest clearance, fires and demographic increase. The 4.2 ka BP event occurred in the early Bronze Age, when the human presence was well-established and widespread all over the region. In the central Mediterranean, the transition from Late Neolithic or Chalcolithic cultures to metallurgic communities is dated at 4.5-4.2 ka BP (ca. 2500-2200 cal. BC), at the same time of marked openings of forests and establishment of first continuous records of anthropogenic indicators (Tinner et al., 2003; Carrión et al., 2010). Repeated openings of forests in an area spanning from Sicily to the Alps have been previously explained by the adoption of innovations and climatic impacts on prehistorical societies over wide areas (through harvest success and the resulting carrying capacity; Tinner et al., 2003, 2009). However, in

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the Balearic Islands climate conditions are considered preponderant over human activity to explain the vegetation changes around 4.2 ka BP (Burjachs et al., 2017). Careful consideration of the geographical vegetation patterns and of the value of anthropogenic indicators, in relation to the ~~documented distribution of archaeological sites~~archaeological record, may help disentangling the effects of human activity versus changes in temperature and precipitation when interpreting

5 palaeovegetational records.

Based on these premises, our aim is to verify to what extent the 4.2 ka BP event affected the distribution of forests in the central Mediterranean region, and to highlight possible geographical patterns that may reflect the responses of vegetation to changes in precipitation and water availability.

2 Materials and methods

10 Following a careful screening of pollen records from Italy, Corsica, and Tunisia, a number of 36 records where selected for this work, based on their geographical location (36° to 45°N), and chronological control (at least two radiocarbon dates or dated tephra layers in the time span 6-2 ka BP) (Fig. 1). The vegetation dynamics of the selected pollen records during the time span 5-3 ka BP was examined, especially concerning changes in AP percentages and floristic composition, to establish whether any variation in forest cover occurred during the 4.2 ka BP event. It should also be considered that pollen image of

15 human actions can be sensibly different under different cultures: the Neolithic spread of agricultural systems would have only caused pollen signals producing fairly local effects (for example presence of cereal-type pollen grains) whilst the deforestation events of the subsequent cultural phases (e.g., Bronze Age) had regional echoes in pollen rain (Mercuri, 2014).

We arbitrarily considered a drop in AP of at least 10% as an event of forest decline, although we are aware that, due to the intrinsic properties of percentage calculations, this value may be indicative of vegetation changes of quite different extent in

20 different sites, depending on the density of vegetation (Magri, 1994). Besides, pollen rain circulation can mask altitudinal displacements of vegetation in mountains and water/river transport may affect pollen representation in plain landscapes. This problem is especially relevant as we have selected pollen records from very diverse geographic situations (bogs, mountain lakes, crater lakes, coastal wetlands, lagoons, marine sediments, etc.). For this reason, we have shortly reported the main geographical features of each site.

25 A further methodological complication is the type and role of anthropological indicators used to detect the human impact on the vegetation. In order to keep an independent view of the interpretation of the pollen anthropological indicators, in the results we have carefully reported the interpretation provided in the original publication of each pollen record. This strategy limits the introduction of systematic errors due to our personal interpretation of palynological data and provides a mediated view of the interpretation of the palynological scientific community.

30 Pollen records for which pollen counts are not available to us, have been digitized from the published pollen diagrams.

Pollen diagrams in Fig. 2 were plotted using the program Psimpoll (Bennett, 2009).

3 Results

The main vegetation changes between 5 ka and 3 ka BP, as recorded in the 36 selected pollen records, are shortly reported and discussed, following the numbering of sites in Fig. 1. The AP percentage diagrams of a selection of sites, representative of a range of environmental conditions, are represented in Fig. 2.

5   (1) Mogge di Ertola (Fig. 2) is a small plateau lying at 1015 m, about 25 km from the Ligurian coast (Guido et al., 2013). Mean annual precipitation is about 2000 mm, with two rainfall peaks in November and March/April. The interval 5-3 ka BP is characterized by dominance of *Abies* accompanied by *Fagus*, deciduous *Quercus* and *Corylus*. Unambiguous signals of local land use in the Mogge di Ertola pollen record only appear since ca. 2 ka BP, when the fir pollen curve decreases at the same time of an increase in microcharcoal particles, suggesting local burning activities.

10   (2) Lago Riane is located at an altitude of 1279 m in the Ligurian Apennines (Branch, 2013). Mean annual precipitation is ca. 1600 mm. The interval 5-3 ka shows highly forested conditions characterized by fluctuations of *Abies* and *Fagus* alternately dominant. A fluctuating environment is also observed around 4.2 ka, during the early Bronze Age, which coincided in Liguria with a period of rapid climate change, characterized by high summer precipitation. A temporary woodland expansion at ca. 3.9-3.6 ka BP was related to a reduction of human pressure on the environment, immediately

15   preceding the development of agricultural terracing during the ~~middle~~ Middle Bronze Age.

(3) Lago di Bargone is situated at 9 km from the Ligurian coast at 831 m a.s.l. (Cruise et al., 2009). Mean annual precipitation is around 1800 mm. Between 5 and 3 ka BP there is a progressive increase in the forest cover, mainly involving an expansion of *Fagus*, *Quercus cerris* and *Q. ilex* communities. During the Bronze Age, the rise in arboreal frequencies suggests a general reduction of human exploitation. There is no evidence of forest decline at 4.2 ka BP.

20   (4) Lago Padule (Fig. 2) lies at an altitude of 1187 m on the north-facing slopes of the Apennines close to the Passo del Cerreto (Watson, 1996). Mean annual precipitation is about 2000 mm. The pollen record points to an *Abies*-dominated densely forested landscape, with increasing abundance of *Fagus*, to form a mixed *Abies-Fagus* complex. There is no evidence of forest decline at 4.2 ka BP.

(5) Pavullo sul Frignano is a karstic former lake located at 675 m a.s.l. on the northern slope of the Tuscan–Emilian Apennines

25   (Vescovi et al., 2010a). Mean annual precipitation is about 970 mm. A marked change in the structure and composition of the vegetation, from an *Abies*-dominated forest to a mixed deciduous semi-open forest characterized by *Quercus*, *Corylus,* and *Fagus*, occurred between 6 ka and 5 ka. After this turnover, the vegetational landscape did not substantially change in the interval 5-3 ka, apart a drop (15%) in AP% recorded in a single sample around 3.6 ka. An increase in anthropogenic taxa (e.g., *Juglans*, cereals, *Plantago*, and *Urtica*) is recorded well after the main vegetation change, around

30   4.5 ka BP. Charcoal-inferred regional fire activity peaked at around 4.2 ka BP, together with an increase in Cerealia type, while forest opening started at ca. 5 ka BP and remained substantially unchanged until and after 4.2 ka BP.

(6) Ospitale is a small bog close to the homonymous village at about 1225 m a.s.l. (Watson, 1996). Mean annual precipitation is about 1700 mm. Between 5 and 3 ka BP, *Abies* dominates a fully forested environment. No change in forest cover is recorded at around 4.2 ka BP, except for a slight development of fir communities.

(7) Lago del Greppo (Fig. 2) is a small and shallow pond located at 1442 m in the Northern Apennines (Vescovi et al., 2010b). Mean annual precipitation is over 2500 mm. Between 5 and 3 ka BP, the pollen record documents densely forested environment (AP>95%), dominated by *Abies* and *Fagus* with significant frequencies of *Picea* (ca. 10%). Despite a progressive decline of *Abies*, the forest remains very dense and almost stable until the present time.

(8) Lago di Massaciuccoli (Fig. 2) is a coastal lake located in the Versilia Plain in northern Tuscany (Colombaroli et al., 2007). The mean annual precipitation is 910 mm, most of which concentrated in autumn and winter. Between 5 and 3 ka BP, the pollen record shows quite stable conditions in the structure of the vegetation, outlining a densely forested environment. Trees and shrubs, ranging from 85% to 95%, are dominated by *Quercus* communities rich in mesic elements such as *Fagus*, *Carpinus, Ostrya* and *Abies*. The main vegetational change is represented by an expansion of evergreen *Quercus*, which became the main woody taxon, accompanied by a slight increase in Ericaceae, at around 4.4 ka BP. Direct evidence for human impact is weak, considering that primary and secondary human indicators like *Plantago*, Cerealia, *Linum*, *Artemisia* and Asteroideae (Behre, 1981) do not show any significant trend. Charcoal-inferred regional fire activity was at a minimum at ca. 4.5-3 ka BP, with no signs of human activity.

(9) Crovani is a coastal pond located in the north-eastern side of Corsica (Reille, 1992). Mean annual precipitation is ca. 650 mm. The vegetation history of the investigated period is characterized by open forest conditions up to 4.9 ka BP, with *Erica arborea* and evergreen oaks as dominant woody taxa, accompanied by a significant abundance of *Alnus*. At ca. 4.4 ka BP, an important opening of the landscape is recorded, mainly involving *Quercus ilex* and *Erica arborea* communities replaced by grasses and sedges. When vegetation recovers, after a few centuries, there is a new increase in evergreen elements, mostly represented by *E. arborea*. Scattered records of cereals represent the main pollen evidence of human activity between 5 and 3 cal. BP.

(10) Lake Creno is a montane lake located at 1310 m in the centre of the island of Corsica (Reille et al., 1999). Mean annual precipitation is ca. 1270 mm. In the interval 5-3 ka there was a period of stability of a densely forested environment, marked by the regional dominance of oak forest with *Betula*. A mixed *maquis* with *Quercus ilex* and *Erica arborea*, dominant at lower elevations, reached the lake altitude. There is no evidence of forest decline at 4.2 ka BP.

(11) Aleria del Sale is a lagoon formed around 5500 years ago (Currás et al., 2017). Mean annual precipitation is ca. 650 mm. Between 5 and 3 ka BP, the vegetation was characterized by deciduous and evergreen *Quercus* communities, as dominant elements, accompanied by other woody taxa including *Alnus*, *Pinus*, *Fagus*, *Corylus* and *Betula*. This floristic admixture probably reflects diverse environmental conditions at regional scale. The main vegetation change is represented by a temporary decline in the main trees; *Quercus* reached a minimum at 4.45 ka BP, whereupon it significantly increased along with a progressive increase in *Erica arborea*, while *Pinus* and *Alnus* reached a minimum around 4.2 ka BP, but subsequently they recovered to previous values. The lack of anthropogenic indicators such as cereal pollen and

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coprophilous fungal spores between 4.45 and 4.2 ka BP, suggesting absence of human activities, was interpreted as the main factor favouring an oak forest recovery.

(12) Greco pond is a coastal wetland located in the Cavallo Island (Lavezzi archipelago; Corsica) (Poher et al., 2017). Mean annual precipitation is ca. 550 mm. A change in the composition of the vegetation, from an *Erica*-dominated semi-open shrubland (AP=60%) to a mixed semi-open *maquis* mainly composed of evergreen and deciduous *Quercus* communities, occurred between 5.5 ka and 5 ka. After this turnover, the vegetational landscape did not substantially change in the interval 5-3 ka BP, except for a clear increase in *Quercus suber* starting from 4.1 ka BP. *Myrtus* increased around 3.8 ka BP. No significant changes in forest cover are reported at 4.2 ka BP.

(13) Lago dell'Accesa (Fig. 2) is a lake situated in the southern part of Tuscany at about 12 km from the Tyrrhenian coast (Drescher-Schneider et al., 2007; Vannière et al., 2008). Mean annual precipitation is ca. 750 mm. From 5 to 3 ka BP, the vegetation surrounding Lago dell'Accesa was a mixed forest dominated by evergreen and deciduous *Quercus* communities. Slight AP percentage oscillations are recorded around 4.2 ka BP, when a marked decline of Mediterranean trees and shrubs was paralleled by an increase in deciduous oaks. After 4.3 ka BP, most anthropogenic indicators start to be recorded in continuous curves; cultivation of cereals and pasture activities are recorded. There is also an increase in fire frequency as recorded by microcharcoal, culminating around 3.4 ka BP.

(14) Lagaccione is an artificially dried out maar lake, close to Bolsena Lake in central Italy, at 355 m a.s.l. (Magri, 1999). Mean annual precipitation is ca. 1030 mm. The pollen record lacks the last 3700 years. At 5 ka BP, the pollen record depicts a densely forested landscape dominated by deciduous oaks, accompanied by *Fagus*, *Corylus* and evergreen oaks, together with many other tree taxa. A clear reduction (-15%) in AP percentages, culminating at 4.2 ka BP, points to a forest decline, mostly related to a decline of *Fagus*. At the same time there is a slight increase in cereal pollen. After 4.2 ka BP, trees partially recovered.

(15) Lago di Vico (Fig. 2) is a maar lake located at 510 m in the northern Lazio region (Magri and Sadori, 1999). Mean annual precipitation is ca. 1050 mm. Between 5 and 3 ka BP, the vegetation was dominated by deciduous oaks accompanied by many evergreen and deciduous elements, composing a floristically diverse forested environment. A temporary forest decline (-15% AP), associated to evidence for agricultural activity (e.g. cereals), was recorded between 4.3 and 3.6 ka BP. During this event, single grains of *Cedrus* pollen are recorded, pointing to an African origin of dominant winds (Magri and Parra, 2002). Anthropogenic indicators disappear after 3.6 ka BP, when a pronounced recovery of trees, notably deciduous *Quercus*, is recorded.

(16) Lingua D'Oca-Interporto refers to a pollen record obtained from the former Stagno di Maccarese, a shallow water pond located in the northern sector of the Tiber mouth channel (Di Rita et al., 2010). Mean annual precipitation is ca. 740 mm. Between 5 and 3 ka BP, the site was characterized by the development of extensive *Alnus*-dominated floodplain forest formations rich in *Salix* and *Fraxinus* stands. This vegetation is the results of complex environmental dynamics triggered by a decrease in the rate of sea level rise that determined deep geomorphic and sedimentological changes in the river floodplains, consistent with coastal barrier accumulation, lagoon habitat formations, river mouth modifications, and peat

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deposition among others (Di Rita et al., 2015). The nearby Bronze Age settlements of Le Marrucole and Le Pagliete did not produce a clear impact on the vegetational landscape (Di Rita et al., 2012). No significant changes in forest cover are reported at 4.2 ka BP, which may have been masked by local hydrological dynamics.

(17) Core RF93-30 was drilled in the central Adriatic Sea, 18 km north of the northern coast of the Gargano promontory at a water depth of 77 m (Oldfield et al., 2003; Mercuri et al., 2012). Mean annual precipitation along the nearest coast is ca. 700 mm. Around 5 ka BP, a widespread forest vegetation was dominated by deciduous and evergreen *Quercus*, *Abies*, and *Fagus*. A drop of *Quercus ilex* type around 4.13 ka is contemporary with a rise of deciduous oaks and a decline of *Abies*. According to Mercuri et al. (2012), the decrease in *Abies* may be a result of clearance of silver fir preceding clearance of oaks, produced by human action after a climate change became established. According to the chronological settings proposed by Oldfield et al. (2003) and Mercuri et al. (2012) a clear drop in AP (-25%) occurs starting around 3.9 ka.

(18) Lago Battaglia is a dried out coastal lake, in the north-eastern margin of the Gargano headland (Caroli and Caldara, 2007). Mean annual precipitation of the area is between 550 and 650 mm. From 5 to 4.2 ka BP, the landscape was characterized by mediterranean evergreen vegetation along the coastline and mixed deciduous forests at higher elevations. Around 4.2 ka BP a temporary decrease in the arboreal vegetation, mainly involving broadleaved trees and *Pinus*, was interpreted as the result of a climate change towards drier conditions. Between 3.5-3 ka BP the forest vegetation recovered with a remarkable expansion of *Pinus*, probably *P. halepensis*, which is a main element of the present landscape in the northern sector of the Gargano headland. Although scattered anthropogenic indicators (e.g. cereals, *Castanea*, and *Vitis*) are present all along the sequence, significant human impact on the natural vegetation seems to have occurred since about 2.7 ka BP.

(19) Lago Salso is a former coastal lake produced by hydrological and geomorphological changes occurred in the extinct Salpi Lagoon (Apulia region, Italy) (Di Rita et al., 2011). The mean annual precipitation is ca. 460 mm. Between 5 and 4.05 ka BP the landscape was characterized by a salt-marsh dominated by *Salicornia* s.l. and *Ruppia*, probably surrounded by evergreen scrubland, mainly composed of *Olea*, *Pistacia* and *Phillyrea*, while extensive broadleaved forests were located at higher elevations inland. Major fluctuations of the salt-marsh vegetation, related to changes in extent of the Salpi Lagoon, were possibly modulated by solar activity (Di Rita, 2013). Between 4.05 and 3.8 ka BP, marked environmental transformations occurred at a regional scale, with an abrupt ~~deforestation event~~opening of the forest involving almost all the broadleaved trees. After 3.8 ka the pollen record is interrupted. However, palaeovegetational information for the interval 3.5-3.2 ka BP is provided by another core (C5) from the same area, depicting an open landscape. Anthropogenic pollen indicators are continuously recorded, consistently with a long-term occupation of the area, since the early Neolithic.

(20) Lago Grande di Monticchio is a maar lake located in the Basilicata region at an elevation of 656 m (Allen et al., 2002). Mean annual precipitation is ca. 800 mm. Between 5 and 3 ka BP, the pollen record points to a densely forested landscape dominated by deciduous *Quercus*, showing a decreasing trend in this interval. Other important trees were *Alnus*, *Ostrya*, *Carpinus*, *Ulmus*, *Quercus ilex*, *Fagus*, and *Abies* and *Taxus* among conifers. At around 4.2 a slight decrease in AP is

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recorded (-5%), just before a gap in the pollen record from 4 to 3.5 ka BP. Despite cereal-type pollen is present all along the record, no vegetation change is unambiguously attributed to human impact by the authors.

(21) Lago Patria is a brackish lagoon connected to the Gulf of Gaeta (Tyrrhenian Sea) through a narrow channel (Di Rita et al., 2018c). Mean annual precipitation is about 800 m. The interval 5-3 ka BP was characterized by mixed deciduous and evergreen oak-dominated forests, rich in both xeric (e.g. evergreen *Quercus*, *Pistacia*, and Ericaceae) and mesic woody taxa (deciduous *Quercus*, *Carpinus betulus*, and *Fagus*). A forest decline is recorded around 4.2 ka BP, especially involving broadleaved trees (-24 %) and corresponding with a temporary decrease of human impact. This event was followed, between 3.9 and 3.3 ka BP, by a forest recovery with a remarkable development of mesic trees, notably *Fagus*, influenced by wet climate conditions. While human settlements are missing from this coastal area between 5 and 3 ka, which suggests a marginal role of human activity in determining landscape changes, there is a continuous presence of anthropogenic pollen indicators in the pollen record, which stimulate new archaeological investigations.

(22) Gulf of Gaeta (Fig. 2) is a marine pollen record from a core recovered at a distance of 15 km from the Campanian coast (central Tyrrhenian Sea) at 93 m below sea level (Margaritelli et al., 2016; Di Rita et al., 2018b). Mean annual precipitation along the coast is about 850 mm. From 5 to 4.75 ka BP a dense forest was composed of mixed temperate and Mediterranean forests, dominated by deciduous and evergreen *Quercus*. From 4.75 to 4.1 ka BP, a forest decline, culminating at around 4.2 ka BP, was mainly related to a decrease in evergreen *Quercus*. High amounts of Cichorioideae characterize this open environment. Anthropogenic pollen taxa, including *Olea*, *Vitis*, *Castanea*, and *Carduus*, show only sporadic occurrences. From 4.1 to 3 ka BP, a new forest development shows a remarkable increase in evergreen and deciduous elements (mainly *Quercus*, *Ostrya*/*Carpinus orientalis*, and *Fagus*) at the same time of a modest increase in anthropogenic indicators. The difference in AP percentages between 5 ka and 4.2 ka BP is over 25%.

(23) Stagno di Sa Curcurica is a small coastal salty lake located in north-eastern Sardinia in the province of Nuoro (Beffa et al., 2016). Mean annual precipitation is ca. 560 mm. A change in the composition of the vegetation, from an *Erica*-dominated maquis to a mixed maquis, in which *Erica* is accompanied by evergreen *Quercus* communities, occurred between 6 ka and 5 ka. After this turnover, the vegetational landscape did not substantially change in the interval 5-3 ka. ~~An increase in anthropogenic taxa (e.g., *Juglans*, cereals, *Plantago*, and *Urtica*) is recorded around 4.5 ka BP, well after the main vegetation change.~~ No significant changes are recorded in either herbaceous taxa or pollen indicative of land use (e.g., *Plantago lanceolata* type, *Rumex acetosella*-type, and Cerealia-type) between 5 and 3 ka BP, but a charcoal-inferred increase of regional fire activity is recorded around 4.5 ka BP.

(24) Mistras Lagoon (Fig. 2) is a brackish lagoon in the central-western part of the Sardinia channel (Di Rita and Melis, 2013). Mean annual precipitation is ca. 560 mm. Up to 4.6 ka BP, the vegetation of the site was characterized by a local Chenopodiaceae/Amaranthaceae-dominated salt-marsh bordered by *Pistacia* scrublands formations, while in the hilly and montane sectors there were mixed oak woodlands. Between 4.6 and 4 ka BP, the area experienced significant environmental changes, related to a rapid saltmarsh decline, caused by local hydrological and sedimentological dynamics, and a general increase in sclerophyllous communities, especially holm oaks, paralleled by a decline in both cork and

deciduous oaks. Rather stable vegetation conditions marked the period between 4 and 3 ka BP, which corresponds to the phase of maximum human frequentation of the area, characterized by the development of the Nuragic civilisation, devoted to cereal cultivation and grape management.

(25) Lago Trifoglietti (1048 m a.s.l.) is part of a natural high-altitude lacustrine system located in the Calabria region (Joannin et al., 2012). The closest meteorological station indicates a mean annual precipitation of 1850 mm. A densely forested landscape, featured by high percentages of mountain trees *Abies* and *Fagus*, was punctuated by a decline in trees between ca. 4.9 and 4.65 ka BP. However, a pollen-based water-depth reconstruction points to relatively deep-water conditions favouring the development of an *Alnus* carr, interpreted as the establishment of wet climate. The interval 3.5–2.5 ka BP, characterized by a new forest decline, was also interpreted as a humid phase due to high water-depth evidence and a new rise in *Alnus*. By contrast, the interval 4.65–3.5 ka BP, interpreted as a shallow-water phase related to increased aridity, corresponds to a period of general forest development. In addition, the authors refer to a dry episode, particularly intense from 4 to 3.6 ka BP, according to the water-depth record, and around 4.2 ka BP, according to the reconstructed annual precipitation record, which appears associated to a temporary decline both in AP (-15 %) and in the main trees (*Fagus*, *Abies*, *Ostrya* and *Quercus* deciduous) starting from 4 ka BP. The pollen record of Trifoglietti shows only poor imprints of agricultural activity and anthropogenic indicators. The strongest evidence of human impact in the surroundings of the site is considered the selective exploitation of fir, especially after 4 ka BP.

(26) Lago Alimini Piccolo (Fig. 2) is a tectonic coastal lake located in the south-eastern part of the Salento Peninsula (Di Rita and Magri, 2009). Mean annual precipitation is ca. 700 mm. Between 5 and 4.35 ka BP, the landscape was covered by dense oak-dominated Mediterranean evergreen vegetation, with *Pistacia*, *Olea*, *Phillyrea* and Ericaceae. Between 4.35 and 3.9 ka BP, the Alimini area experienced a distinct opening of the forest, particularly affecting evergreen oaks, with a complete absence of both cereal pollen and other primary anthropogenic indicators. Between 3.9 and 3 ka BP, a new forest expansion was characterized by a remarkable increase in evergreen elements, including Mediterranean oaks. Afterwards, the forest cover shows a steady and moderate depletion through time, which might be due to a progressive increase of human activities during the Bronze Age, culminated with a remarkable increase in *Olea* at around 3.2 ka BP, consistent with management of the olive resource by local populations.

(27) Urio Quattrocchi is a small lake (0.5 ha) located at 1044 m a.s.l. in the western Nebrodi Mountains (northern Sicily), about 13 km from the Tyrrhenian Sea (Bisculm et al., 2012). Mean annual precipitation is ca. 990 mm. Between 5 and 3 ka BP, the pollen record shows a first phase characterized by a dramatic forest opening culminated at ca. 4.7 ka BP with a minimum in AP (20%), mostly reflecting a drop in deciduous and evergreen *Quercus*. According to the authors, crop and weed taxa such as cerealia, Cichorioideae, *Plantago*, Asteroideae and *Rumex*, together with high charcoal influx at 5.0–4.5 ka BP, suggest that human activities and anthropogenic fire may have caused the forest decline. This vegetation change was followed by significant recovery of the woody taxa, which were fully restored at ca. 3.4~~peaking at ca. 3.2~~ ka BP (AP>80%), favoured by a remarkable expansion of oaks (*Quercus cerris*/*suber* > 60%) accompanied by the development of *Fagus* communities.

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(28) Urgo Pietra Giordano (Fig. 2) is a small lake located at 1323 m a.s.l. in the Madonie Mountains (northern Sicily) (Tinner et al., 2016). Mean annual precipitation is around 900 mm. Between 5 and 4.7 ka BP, *Fagus sylvatica* dominated the densely forested environment, together with *Ilex aquifolium*, forming beech-holly mesophilous forest. Deciduous oaks were also abundant in this interval. Beech-holly forests declined at the onset of the Bronze Age at 4.5-4.15 ~~cal~~ ka BP and were massively destroyed due to burning at 4.15-3.65 ~~cal~~ ka BP, when all the dominant trees show a minimum. Microcharcoal shows a first peak around 4.5 ka BP and a second peak after 3.9 ka BP, but has very low values around 4.2 ka BP. After 3.65 ka BP ~~this phase~~ the forest experienced a new rapid recovery, especially favouring beech and oaks, while holly almost completely disappeared.

(29) Lago di Pergusa is located in the central part of Sicily at an elevation of 667 m (Sadori and Narcisi, 2001). Mean annual precipitation is around 650 mm. At 5 ka BP the vegetation was dominated by deciduous *Quercus*, with *Q. ilex*, *Olea* and *Ulmus* also abundant. A clear drop of AP concentration and percentages is found around 4.45 ka BP, along with an increase in floristic richness. Deciduous trees show a moderate decline followed by a rapid recovery around 4.1 ka. Evergreen oaks together with *Olea* show a significant increase only around 3.5 ka BP.

(30) Biviere di Gela (Fig. 2) is a coastal lake in south-east Sicily (Noti et al., 2009). Mean annual precipitation is ca. 400 mm. Evergreen forests and scrublands composed of *Q. ilex*, *Olea* and *Pistacia* dominated the landscape until ca. 5 ka BP, after which time they declined in response to human impact, which was probably exacerbated by a general trend towards dry climate. A partial shift towards *Pistacia*-dominated shrublands was probably a direct consequence of an intense agricultural and pastoral activity, suggested by an increase in Cichorioideae, Brassicaceae, *Rumex acetosella* and *Sporormiella*. A major reduction of the evergreen vegetation cover was recorded between 4.5 and 3.7 cal. BP, with a minimum at 4.2 ka BP, in correspondence with a strong increase in anthropogenic indicators such as *Plantago lanceolata*-type and in charcoal-inferred regional fire activity, and was followed by a recovery between 3.7 and 2.6 cal. BP, contemporarily to a slight reduction of human impact.

(31) Gorgo Basso is a small lake of karstic origin located in south-western Sicily, ca. 2.2 km from the sea (Tinner et al., 2009). Mean annual precipitation is ca. 450 mm. Between 5 and 3 ka BP, the landscape was characterized by a dense evergreen *Olea-Quercus ilex* forest. This interval was punctuated by a major event of evergreen cover reduction at 4.5-3.7 cal. BP, corresponding to an increase in cereals, *Plantago lanceolata* and charcoal particle influx. During this time-interval, indicators of palaeosalinity at Gorgo Basso suggest freshwater conditions, differently from the nearby Lago Preola, where admixing of seawater may explain a reconstructed salinity >10000 mg/L (Curry et al., 2016).

(32) Lago Preola is a medium-sized lake of ca. 33 ha, located approx. 2 km from Gorgo Basso (Calò et al., 2012). Mean annual precipitation is ca. 450 mm. Between 5 and 3 ka BP, *Pistacia* scrublands dominated the landscape together with *Quercus ilex* and *Olea* communities. The arboreal vegetation shows a fluctuating trend with a drop of *Quercus ilex* around 4.2 ka BP, which was replaced by *Pistacia* scrublands. Human disturbance, which started during the Neolithic at around 7.5 ka BP and contributed to reduce the evergreen forest in favour of the *Pistacia* scrubland, intensified from 2.6 to 2.2 ka BP, determining a progressive opening of the landscape.

(33) Majen El Orbi is a peatland located at 200 a.s.l. in reliefs facing the north-western coast of Tunisia (Stambouli-Essassi et al., 2007). Mean annual precipitation is ca. 1200 mm. Between 5 and 3 ka BP, the landscape was characterized by an admixture of deciduous and evergreen forest communities dominated by *Quercus canariensis*, *Q. suber* and *Erica arborea*, with high amounts of other sclerophyllous trees, notably *Q. coccifera* and *Myrtus communis*. The main change in forest cover occurred around 4.5 ka BP, featured by a dramatic decline of *Q. canariensis* populations, an overall decrease in woody taxa, and a contemporary remarkable development of Apiaceae, accompanied by high amounts Poaceae, related to arid climate conditions. After this event the forest cover started recovering around 4.2 with *E. arborea*, *M. communis*, and *Q. coccifera* shrubland, followed by a complete recovery of the *Q. canariensis* forest.

(34) Majen Ben H'mida is a peatland located at 330 m a.s.l. in the massif of Djebel Chitane (Stambouli-Essassi et al., 2007). Mean annual precipitation is ca. 1400 mm. Between 5 and 3 ka BP, the vegetation of the site was characterized by *Q. canariensis*, *E. arborea* and *Q. suber*, the latter increasing after 4.5 ka BP. A major vegetation change occurred around 4 ka BP, determining the drop of the main woody taxa, related to a climate change towards arid conditions, possibly exacerbated by the impact of human activities.

(35) Dar Fatma is a peatland located at 780 m a.s.l. in the north-western side of Tunisia (Stambouli-Essassi et al., 2007). Mean annual precipitation is around 1200 mm. Between 5 and 3 ka BP, the pollen record from Dar Fatma I shows a semi-open landscape dominated by Poaceae. The forest vegetation was characterized by stands of *Q. suber* and *E. arborea*, showing a remarkable decline around 4.85 ka BP. This process corresponds to a biodiversity increase in herbaceous taxa and the contemporary first occurrence of cereals, suggesting a role of human impact in the vegetation change.

(36) Djebel Ghorra (Fig. 2) is a peatland located at 1203 m a.s.l. in Tunisia (Ben Tiba, 1995; Stambouli-Essassi et al., 2007). Mean annual precipitation is ca. 1100 mm. The interval 5-3 ka shows a landscape dominated by *Q. canariensis*, accompanied by other woody taxa forming woodland and shrubland communities (e.g., *Q. ilex*, *Q. suber* and *E. arborea*). Forest conditions, marked by particularly high amounts of *Q. canariensis* (>70%), were recorded especially until 4.9 ka BP. Afterwards, the site experienced a rapid forest decline, culminated at 4.3 ka BP, matched by a development of Poaceae. After a temporary forest recovery at 3.9 ka BP, the site was marked by a new vegetation opening and widespread grassland formations.

4 Discussion

The vegetation dynamics in the central Mediterranean during the 4.2 ka BP event, as depicted by pollen records, is rather diverse, as it ranges from cases in which no clear change is observed to dramatic openings of the forest (Fig. 2). Considering the geographical location of the sites and their water availability, it is possible to distinguish four main situations (Figs 1-3):

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1. Sites with no ~~deforestation~~ forest decline or vegetation change around 4.2 ka BP: all the sites located north of 43°N show no significant variation in forest cover and composition (blue records in Figs 1-3). They include mountain sites with mean annual precipitation >2000 mm (e.g., Lago del Greppo, Lago Padule, Mogge di Ertola), as well as hilly or coastal sites with mean annual precipitations <1000 mm (e.g., Pavullo nel Frignano, Lago di Massaciuccoli). In most of these records, a slight and progressive increase in *Fagus* to the expenses of *Abies* is observed before and during the 4.2 ka BP event. At Lago di Massaciuccoli there was an expansion of evergreen *Quercus*. Considering the diversity of vegetation composition and of mean annual precipitation values of these sites, it appears that a possible common factor determining no vegetation change at 4.2 ka is the location north of 43°N. At this latitude in the central Mediterranean, the prevalent climate mode has a North Atlantic influence~~, and a minor influence of the north African high pressures~~. The NAO oscillation, besides conveying most of the storm tracks through the North Atlantic westerlies, strongly influences the northern Mediterranean cyclogenesis (e.g. Gulf of Genoa cyclogenesis) (Trigo et al., 2002), which pushes winter humid winds in the northern sectors of the central Mediterranean where they discharge precipitations once they are blocked by the reliefs of the Apennines and Alps. Negative NAO circulation phases in the north-central Mediterranean would determine positive precipitation anomaly (Trigo et al., 2004), as in most of central Europe and the south-western Mediterranean regions (Zielhofer et al., 2017; Di Rita et al., 2018a), as experienced also during the Bond events (Martín-Puertas et al., 2008, Trouet et al., 2009; Olsen et al., 2012). The 4.2 climate event, corresponding to Bond event 3 and to a rapid inversion of the NAO index towards negative values, is expected to have produced humid climate conditions in the north-central Mediterranean and in the south-western Mediterranean (Zielhofer et al., 2018). ~~Thus, it is likely that the 4.2 climate event either did not produce a significant climate change in central northern Italy or was overshadowed by the effects of increased humid conditions, consistent with negative NAO index and Bond event 3~~However, the speleothem records over the Apuan Alps (Renella and Corchia Cave) show consistent evidence of reduced cave recharge in a period ranging from ca. 4.5 to 3.8 ka (Isola et al., 2018; Bini et al., 2018). These results imply a reduction of cyclones originating in the North Atlantic and of cyclogenetic activity in the Gulf of Genoa, pointing to a scenario of lower mean annual temperature, reduced precipitation during winter, and cooler and wetter summer conditions (Isola et al., 2018). A possible explanation to reconcile pollen and speleothem evidence, in a phase when the NAO index is not well defined and requires further investigations, is that a general decrease in precipitation in the very humid area of the northern Apennines (up to 2500 mm/year) was sufficient to determine a change in the speleothem record, but not in the vegetation. Besides, the speleothem record suggesting wetter summer conditions is consistent with the development a beech forest, as shown by the montane pollen sites of the northern Apennines (Branch, 2013). The different sensitivity of speleothem and pollen records may help to better define the geographical area influenced by the 4.2 ka BP event.

2. Sites with a clear opening of forests around 4.2 ka BP: several sites from central Italy at latitudes <43°N and all the sites located at latitudes <39°N show drops of over 10% in AP percentages (red records in Figs 1-3). Their elevations range from the sea level to over 1300 m a.s.l. and mean annual precipitation values range from 400 to 1400 mm (Fig. 3). The vegetation composition of these sites is very diverse, as it is characterized by mixed oak forests with a significant amount

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of *Fagus* in sites from central Italy (Lagaccione and Lago di Vico), mixed deciduous and evergreen oak-dominated forests in Tyrrhenian southern Italy (Gulf of Gaeta and Lago Patria), evergreen scrubland, mainly composed of evergreen oaks, *Olea*, and *Pistacia* or *Pinus* in Apulia (Lago Battaglia, Lago Salso, and Lago Alimini Piccolo), deciduous oak-dominated forests in central-northern Sicily (Urio Quattrocchi, Urgo Pietra Giordano, and Lago di Pergusa), scrublands mainly composed of *Q. ilex*, *Olea* and *Pistacia* in coastal sites of southern Sicily (Biviere di Gela, Gorgo Basso, and Lago Preola), and admixtures of deciduous and evergreen forest communities dominated by *Q. canariensis*, *Q. suber* and *E. arborea* in northern Tunisia (Majen El Orbi, Majen Ben H'mida, and Dar Fatma). In these sites, independently of altitude and vegetation composition, AP percentages drop around 4.4-4.3 ka BP, reach a minimum around 4.2 ka BP and progressively recover. At all sites, the recovery process is complete by 3.6 ka BP. There are however some differences among sites in the timing, duration, and intensity of the vegetation change. The forest decline is earlier in the Tunisian and Sicilian sites, followed by the sites in southern Italy, and then in central Italy (Fig. 2). The time interval characterized by open vegetation appears longer in Sicily than in peninsular Italy (Fig. 2). Although these differences may be partly due to unprecise dating of the records, a general delay in the more northern sites is visible. Considering the progressive geographical pattern of the opening of forests in the central Mediterranean, which is ~~clearly connected~~coeval to the 4.2 ka BP climate event documented in many Mediterranean sites, we suggest that it may be explained by a progressive northward displacement of the north African high pressure cell, conveying arid air masses and inducing torrid temperatures in the central Mediterranean, in a way similar to the modern heath-waves moving from Africa (Di Rita and Magri, 2009; Di Rita et al. 2018b). The frequent reiteration and persistence of such conditions around 4.2 ka BP may have severely affected the southern regions of the central Mediterranean (up to 39°N) and partly influenced also central Italy (up to 43°N). Similarly, the intensity of ~~deforestation~~the opening of the forest was generally stronger in the southern sites than in the sites located at latitudes >39°N (Fig. 2). This difference cannot be simply ascribed to precipitation, elevation and vegetation composition at the studied sites. For example, the Sicilian sites, where ~~deforestation effects~~the forest decline ~~were~~was always very marked, have at present mean annual precipitations ranging from 400 to 1000 mm and elevations from the sea level to over 1300 m, and are characterized by a variety of vegetation types ranging from mediterranean scrubland to beech forest. Instead, a relation may be found between intensity of forest decline and latitude, as all the sites where AP dropped at 4.2 ka BP are located south of 43°N, and all the sites south of 39°N show a clear ~~deforestation~~ forest decline~~event~~ (Fig. 3). Although the ~~effect of~~opening of forests coeval to the 4.2 ka event is especially visible in the southern regions, all sites south of 43°N with mean annual precipitations <500 mm are affected by this ~~dry~~ event (Fig. 3). This suggests that the environments suffering for water deficit may be particularly vulnerable to the climatic regime induced by ~~the~~ a displacement of the north African high-pressure cell, so to undergo a general ~~deforestation~~forest decline. A further factor that may have influenced the vegetation of the southern regions in the central Mediterranean is an extensive and intense human impact on the landscape, documented by archaeological sites~~, and~~ anthropogenic indicators in pollen records and a rich archaeobotanical evidence (Mariotti Lippi et al., 2018). While widespread human presence in the early Bronze age is attested in all the Italian territory, values for anthropogenic pollen indicators are higher in southern Italy

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and Sicily than elsewhere, indicating that human activity was particularly intense during these events of forest decline. One possible explanation for the increased presence of anthropogenic indicators at the same time of a forest decline in response to a climate change towards aridity is that a dry event may have spurred the expansion of agriculture and the diffusion of human settlements in southern Italy and Sicily by thinning the woodland, aiding its clearance by farmers (Magri, 1995; Yll et al., 1997; Lawson et al., 2004). Archaeological evidence indicates that the beginning of the Neolithic era occurred earlier in dry areas of Sicily and southern Italy (Natali and Forgia, 2018) than in compatatively wetter areas of central and northern Italy (Radi and Petrinelli Pannocchia, 2018). In addition, ecosystems and vegetation were less resilient and more vulnerable to human disturbance with increasing heat and drought along a north-south gradient. This is also consistent with the evidence that after 4.2 ka BP a new progressive change towards more humid conditions favoured the recovery of forest vegetation, independently of the widespread presence of human communities. In this case, human activity was not able to hinder the new diffusion of forests that expanded everywhere in the south-central Mediterranean after the 4.2 ka event.

3. Sites with an unclear vegetation change around 4.2 ka BP. We include in this category some sites of central and southern Italy (latitude between 39°-43°N) with compositional variations in vegetation but no clear drop in AP percentages around 4.2 ka BP, as well as some doubtful cases that we will shortly discuss. These sites are represented in yellow in Figs 1-3. We do not not include in this list Lake Preola, where a clear drop in trees peaking around 4.2 ka BP is compensated by a shrubland (Calò et al., 2012). By contrast, we include Lago dell'Accesa, where a drop in evergreen oaks around 4.2 ka BP is compensated by deciduous oaks, which contribute maintaining forested conditions, in spite of a significant compositional change in vegetation (Drescher-Schneider et al., 2007; Vannière et al., 2008). At Lingua d'Oca-Interporto, the vicinity of the Tiber river and of the Tyrrhenian Sea caused repeated floods and ingressions of marine water, which severely affected the record of vegetation dynamics in the hills behind the large coastal wetland, making it difficult to recognize any vegetation change in response to climate events (Di Rita et al., 2015). The Adriatic core RF93-30, which shows a clear drop in AP starting only around 3.9 ka BP, collects pollen from the Po valley and northcentral Apennines, and only in part from the central and southern Italian peninsula, in spite of its location just north of the Gargano Promontory (Mercuri et al., (2012)., according to the age-depth model proposed by Oldfield et al. (2003) and Mercuri et al. (2012), which assumed that the tephra layer found at the time of the AP drop is the 'Avellino' tephra dated around 3.8 ka BP. However, the tephrochronological analysis on the RF93-30 core did not attribute this tephra layer to the Avellino eruption (Calanchi et al., 1998; Calanchi and Dinelli, 2008), so the chronology of the AP drop may need to be revised. At Lago Grande di Monticchio, a slight decrease in AP is recorded (-5%) just before a gap in the pollen record from 4 to 3.5 ka BP (Allen et al., 2002), that may have contributed to mask the 4.2 ka BP event. At Lago Trifoglietti, the authors report an intense dry episode around 4.2 ka BP shown by the reconstructed annual precipitation record, which is however not visible in the pollen record (Joannin et al., 2012). One possible explanation for this discrepancy is that in this mountain area a high mean annual precipitation (ca. 1850 mm) favours the development of a dense forest, so that even a

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marked decrease in moisture conditions may not provoke any severe decline of forest cover. On the whole, in these "uncertain sites" different factors may have contributed to partially mask a forest decline.

4. Pollen records from Corsica and Sardinia: except for the coastal site of Crovani, where *Q. ilex* and *E. arborea* communities were replaced by grasses and sedges around 4.4 ka BP, no significant change is visible ~~in the Corsican and Sardinian sites~~around 4.2 ka BP. The vegetational dynamics of these island is quite different from central and southern Italy, although these regions are located at the same latitude and have similar mean annual precipitation values. For this reason, the Sardinian-Corsican pollen records have been separated in a different group marked in green in Figs 1-3. They are from both coastal (Crovani, Aleria del Sale, Greco pond, Sa Curcurica, and Mistras Lagoon) and inland (Lake Creno) sites, representing different vegetation types. The different dynamics of forest vegetation compared to the Italian Peninsula suggests that the two regions may be subject to different prevalent ~~climate modes~~air masses circulation, Sardinia and Corsica being not substantially affected by the north African climate system. However, the pollen records from Mistras and Sa Curcurica, showing pollen of *Betula* of northern origin before and after, but not during the 4.2 ka BP event, suggests that an attenuation of the North Atlantic influence occurred at this time, without determining any significant forest decline.

4 Conclusions

The examination of pollen records from the central Mediterranean regions in the time interval around 4.2 ka BP has allowed the recognition of vegetation dynamics reflecting a geographical pattern, related to latitude and precipitation regime.

We have found that sites located between 43° and 45°N show no significant vegetation change in correspondence with the 4.2 ka event, independently on latitude, elevation, and forest composition. In these regions, it is likely that the 4.2 event either produced only a modest decrease of precipitation, not sufficient to determine a forest decline, or produced a winter decrease and a summer increase of precipitation, as suggested by speleothem records (Isola et al., 2018), favoring the development of mountain forests.~~either did not produce a significant climate change or was overshadowed by increased humid conditions, consistent with the peculiar atmospheric configuration produced by negative NAO index and Bond event 3~~.

Several sites located in the Italian Peninsula between 39°-43°N show a marked ~~opening of the~~ forest decline, suggesting that a lowering of rainfall occurred, sufficiently strong to determine a vegetation change. However, in some sites this pattern is not clear, as it determined only changes in vegetation composition and not in forest cover. In other sites, problems of local pollen representation, chronological setting, gaps in the pollen record, as well as local very high rainfall may have masked the 4.2 ka BP event.

In southern Italy, Sicily and Tunisia, between 36°-39°N, a drop in AP around 4.2 ka BP is always visible, and in some cases dramatic~~. This indicates that this region was severely affected by a climate change towards arid conditions that lasted a few hundreds of years and was~~, followed by a recovery of forest vegetation in the M~~m~~iddle Bronze ~~age~~ Age. We suggest that southern Italy and Tunisia were under the prevalent influence of a north African climate system, characterized by a persistent high-pressure cell. At the same time, the pollen records from this region document increasing agro-pastoral human activity,

which may have been favored by a natural opening of the forest. At the end of the ~~arid~~ 4.2 ka BP event, human activity was not able to hold back a new spread of forest vegetation.

In Sardinia and Corsica, no clear change in vegetation is observed at the same time, ~~probably because these islands where at the margin of the area of the central Mediterranean affected by the 4.2 ka event~~although the pollen record suggests possible changes in the prevalent provenance of winds..

This review of the vegetation changes in the central Mediterranean region during the 4.2 ka BP event points to a general vulnerability of forest communities south of 43°N, and especially south of 39°N, in response to arid events. The northward displacement of the North African high-pressures over the Italian Peninsula, also at present often affecting the annual hydroclimate regime, may have induced a dramatic change in forest ecosystems during the 4.2 ka BP event, and may be responsible for similar ecological disruptions also in the future.

5 Author contributions

FDR and DM contributed equally in conceiving this review and writing the paper.

6 Competing interests

The authors declare that they have no conflict of interest.

7 Acknowledgments

8 Data and materials availability

All data needed to evaluate the conclusions in the paper are presented in the paper. Additional data related to this paper may be requested from the authors.

References

Allen, J. R. M., Watts, W. A., McGee, E. and Huntley, B.: Holocene environmental variability—the record from Lago Grande di Monticchio, Italy, Quaternary International, 88(1), 69–80, 2002.

Attorre, F., Alfo', M., Sanctis, M. D., Francesconi, F. and Bruno, F.: Comparison of interpolation methods for mapping climatic and bioclimatic variables at regional scale, International Journal of Climatology, 27(13), 1825–1843, doi:10.1002/joc.1495, 2007.

Attorre, F., Francesconi, F., Valenti, R., collalti, A. and Bruno, F.: Produzione di mappe climatiche e bioclimatiche mediante Universal Kriging con deriva esterna: teoria ed esempi per l'italia, Forest@ - Journal of Silviculture and Forest Ecology, 5, 8–19, 2008.

Beffa, G., Pedrotta, T., Colombaroli, D., Henne, P. D., van Leeuwen, J. F. N., Süsstrunk, P., Kaltenrieder, P., Adolf, C., Vogel, H., Pasta, S., Anselmetti, F. S., Gobet, E. and Tinner, W.: Vegetation and fire history of coastal north-eastern Sardinia (Italy) under changing Holocene climates and land use, Vegetation History and Archaeobotany, 25(3), 271–289, doi:10.1007/s00334-015-0548-5, 2016.

Behre, K.-E.: The interpretation of anthropogenic indicators in pollen diagrams, Pollen et spores, 23(2), 225–245, 1981.

Ben Tiba, B.: Cinq millénaires d'histoire de la végétation à Djebel El Ghorra, CIFEG, Publ. Occas., Orléans., 1995.

Bennett, K. D.: 'psimpoll'and 'pscomb': C programs for analysing pollen data and plotting pollen diagrams (version 4.27), Available online from Queen's University Quaternary Geology program at URL http://www. chrono. qub. ac. uk/psimpoll. html, 2009.

Benslimane, M., Hamimed, A., Zerey, W. E., Khaldi, A. and Mederbal, K.: Analyse et suivi du phénomène de la désertification en Algérie du nord, VertigO - la revue électronique en sciences de l'environnement, (Volume 8 Numéro 3), doi:10.4000/vertigo.6782, 2009.

Bini, M., Zanchetta, G., Persoiu, A., Cartier, R., Català, A., Cacho, I., Dean, J. R., Di Rita, F., Drysdale, R. N., Finnè, M., Isola, I., Jalali, B., Lirer, F., Magri, D., Masi, A., Marks, L., Mercuri, A. M., Peyron, O., Sadori, L., Sicre, M.-A., Welc, F., Zielhofer, C. and Brisset, E.: The 4.2 ka BP Event in the Mediterranean Region: an overview, Climate of the Past Discussions, 1–36, doi:10.5194/cp-2018-147, 2018.

Bisculm, M., Colombaroli, D., Vescovi, E., van Leeuwen, J. F. N., Henne, P. D., Rothen, J., Procacci, G., Pasta, S., La Mantia, T. and Tinner, W.: Holocene vegetation and fire dynamics in the supra-mediterranean belt of the Nebrodi Mountains (Sicily, Italy), Journal of Quaternary Science, 27(7), 687–698, doi:10.1002/jqs.2551, 2012.

Branch, N. P.: Early–Middle Holocene vegetation history, climate change and human activities at Lago Riane (Ligurian Apennines, NW Italy), Vegetation History and Archaeobotany, 22(4), 315–334, doi:10.1007/s00334-012-0384-9, 2013.

Burjachs, F., Pérez-Obiol, R., Picornell-Gelabert, L., Revelles, J., Servera-Vives, G., Expósito, I. and Yll, E.-I.: Overview of environmental changes and human colonization in the Balearic Islands (Western Mediterranean) and their impacts on vegetation composition during the Holocene, Journal of Archaeological Science: Reports, 12, 845–859, doi:10.1016/j.jasrep.2016.09.018, 2017.

Calanchi, N. and Dinelli, E.: Tephrostratigraphy of the last 170 ka in sedimentary successions from the Adriatic Sea, Journal of Volcanology and Geothermal Research, 177(1), 81–95, doi:10.1016/j.jvolgeores.2008.06.008, 2008.

Calanchi, N., Cattaneo, A., Dinelli, E., Gasparotto, G. and Lucchini, F.: Tephra layers in Late Quaternary sediments of the central Adriatic Sea, Marine Geology, 149(1–4), 191–209, doi:10.1016/S0025-3227(98)00030-9, 1998.Calò, C., Henne, P. D., Curry, B., Magny, M., Vescovi, E., La Mantia, T., Pasta, S., Vannière, B. and Tinner, W.: Spatio-temporal patterns

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of Holocene environmental change in southern Sicily, Palaeogeography, Palaeoclimatology, Palaeoecology, 323–325, 110–122, doi:10.1016/j.palaeo.2012.01.038, 2012.

Caroli, I. and Caldara, M.: Vegetation history of Lago Battaglia (eastern Gargano coast, Apulia, Italy) during the middle-late Holocene, Vegetation History and Archaeobotany, 16(4), 317–327, doi:10.1007/s00334-006-0045-y, 2007.

5 Carrión, J. S., Fernández, S., González-Sampériz, P., Gil-Romera, G., Badal, E., Carrión-Marco, Y., López-Merino, L., López-Sáez, J. A., Fierro, E. and Burjachs, F.: Expected trends and surprises in the Lateglacial and Holocene vegetation history of the Iberian Peninsula and Balearic Islands, Review of Palaeobotany and Palynology, 162(3), 458–475, doi:10.1016/j.revpalbo.2009.12.007, 2010.

Colombaroli, D., Marchetto, A. and Tinner, W.: Long-term interactions between Mediterranean climate, vegetation and fire
10 regime at Lago di Massaciuccoli (Tuscany, Italy), Journal of Ecology, 95(4), 755–770, doi:10.1111/j.1365-2745.2007.01240.x, 2007.

Cruise, G. M., Macphail, R. I., Linderholm, J., Maggi, R. and Marshall, P. D.: Lago di Bargone, Liguria, N Italy: a reconstruction of Holocene environmental and land-use history, The Holocene, 19(7), 987–1003, doi:10.1177/0959683609343142, 2009.

15 Cullen, H. M., Hemming, S., Hemming, G., Brown, F. H., Guilderson, T., Sirocko, F. and others: Climate change and the collapse of the Akkadian empire: Evidence from the deep sea, Geology, 28(4), 379–382, 2000.

Currás, A., Ghilardi, M., Peche-Quilichini, K., Fagel, N., Vacchi, M., Delanghe, D., Dussouillez, P., Vella, C., Bontempi, J. M. and Ottaviani, J.-C.: Reconstructing past landscapes of the eastern plain of Corsica (NW Mediterranean) during the last 6000 years based on molluscan, sedimentological and palynological analyses, Journal of Archaeological Science:
20 Reports, 12, 755–769, doi:10.1016/j.jasrep.2016.09.016, 2017.

Curry, B., Henne, P. D., Mesquita-Joanes, F., Marrone, F., Pieri, V., La Mantia, T., Calò, C. and Tinner, W.: Holocene paleoclimate inferred from salinity histories of adjacent lakes in southwestern Sicily (Italy), Quaternary Science Reviews, 150, 67–83, doi:10.1016/j.quascirev.2016.08.013, 2016.

Di Rita, F.: A possible solar pacemaker for Holocene fluctuations of a salt-marsh in southern Italy, Quaternary International,
25 288, 239–248, 2013

Di Rita, F. and Magri, D.: Holocene drought, deforestation and evergreen vegetation development in the central Mediterranean: a 5500 year record from Lago Alimini Piccolo, Apulia, southeast Italy, The Holocene, 19(2), 295–306, doi:10.1177/0959683608100574, 2009.

Di Rita, F. and Magri, D.: An overview of the Holocene vegetation history from the central Mediterranean coasts, Journal of
30 Mediterranean Earth Sciences, 4, 35–52, 2012.

Di Rita, F. and Melis, R. T.: The cultural landscape near the ancient city of Tharros (central West Sardinia): vegetation changes and human impact, Journal of Archaeological Science, 40(12), 4271–4282, doi:10.1016/j.jas.2013.06.027, 2013.

Di Rita, F., Celant, A. and Magri, D.: Holocene environmental instability in the wetland north of the Tiber delta (Rome, Italy): sea-lake-man interactions, Journal of Paleolimnology, 44(1), 51–67, doi:10.1007/s10933-009-9385-9, 2010.

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Di Rita, F., Simone, O., Caldara, M., Gehrels, W. R. and Magri, D.: Holocene environmental changes in the coastal Tavoliere Plain (Apulia, southern Italy): A multiproxy approach, Palaeogeography, Palaeoclimatology, Palaeoecology, 310(3–4), 139–151, doi:10.1016/j.palaeo.2011.06.012, 2011.

Di Rita, F., Celant, A. and Conati Barbaro, C.: Interazioni tra clima, ambiente e uomo nell'evoluzione olocenica del delta del Tevere: dati paleobotanici e ritrovamenti archeologici, Rendiconti Online della Società Geologica Italiana, 18, 19–23, 2012.

Di Rita, F., Celant, A., Milli, S. and Magri, D.: Lateglacial–early Holocene vegetation history of the Tiber delta (Rome, Italy) under the influence of climate change and sea level rise, Review of Palaeobotany and Palynology, 218, 204–2016, doi:10.1016/j.revpalbo.2014.12.005, 2015.

Di Rita, F., Fletcher, W. J., Aranbarri, J., Margaritelli, G., Lirer, F. and Magri, D.: Holocene forest dynamics in central and western Mediterranean: periodicity, spatio-temporal patterns and climate influence, Scientific Reports, 8, 8929, doi:10.1038/s41598-018-27056-2, 2018a.

Di Rita, F., Lirer, F., Bonomo, S., Cascella, A., Ferraro, L., Florindo, F., Insinga, D. D., Lurcock, P. C., Margaritelli, G., Petrosino, P., Rettori, R., Vallefuoco, M. and Magri, D.: Late Holocene forest dynamics in the Gulf of Gaeta (central Mediterranean) in relation to NAO variability and human impact, Quaternary Science Reviews, 179, 137–152, doi:10.1016/j.quascirev.2017.11.012, 2018b.

Di Rita, F., Molisso, F. and Sacchi, M.: Late Holocene environmental dynamics, vegetation history, human impact, and climate change in the ancient Literna Palus (Lago Patria; Campania, Italy), Review of Palaeobotany and Palynology, 258, 48–61, doi:10.1016/j.revpalbo.2018.06.005, 2018c.

Dixit, Y., Hodell, D. A. and Petrie, C. A.: Abrupt weakening of the summer monsoon in northwest India 4100 yr ago, Geology, 42(4), 339–342, doi:10.1130/G35236.1, 2014.

Dixit, Y., Hodell, D. A., Giesche, A., Tandon, S. K., Gázquez, F., Saini, H. S., Skinner, L. C., Mujtaba, S. A. I., Pawar, V., Singh, R. N. and Petrie, C. A.: Intensified summer monsoon and the urbanization of Indus Civilization in northwest India, Scientific Reports, 8(1), doi:10.1038/s41598-018-22504-5, 2018.

Drescher-Schneider, R., de Beaulieu, J.-L., Magny, M., Walter-Simonnet, A.-V., Bossuet, G., Millet, L., Brugiapaglia, E. and Drescher, A.: Vegetation history, climate and human impact over the last 15,000 years at Lago dell'Accesa (Tuscany, Central Italy), Vegetation History and Archaeobotany, 16(4), 279–299, doi:10.1007/s00334-006-0089-z, 2007.

Guido, M. A., Menozzi, B. I., Bellini, C., Placereani, S. and Montanari, C.: A palynological contribution to the environmental archaeology of a Mediterranean mountain wetland (North West Apennines, Italy), The Holocene, 23(11), 1517–1527, doi:10.1177/0959683613496294, 2013.

Isola, I., Zanchetta, G., Drysdale, R. N., Regattieri, E., Bini, M., Bajo, P., Hellstrom, J. C., Baneschi, I., Lionello, P., Woodhead, J. and Greig, A.: The 4.2 ka BP event in the Central Mediterranean: New data from Corchia speleothems (Apuan Alps, central Italy), Climate of the Past Discussions, 1–24, doi:10.5194/cp-2018-127, 2018.

19

Joannin, S., Brugiapaglia, E., de Beaulieu, J.-L., Bernardo, L., Magny, M., Peyron, O., Goring, S. and Vannière, B.: Pollen-based reconstruction of Holocene vegetation and climate in southern Italy: the case of Lago Trifoglietti, Climate of the Past, 8(6), 1973–1996, doi:10.5194/cp-8-1973-2012, 2012.

Kaniewski, D., Marriner, N., Cheddadi, R., Guiot, J. and Van Campo, E.: The 4.2 ka BP event in the Levant, Climate of the Past Discussions, doi:10.5194/cp-2018-82, 2018.

Lawson, I., Frogley, M., Bryant, C., Preece, R. and Tzedakis, P.: The Lateglacial and Holocene environmental history of the Ioannina basin, north-west Greece, Quaternary Science Reviews, 23(14–15), 1599–1625, doi:10.1016/j.quascirev.2004.02.003, 2004.

Liu, F. and Feng, Z.: A dramatic climatic transition at ~4000 cal. yr BP and its cultural responses in Chinese cultural domains, The Holocene, 22(10), 1181–1197, doi:10.1177/0959683612441839, 2012.

Magny, M., Combourieu-Nebout, N., de Beaulieu, J. L., Bout-Roumazeilles, V., Colombaroli, D., Desprat, S., Francke, A., Joannin, S., Ortu, E., Peyron, O., Revel, M., Sadori, L., Siani, G., Sicre, M. A., Samartin, S., Simonneau, A., Tinner, W., Vannière, B., Wagner, B., Zanchetta, G., Anselmetti, F., Brugiapaglia, E., Chapron, E., Debret, M., Desmet, M., Didier, J., Essallami, L., Galop, D., Gilli, A., Haas, J. N., Kallel, N., Millet, L., Stock, A., Turon, J. L. and Wirth, S.: North-south palaeohydrological contrasts in the central Mediterranean during the Holocene: tentative synthesis and working hypotheses, Climate of the Past, 9(5), 2043–2071, doi:10.5194/cp-9-2043-2013, 2013.

Magri, D.: Late-Quaternary changes of plant biomass as recorded by pollen-stratigraphical data: a discussion of the problem at Valle di Castiglione, Italy, Review of palaeobotany and palynology, 81(2), 313–325, 1994.

Magri, D.: Some questions on the late-Holocene vegetation of Europe, The Holocene, 5(3), 354–360, 1995.

Magri, D.: Late Quaternary vegetation history at Lagaccione near Lago di Bolsena (central Italy), Review of Palaeobotany and Palynology, 106(3), 171–208, 1999.

Magri, D. and Parra, I.: Late Quaternary western Mediterranean pollen records and African winds, Earth and Planetary Science Letters, 200(3), 401–408, 2002.

Magri, D. and Sadori, L.: Late Pleistocene and Holocene pollen stratigraphy at Lago di Vico, central Italy, Vegetation history and archaeobotany, 8(4), 247–260, 1999.

Magri, D., Agrillo, E., Di Rita, F., Furlanetto, G., Pini, R., Ravazzi, C. and Spada, F.: Holocene dynamics of tree taxa populations in Italy, Review of Palaeobotany and Palynology, 218, 267–284, doi:10.1016/j.revpalbo.2014.08.012, 2015.

Magri, D., Di Rita, F., Aranbarri, J., Fletcher, W. and González-Sampériz, P.: Quaternary disappearance of tree taxa from Southern Europe: Timing and trends, Quaternary Science Reviews, 163, 23–55, doi:10.1016/j.quascirev.2017.02.014, 2017.

Margaritelli, G., Vallefuoco, M., Di Rita, F., Capotondi, L., Bellucci, L. G., Insinga, D. D., Petrosino, P., Bonomo, S., Cacho, I., Cascella, A., Ferraro, L., Florindo, F., Lubritto, C., Lurcock, P. C., Magri, D., Pelosi, N., Rettori, R. and Lirer, F.: Marine response to climate changes during the last five millennia in the central Mediterranean Sea, Global and Planetary Change, 142, 53–72, doi:10.1016/j.gloplacha.2016.04.007, 2016.

Mariotti Lippi, M. Florenzano, A., Rinaldi, R., Allevato, E., Arobba, D., Bacchetta, G., Bal, M.-C., Bandini Mazzanti, M., Benatti, A., Beneš, J., Bosi, G., Buonincontri, M., Caramiello, R., Castelletti, L., Castiglioni, E., Celant, A., Clò, E., Costantini, L., Di Pasquale, G., Di Rita, F., Fiorentino, G., Furlanetto, G., Giardini, M., Grillo, O., Guido, M., Herchenbach, M., Magri, D., Marchesini, M., Maritan, M., Marvelli, S., Masi, A., Miola, A., Montanari, C., Montecchi, M.C., Motella, S., Nisbet, R., Orrù, M., Peña Chocarro, L., Pepe, C., Perego, R., Rattighieri, E., Ravazzi, C., Rottoli, M., Rowan, E., Sabato, D., Sadori, L., Sarigu, M., Torri, P., Ucchesu, M. and Mercuri, A. M.: The Botanical Record of Archaeobotany Italian Network - BRAIN: a cooperative network, database and website, Flora Mediterranea, 28, doi:10.7320/FlMedit28.365, 2018. Marshall, M. H., Lamb, H. F., Huws, D., Davies, S. J., Bates, R., Bloemendal, J., Boyle, J., Leng, M. J., Umer, M. and Bryant, C.: Late Pleistocene and Holocene drought events at Lake Tana, the source of the Blue Nile, Global and Planetary Change, 78(3–4), 147–161, doi:10.1016/j.gloplacha.2011.06.004, 2011.

Martìn-Puertas, C., Matthes, K., Brauer, A., Muscheler, R., Hansen, F., Petrick, C., Aldahan, A., Possnert, G., van Geel, B.: Regional atmospheric circulation shifts induced by a grand solar minimum, Nature Geoscience, 5, 397–401, 2012.

Mercuri, A. M.: Genesis and evolution of the cultural landscape in central Mediterranean: the 'where, when and how' through the palynological approach, Landscape Ecology, 29(10), 1799–1810, doi:10.1007/s10980-014-0093-0, 2014.

Mercuri, A. M., Mazzanti, M. B., Torri, P., Vigliotti, L., Bosi, G., Florenzano, A., Olmi, L. and N'siala, I. M.: A marine/terrestrial integration for mid-late Holocene vegetation history and the development of the cultural landscape in the Po valley as a result of human impact and climate change, Vegetation History and Archaeobotany, 21(4–5), 353–372, doi:10.1007/s00334-012-0352-4, 2012.

Natali, E. and Forgia, V.: The beginning of the Neolithic in Southern Italy and Sicily, Quaternary International, 470, 253–269, doi:10.1016/j.quaint.2017.07.004, 2018.

Noti, R., van Leeuwen, J. F. N., Colombaroli, D., Vescovi, E., Pasta, S., La Mantia, T. and Tinner, W.: Mid- and late-Holocene vegetation and fire history at Biviere di Gela, a coastal lake in southern Sicily, Italy, Vegetation History and Archaeobotany, 18(5), 371–387, doi:10.1007/s00334-009-0211-0, 2009.

Oldfield, F., Asioli, A., Accorsi, C. A., Mercuri, A. M., Juggins, S., Langone, L., Rolph, T., Trincardi, F., Wolff, G., Gibbs, Z. and others: A high resolution late Holocene palaeo environmental record from the central Adriatic Sea, Quaternary Science Reviews, 22(2), 319–342, 2003.

Olsen, J., Anderson, N.J., Knudsen, M.F.: Variability of the North Atlantic Oscillation over the past 5,200 years, Nature Geoscience, 5, 808–812, 2012.

Poher, Y.: Dynamique de la biodiversité et changements environnementaux en Corse depuis 7000 ans: éclairages paléoentomologiques et paléobotaniques, Biodiversité et Ecologie. Aix Marseille Université., 2017.

Poher, Y., Ponel, P., Médail, F., Andrieu-Ponel, V. and Guiter, F.: Holocene environmental history of a small Mediterranean island in response to sea-level changes, climate and human impact, Palaeogeography, Palaeoclimatology, Palaeoecology, 465, 247–263, doi:10.1016/j.palaeo.2016.10.037, 2017.

21

Radi, G. and Petrinelli Pannocchia, C.: The beginning of the Neolithic era in Central Italy, Quaternary International, 470, 270–284, doi:10.1016/j.quaint.2017.06.063, 2018.Reille, M.: New pollen-analytical researches in Corsica: the problem of Quercus ilex L. and Erica arborea L., the origin of Pinus halepensis Miller forests, New Phytologist, 122(2), 359–378, 1992.

5   Reille, M., Gamisans, J., Andrieu-Ponel, V. and de Beaulieu, J.-L.: The Holocene at Lac de Creno, Corsica, France: a key site for the whole island, New Phytologist, 141(2), 291–307, 1999.

Sadori, L. and Narcisi, B.: The Postglacial record of environmental history from Lago di Pergusa, Sicily, The Holocene, 11(6), 655–671, 2001.

Smaoui, A.: Bioclimat et Végétation de la Tunisie et des régions prospectées pendant le 12ème ITER Mediterraneum de
10   OPTIMA, Bocconea, 27(1), 13–20, doi:10.7320/Bocc27.1.013, 2015.

Stambouli-Essassi, S., Roche, E. and Bouzid, S.: Evolution de la végétation et du climat dans le Nord-ouest de la Tunisie au cours des 40 derniers millénaires, Geo-Eco-Trop, 31, 171–214, 2007.

Staubwasser, M., Sirocko, F., Grootes, P. M. and Segl, M.: Climate change at the 4.2 ka BP termination of the Indus valley civilization and Holocene south Asian monsoon variability, Geophysical Research Letters, 30(8),
15   doi:10.1029/2002GL016822, 2003.

Tinner, W., Lotter, A. F., Ammann, B., Conedera, M., Hubschmid, P., van Leeuwen, J. F. N. and Wehrli, M.: Climatic change and contemporaneous land-use phases north and south of the Alps 2300 BC to 800 AD, Quaternary Science Reviews, 22(14), 1447–1460, doi:10.1016/S0277-3791(03)00083-0, 2003.

Tinner, W., van Leeuwen, J. F. N., Colombaroli, D., Vescovi, E., van der Knaap, W. O., Henne, P. D., Pasta, S., D'Angelo, S.
20   and La Mantia, T.: Holocene environmental and climatic changes at Gorgo Basso, a coastal lake in southern Sicily, Italy, Quaternary Science Reviews, 28(15–16), 1498–1510, doi:10.1016/j.quascirev.2009.02.001, 2009.

Tinner, W., Vescovi, E., van Leeuwen, J. F. N., Colombaroli, D., Henne, P. D., Kaltenrieder, P., Morales-Molino, C., Beffa, G., Gnaegi, B., van der Knaap, W. O., La Mantia, T. and Pasta, S.: Holocene vegetation and fire history of the mountains of Northern Sicily (Italy), Vegetation History and Archaeobotany, 25(5), 499–519, doi:10.1007/s00334-016-0569-8,
25   2016.

Trigo, I. F., Bigg, G. R. and Davies, T. D.: Climatology of cyclogenesis mechanisms in the Mediterranean, Monthly Weather Review, 130, 549–569, 2002.

Trigo, R. M., Pozo-Vázquez, D., Osborn, T. J., Castro-Díez, Y., Gámiz-Fortis, S., Esteban-Parra, M. J.: North Atlantic oscillation influence on precipitation, river flow and water resources in the Iberian Peninsula, International Journal of
30   Climatology, 24, 925–944, 2004.

Trouet, V., Esper, J., Graham, N.E., Baker, A., Scourse, J.D., and Frank, D.C.: Persistent positive north Atlantic oscillation mode dominated the medieval climate anomaly, Science 324, 78-80, 2009.

Vannière, B., Colombaroli, D., Chapron, E., Leroux, A., Tinner, W. and Magny, M.: Climate versus human-driven fire regimes in Mediterranean landscapes: the Holocene record of Lago dell'Accesa (Tuscany, Italy), Quaternary Science Reviews, 27(11–12), 1181–1196, doi:10.1016/j.quascirev.2008.02.011, 2008.

Vescovi, E., Kaltenrieder, P. and Tinner, W.: Late-Glacial and Holocene vegetation history of Pavullo nel Frignano (Northern Apennines, Italy), Review of Palaeobotany and Palynology, 160(1–2), 32–45, doi:10.1016/j.revpalbo.2010.01.002, 2010a.

Vescovi, E., Ammann, B., Ravazzi, C. and Tinner, W.: A new Late-glacial and Holocene record of vegetation and fire history from Lago del Greppo, northern Apennines, Italy, Vegetation History and Archaeobotany, 19(3), 219–233, doi:10.1007/s00334-010-0243-5, 2010b.

Walker, M. J. C., Berkelhammer, M., Björck, S., Cwynar, L. C., Fisher, D. A., Long, A. J., Lowe, J. J., Newnham, R. M., Rasmussen, S. O. and Weiss, H.: Formal subdivision of the Holocene Series/Epoch: a Discussion Paper by a Working Group of INTIMATE (Integration of ice-core, marine and terrestrial records) and the Subcommission on Quaternary Stratigraphy (International Commission on Stratigraphy), Journal of Quaternary Science, 27(7), 649–659, doi:10.1002/jqs.2565, 2012.

Watson, C. S.: The vegetational history of the northern Apennines, Italy: information from three new sequences and a review of regional vegetational change, Journal of Biogeography, 23(6), 805–841, 1996.

Weiss, H.: 4.2 ka BP Megadrought and the Akkadian Collapse, Oxford University Press., Weiss, H., Oxford., 2017.

Weiss, H., Courty, M.-A., Wetterstrom, W., Guichard, F., Senior, L., Meadow, R. and Curnow, A.: The Genesis and Collapse of Third Millennium North Mesopotamian Civilization, Science, 261(5124), 995–1004, doi:10.1126/science.261.5124.995, 1993.

Yll, E.-I., Perez-Obiol, R., Pantaleon-Cano, J. and Roure, J. M.: Palynological evidence for climatic change and human activity during the Holocene on Minorca (Balearic Islands), Quaternary Research, 48(3), 339–347, 1997.

Zielhofer, C., Fletcher, W.J.,— Mischke, S., De Batist, M., Campbell, J.F.E., Joannin S., Tjallingii, R., El Hamouti, N., Junginger, A., Stele. A., Bussmann, J., Schneider, B., Lauer, T., Spitzer, K., Strupler, M., Brachert, T., and Mikdad, A.: Atlantic forcing of Western Mediterranean winter rain minima during the last 12,000 years, Quaternary Science Reviews, 157, 29-51, 2017.

Zielhofer, C., Köhler, A., Mischke, S., Benkaddour A., Mikdad, A., Fletcher W. J.: Western Mediterranean hydro-climatic consequences of Holocene iceberg advances (Bond events), Climate of the past discussion, https://doi.org/10.5194/cp-2018-97.
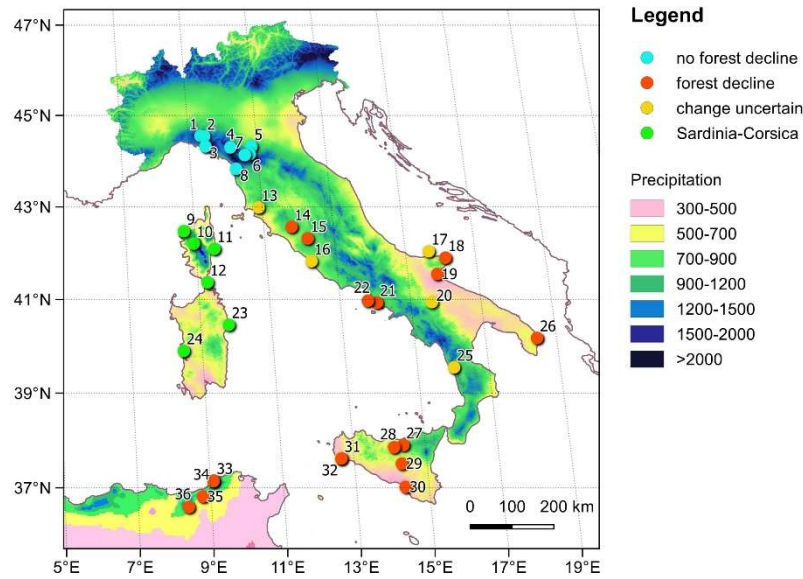
Figure 1: Map of the mean annual precipitation in the central Mediterranean (modified from Attorre et al., 2007, 2008; Benslimane, 2009; Smaoui, 2015; Poher, 2017). Red dots represent the pollen sites selected for this work: 1. Mogge di Ertola: Guido et al., 2013; 2. Lago Riane: Branch, 2013; 3. Lago di Bargone: Cruise et al., 2009; 4. Lago Padule: Watson, 1996; 5. Pavullo nel Frignano: Vescovi et al., 2010a; 6. Ospitale: Watson, 1996; 7. Lago del Greppo: Vescovi et al., 2010b; 8. Lago di Massaciuccoli: Colombaroli et al. 2007; 9. Crovani: Reille, 1992; 10. Creno: Reille et al., 1999; 11. Aleria del Sale: Currás et al., 2017; 12. Greco Pond: Poher et al., 2017; 13. Lago dell'Accesa: Drescher-Schenider et al., 2007; Vannière et al., 2008; 14. Lagaccione: Magri, 1999; 15. Lago di Vico: Magri and Sadori, 1999; 16. Lingua d'Oca-Interporto: Di Rita et al., 2010; 17. RF93-30: Mercuri et al., 2012; 18. Lago Battaglia: Caroli and Caldara, 2007; 19. Lago Salso: Di Rita et al., 2011; 20. Lago Grande di Monticchio: Allen et al., 2002; 21. Lago Patria: Di Rita et al., 2018c; 22. Golfo di Gaeta: Margaritelli et al., 2016; Di Rita et al., 2018b; 23. Sa Curcurica: Beffa et al., 2016; 24. Mistras Lagoon: Di Rita and Melis, 2013; 25. Lago Trifoglietti: Joannin et al., 2012; 26. Lago Alimini Piccolo: Di Rita and Magri, 2009; 27. Urio Quattrocchi: Bisculm et al., 2012; 28. Urgo Pietra Giordano: Tinner et al., 2016; 29. Lago di Pergusa: Sadori and Narcisi 2001; 30. Biviere di Gela: Noti et al., 2009; 31. Gorgo Basso: Tinner et al., 2009; 32. Lago Preola: Calò et al., 2012; 33. Majen el Orbi: Stambouli-Essassi et al., 2007; 34. Majen Ben H'mida: Stambouli-Essassi et al., 2007; 35. Dar Fatma I: Stambouli-Essassi et al., 2007; 36. Djebel Ghorra: Ben Tiba, 1995; Stambouli-Essassi et al., 2007.
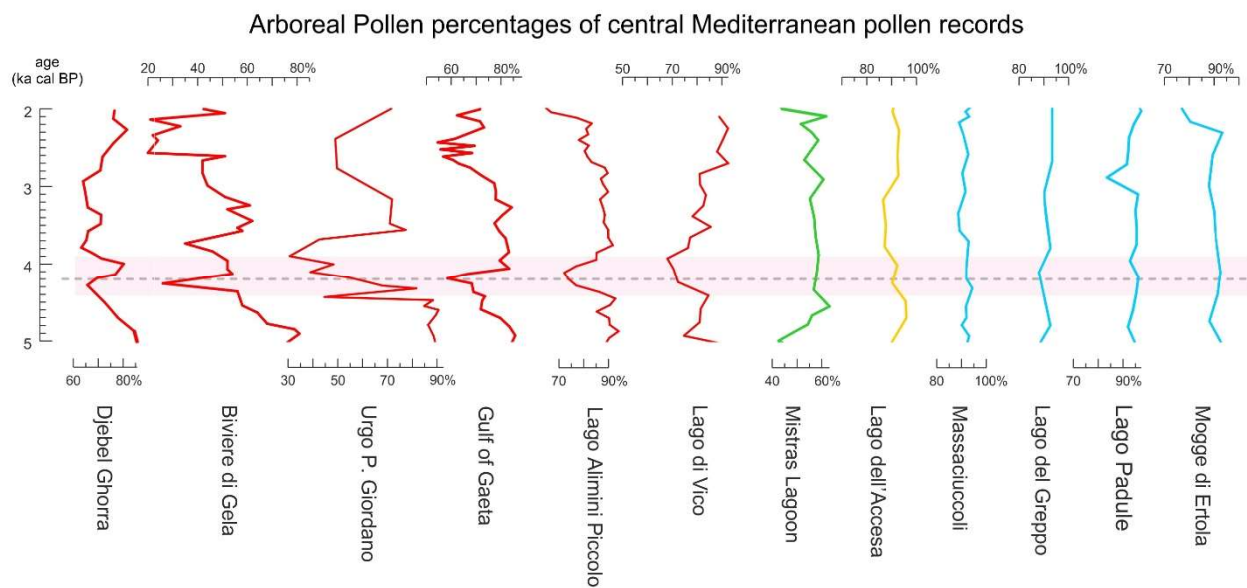
Figure 2: Arboreal Pollen (AP) percentage diagrams of selected sites from the central Mediterranean. The following pollen records have been redrawn from the original publications: Biviere di Gela: Noti et al., 2009; Urgo Pietra Giordano: Tinner et al., 2016; Lago dell'Accesa: Drescher-Schenider et al., 2007; Lago di Massaciuccoli: Colombaroli et al. 2007; Lago del Greppo: Vescovi et al., 2010b; Lago Padule: Watson, 1996; Mogge di Ertola: Guido et al., 2013. The record of Djebel Ghorra (Ben Tiba, 1995) was redrawn from Stambouli-Essassi et al., 2007. The records from the Gulf of Gaeta (Di Rita et al., 2018b), Lago Alimini Piccolo (Di Rita and Magri, 2009), Lago di Vico (Magri and Sadori, 1999), and Mistras Lagoon (Di Rita and Melis, 2013) were analysed by the authors.

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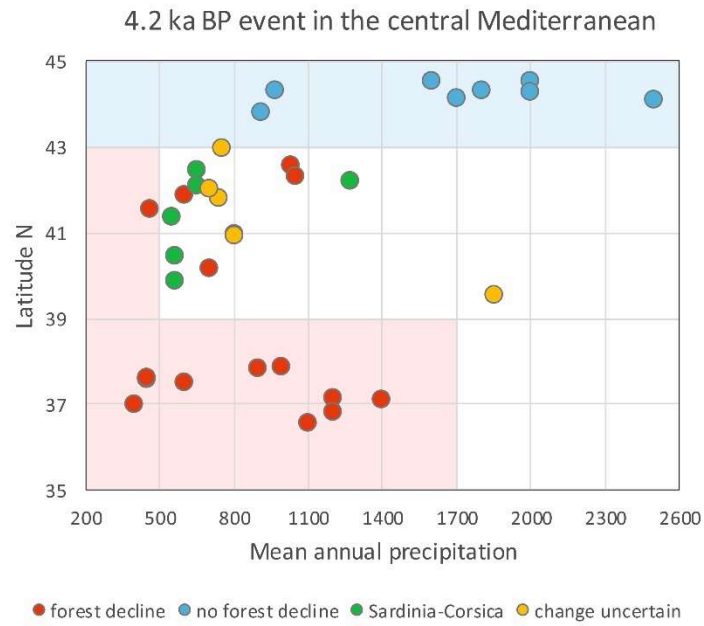
Figure 3: The latitude of the pollen records from the central Mediterranean is plotted against the respective mean annual precipitation. Red dots represent the pollen sites where a deforestation is clear during the 4.2 ka BP event, blue dots represents sites where there is no deforestation at 4.2 ka BP; green dots represents sites from Corsica and Sardinia, where there is a compositional change of vegetation, but no overall deforestation; yellow dots represent sites showing unclear vegetation changes around 4.2 ka.

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