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Climate of the Past Discussions

Interactive comment on "The 4.2 ka BP event in the vegetation record of the central Mediterranean" *by* Federico Di Rita and Donatella Magri

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Reply to reviewer #1:

We really appreciate Willy Tinner's comments. In most cases we completely agree with him. In particular, we have addressed his comments as follows:

COMMENT: The authors address the effects of the 4.2 ka BP event on forest structure and vegetation composition by using pollen records as proxy for vegetation change. The topic is interesting and timely and suited for discussion in Climate of the Past. The paper concentrates on well-established tools, concepts and ideas and the conclusions reached are interesting.

REPLY: Thanks for the appreciation.

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COMMENT: However the scientific methods used and assumptions made are not always valid. In particular pollen-independent evidence of rapid and/or strong climatic change at 4.2 ka BP is not sufficiently developed or considered. This proxy deficiency leads to interpretations and conclusions that are not fully supported by the results. Thus, the paper could be markedly improved by developing and considering independent data and literature, especially on palaeoclimatic evidence, processes and mechanisms that may have affected the response of past vegetation.

REPLY: Our paper is not focused on palaeoclimate changes and underlying mechanisms, but is aimed to highlight possible geographical patterns in vegetation changes during the 4.2 ka BP event. To that purpose, we have compared the drops in AP percentages with totally independent data, that is latitude and modern mean annual precipitation of the pollen sites. We have also added comparison with the independent speleothem records from Italy.

COMMENT: Similarly the effects of prehistoric land use on vegetation change need to be considered more carefully. In summary, to investigate the effects of the 4.2 ka BP event on vegetation the most important move is the disentanglement of climatic and human effects, this can be reached by providing (at least) three independent lines of evidence (climate, land use, vegetation change).

REPLY: In order to avoid a subjective interpretation of prehistoric land use on vegetation, we have carefully reported for each selected pollen site the independent interpretation provided in the original publication.

COMMENT: 1) The introduction identifies the 4.2 ka BP as a drought event in the Mediterranean and neighboring areas. This may apply for the eastern realm, while in the western realm recent evidence points to humid conditions (e.g. in Morocco and Spain, Zielhofer et al., 2018) or at least to inhomogeneous moisture change patterns. Thus, to assess conditions in the central Mediterranean, it is important to show the available paleoclimatic evidence in regard to this particular Holocene climatic event.

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Here the authors should significantly improve the coverage of available palaeoclimatic non-pollen data from the central Mediterranean by considering key studies such as e.g. Drysdale et al. (2006), Giraudi et al. (2011); Zanchetta et al. (2013, 2016) and Curry et al. (2016). A procedure to identify the magnitude and direction of the 4.2 ka BP event in the central Mediterranean is particularly needed in the introduction and discussion, where the evidence and nature of the 4.2 ka BP event is elaborated. Because of potential synchronisms between European climate and cultural change it is crucial to carefully identify the triggers of vegetation change and to avoid using pollen (e.g. arboreal pollen, AP) as a proxy for climate change.

REPLY: In our manuscript we have made clear that "this palaeovegetational event is more or less coeval to the drought event that has been recognized in the eastern Mediterranean regions ..." [page 11, line 26-] and that "The 4.2 climate event, corresponding to Bond event 3 and 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)" [p 11. L. 22]. Anyway, as suggested, we have added reference to pollen-independent data from the Mediterranean, which has been reviewed in detail in a recently published paper on the 4.2 cal BP in the same special volume of Climate of the Past (Bini et al., 2018).

COMMENT: Sentences such as ": 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 geographical pattern of the opening of forests in the central Mediterranean, which is clearly connected to the 4.2 ka PB 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" illustrate that, without providing first the non-pollen evidence of climate change and addressing the strength of the linkage between opening of vegetation and climate in the study

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region, such a reasoning may appear circular.

REPLY: In the above-mentioned sentence we do not refer to climate change but to a progressive vegetation change, which is correctly inferred from pollen analysis (no circular reasoning!). The progressive northward displacement of the north African high-pressure cell is an hypothesis.

COMMENT: The authors may provide more details on the nature of the underlying proxies, when aridity or humidity is mentioned throughout the text (e.g. in the results section: what is the pollen-independent evidence for stating “an overall decrease in woody taxa, and a contemporary remarkable development of Apiaceae, accompanied by high amounts Poaceae; related to arid climate conditions”?; or e.g. what is the basis for inferring increased precipitation in “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”?).

REPLY: In the above-mentioned sentences we quote the original publications of the pollen records. In the case of the remarkable development of Apiaceae, Stamboulli-Esassi et al. (2007) write: “En cours de période s’intercale, ca. 4000 B.P., une phase sèche de grande intensité provoquant un recul important de tous les taxons ligneux au profit d’une extension maximale du milieu ouvert herbacé”. Concerning the climate in Liguria, Branch (2013) writes that “there is good evidence to suggest that the Early Bronze Age in Liguria coincided with a period of rapid climate change, characterised by higher summer precipitation, and probably colder winters (the ‘4.2 ka event’; Magny et al. 2007, 2009b)”. In these cases, we use the independent interpretations of the different authors that studied the mentioned pollen records.

COMMENT: 2) The archaeological evidence for assessing the anthropogenic impact should be discussed. The time around 4.2 ka BP (ca. 2200 cal. BC) marks the onset of the Bronze Age in Europe. In the central Mediterranean the transition from Late Neolithic or Chalcolithic cultures (e.g. Bell Beaker) to metallurgic communities is dated

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at 4.5-4.2 ka BP (ca. 2500-2200 cal. BC), with paramount impacts on ecosystems and vegetation (e.g. marked openings of forests, establishment of first continuous records of anthropogenic indicators; Tinner et al., 2003; Carrion et al., 2010; Burjachs et al., 2017). Therefore, a careful attribution of forest opening solely to climate also requires the falsification of the alternative human-impact hypothesis. This hypothesis assumes that the opening of forests at the study sites were caused by an important and synchronous change in European and central Mediterranean human cultures at 4.5-4.2 ka BP, when first Bronze tools were introduced. Indeed, synchronous and repeated culturally-triggered openings of forests have been inferred for an area spanning from Sicily to the Alps and 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)."

REPLY: We have included these comments in the introduction. However, we have omitted mentioning the Bell Beaker culture, as it was distributed in Germany, British Islands, Iberian Peninsula, but was very marginal in the central Mediterranean. Besides we have added that the suggested reference Burjachs et al. (2017) points to a climatic rather than human cause for the 4.2 ka BP opening of vegetation in the Balearic Islands.

COMMENT: Given the pattern of vegetation change observed by the authors in the central Mediterranean (increasing opening of forests towards south), a reasonable and parsimonious explanation is that ecosystems and vegetation were less resilient to human disturbance with increasing summer heat and (resulting) summer drought along a north-south gradient. An inverse relationship as advocated by the authors such as humans benefitting from arid conditions is highly unlikely given that in the Mediterranean, agriculture is limited by drought (Zanchetta et al., 2013). Moreover, at the onset of the Bronze Age, humans were able to successfully conduct agriculture and open forests under very wet but warm conditions south of the Alps (under mean annual precipitation > 1500 mm, summer precipitation > 600 mm, mean July temperatures ca. 22_C, e.g.

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Tinner et al., 2003).

REPLY: We thank the reviewer for this comment, which gives us the occasion to point out that agriculture started in arid regions characterized by open vegetation (the Levant and Middle East) and was introduced in temperate areas characterized by forest vegetation (e.g. the Balkan Peninsula and central Europe) only in the following millennia. All the same, in Italy, agriculture started in Sicily and Apulia (the most arid regions of the Peninsula) and spread in northern Italy only several centuries later (Natali and Forgia, 2018; Radi and Petrinelli Pannocchia, 2018). We agree that ecosystems and vegetation were less resilient to human disturbance with increasing heat and drought along a north-south gradient and have added this point in the discussion.

COMMENT: 3) A third major issue to be fixed concerns the attribution of climate change and vegetation responses to NAO "forcing". NAO is primarily a winter pattern of atmospheric circulation variability (Bonaccorso et al., 2015), not a climate mode or even more dubious, a climate forcing. Therefore statements such as e.g. in the introduction "the climate-sensitive position of this region, located at the interface between two large continents (Europe and Africa) and subject to climate forcing from both the North Atlantic Oscillation NAO and" should be avoided. Instead of being a forcing itself, the high-frequency seasonal NAO atmospheric pattern may emerge through e.g. volcanic forcing (Ortega et al., 2015). Moreover, being primarily a winter seasonal atmosphere pressure pattern it has no clear link to climatic (i.e. multi-decadal) summer aridity, although winter drought might be associated to NAO patterns at quasi-decadal scales (Hurrell and VanLoon, 1997). Instead, summer aridity would be needed to explain forests collapse in response to dry conditions. A debated and weak summer counterpart to the NAO is the Summer North Atlantic Oscillation (SNAO; Schubert et al., 2016), the correlations here between atmospheric patterns and summer precipitations are weak and the pattern restricted to sites north of 40_N (Blade et al., 2012). A general attribution of multi-decadal periods with dry summers to NAO patterns (and SNAO south of 40 _N) is thus inappropriate. Moreover, unambiguously linking palaeoclimatic

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(winter) variability to NAO variability requires annual resolutions and precisions (Mischel et al., 2015; Ortega et al., 2015), conditions which are almost impossible to reach for the Holocene and certainly do not apply to the study sites summarized by the authors. Taken together, on the basis of the mismatch of seasonal and temporal scales, associating multi-decadal (summer) drought phases with seasonal NAO atmospheric winter patterns remains inappropriate, even if previously done in the Holocene palaeoclimatic literature, as e.g. cited by the authors. Overall, the link between large scale modes of variability such as NAO and drought is still unclear (Schubert et al., 2016), if climate forcing is of interest here, then the authors may refer to summer patterns potentially linked to reduced precipitation (e.g. high-pressure field anomalies over the Mediterranean realm) and their potential multi-decadal forcings (e.g. solar forcing, volcanic forcing, thermohaline circulation).

REPLY:In our text, we have never mentioned summer aridity as a possible cause for forest decline, as evergreen forest may decline also due to winter aridity. Thus, we think we do not need to correct this issue, which is not exactly related to our main purpose, that is to find a geographical pattern for the 4.2 forest decline in the central Mediterranean. Concerning the NAO pattern, we have changed the term “forcing”, as suggested, and deleted some sentences concerning the NAO. However, we cannot deny that NAO variability is a most important atmospheric pattern influencing precipitation variability in the central Mediterranean. Persistent positive/negative NAO phases provide a dynamical explanation of climate variability even at a centennial scale, as discussed in a wide scientific literature (e.g., Trouet et al., Science 324: 78-80; 2009; Magny et al., Clim. Past, 9: 2043–2071, 2013; Zielhofer et al., Quaternary Science Reviews 157: 29-51, 2017).

COMMENT: A) At Pavullo (Vescovi et al., 2010) charcoal-inferred regional fire activity peaked at around 4200 cal BP, together with an increase of human indicators such as Cerealia type, forest opening had started at ca. 5000 cal BP and remained substantial until and after 4200 cal BP, please mention in the result section of this site.

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REPLY: Changed as suggested

COMMENT: B) At Lago di Massaciuccoli (Colombaroli et al., 2007) charcoal-inferred regional fire activity is at a minimum at ca. 4500-3000 cal BP with no signs of human activity, please mention in the result section of this site.

REPLY:Changed as suggested

COMMENT: C) At Sa Curcurica (Beffa et al., 2016) the increase in anthropogenic indicators (e.g. Plantago lanceolata-type, Cerealia-type but no Juglans) around 4500 cal BP coincided with a charcoal-inferred increase of regional fire activity, please correct and mention in the result section of this site.

REPLY: We have checked once again: at Sa Curcurica Plantago lanceolata-type and Cerealia-type do not increase at 4500 cal. BP. We have added the charcoal-inferred increase of regional fire activity as suggested.

COMMENT: D) The onset of a huge forest opening at Urio Quattrocchi (Bisculm et al., 2012) is dated at ca. 5000 cal BP, by 4200 cal BP the forests were already recovering since about ca. 400 years to be fully restored at ca 3400 cal BP: how should such forest dynamics be connected to the 4.2 ka BP event? Please explain. On the other hand openings are related to human impact and fire increase caused by land use.

REPLY: In our manuscript this vegetation dynamics is correctly described, in agreement with the comments of the reviewer: “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.” We have corrected that the woody taxa were fully restored at ca. 3.4 ka BP (AP>80%)”. As we discuss later in the paper, this dynamic is related to the 4.2 ka BP event because the vegetation change over the Mediterranean is time-

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transgressive, occurring before 4.2 ka BP in the most southern regions and after 4.2 in central Italy.

COMMENT: E) At Biviere di Gela (Noti et al., 2009) the strong opening of forests at ca. 4300 cal BP is recorded just in one sample, there again it coincides with a strong increase in anthropogenic indicators such as Plantago lanceolata-type and in charcoal-inferred regional fire activity, please mention in the result section of this site.

REPLY: Changed as suggested

COMMENT: F) At Urgo Pietra Giordano (Tinner et al., 2016) the forest opening at the onset of the Bronze Age ca. 4400-3700 cal BP was again connected to increased charcoal-inferred fire activity and regular presence of human-impact indicators. Please mention in the result section of this site.

REPLY: We have mentioned the peaks in microcharcoal around 4.5 and 3.9 ka BP, as suggested

COMMENT: G) At Gorgo Basso (Tinner et al., 2009) and Preola (Calò et al., 2012) pollen independent quantitative palaeo-salinity reconstructions do not show any significant drying at around 4200 cal. BP (Curry et al., 2016), if compared to the past ca. 4500 years. In agreement with lake-level reconstructions (Magny et al., 2011) they suggest, however, that salinity was lower in the preceding ca. 1000-2000 years (ca. 4500-6000 cal BP). Please mention in the result sections of these sites and address the implications of this finding.

REPLY: Changed as suggested

COMMENT: Concluding remark: Federico Di Rita and Donatella Magri describe the spatial extent of an interesting vegetational pattern that occurred ca. around ca. 4200 years ago in the central Mediterranean. On the basis of the available palaeoecological data it is impossible to assign the opening of the forest vegetation in the Central Mediterranean to human or climate impact alone. Increasing forest openings from

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north to south are explainable by the increasing sensitivity of Mediterranean forest vegetation to human and/or drought disturbance along a summer-heat and summer-moisture gradient.

REPLY: We completely agree, although it is questionable whether summer or winter moisture gradient are more important.

COMMENT: It is highly unlikely that increasing drought would have advantaged agriculture south of 39âŰęN under summerdry conditions.

REPLY: we have discussed above that agriculture started in semiarid areas south of 39°N.

COMMENT: Finally, on the basis of the presented results it is unclear if south of 39âŰęN and west of 20âŰę E, the 4.2 cal BP event was characterized by dry or moist conditions (Curry et al., 2016; Zielhofer et al., 2018). Answering this question will require new high-resolution and pollen-independent palaeoclimatic records.

REPLY: we agree. More work is needed to define past climate conditions and mechanisms.

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