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

W. Tinner (Referee)

willy.tinner@ips.unibe.ch

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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. 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. 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). The following comments should be addressed and the text refined accordingly, before final acceptance.

Specific comments

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. 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.

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 region, such a reasoning may appear circular. Specifically, to avoid such an impression, 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”?).

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 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). 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. Tinner et al., 2003).

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 (winter) variability to NAO variability requires annual resolutions and precisions (Mis-

chel 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).

Minor comments

Regarding selected sites (just from own research, but please check other sites in regard to similar issues):

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.

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.

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.

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.

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.

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.

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.

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 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. It is highly unlikely that increasing drought would have advantaged agriculture south of 39°N under summer-dry conditions. Finally, on the basis of the presented results it is unclear if south of 39°N and west of 20° 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.

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