Author's response to anonymous Reviewer#2 - "Holocene aridification trend interrupted by millennial- and centennial-scale climate fluctuations from a new sedimentary record from Padul (Sierra Nevada, southern Iberian Peninsula)"

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Firstly, we would like to thank anonymous reviewer#2 for his/her comments and constructive suggestions, which will improve the manuscript, and for recommending this study for publication in Climate of the Past. Please find enclosed point by point responses to the comments.

The referee suggestions and comments are displayed in black, and our answers in blue. We marked the lines over the MS that we are going to modify and we show the modifications (in inverted commas). In the case that we do not follow the reviewer suggestions we discuss the reasons.

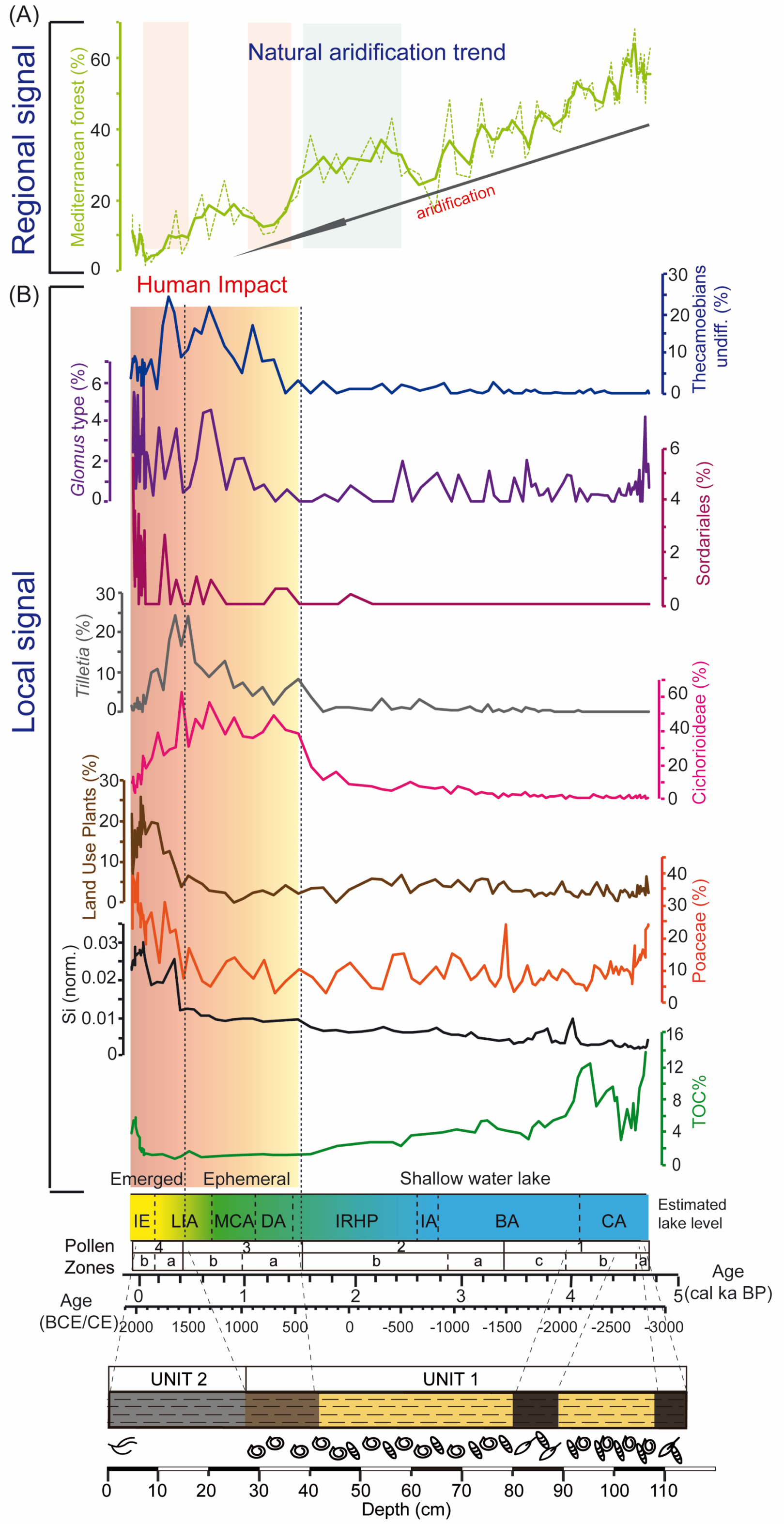
General

This manuscript is quite interesting, bringing lights on a period not yet explored in this notorious site and worthy to be published. Nevertheless I suspect the authors to partly over-interpret their datasets in order to demonstrate that they confirm a model of late-Holocene climate changes identified in other western Mediterranean sites (reinforcement syndrom). Here are my remarks along the text:

Conclusion: A further study on the micro charcoal could trace the rhythms in aridification (or land-use). I invite the authors to clarify some elements of their demonstration.

Thanks for your suggestions. In this study we found a linear increasing trend in deforestation very similar to the decrease in insolation and we do not find clear evidences (with any of the studied proxies) of humans impacting the area until the last ca. 1500 years so we cannot really assume that humans were also contributing to that decrease in forest species in the area. Therefore we related that deforestation mostly to climate. In addition, there seems to be a correlation of our record with global climate variability, which also supports our suggestion.
In the new version of the manuscript we inserted a new figure 8 (see below) trying to clarify and separate natural vs. anthropic signals. Considering the importance of human activity in the area, notably in the top part of the sedimentary record, we changed the title for "Holocene aridification trend and human impact interrupted by millennial- and centennial-scale climate fluctuations from a new sedimentary record from Padul (Sierra Nevada, southern Iberian Peninsula)".

The suggestion of including the charcoal analysis from this sediment record to this manuscript is a great idea but this is the Masters thesis study that Cole Webster is carrying out at present under supervision of R. Scott Anderson at NAU, Arizona, USA. So even if we understand how important is to have a fire-proxy record to compare with the vegetation and sedimentation dynamics we do not have these data yet.



This is new Figure 8 that includes the Mediterranean forest, which we believe is mostly a regional climate proxy, and local human activity indicators such as cultivars (land use plants), fungi related with grain cultivation (Tilletia), livestock occurrence (most likely Thecamoebians, Cichoroideae, see text) and soil erosion (Si, TOC, Glomus). Note the time when we have evidences of humans shaping the environment at ca. 1500 cal yr BP. Previously to that period there does not seem to be clear evidences of human impact in the area.

Comments

1/ Study site: the information on the geological context (lines: 127-133) could be (at least partly) presented before the short description of the regional vegetation.

Ok, this is a good idea. We moved the part of the specific vegetation description from Padul right after the geological setting so it reads better.

Now it says:

"The Padul basin is situated at approximately 725 m of elevation in the southeastern part of the Granada Basin, at the foothill of the southwestern Sierra Nevada, Andalucía, Spain (Fig. 1). This is one of the most seismically active areas in the southern Iberian Peninsula with numerous faults in NW-SE direction, with the Padul fault being one of these active normal faults (Alfaro et al., 2001). It is a small extensional basin approximately 12 km long and covering an area of approximately 45 km^2, which is bounded by the Padul normal fault. The sedimentary in-filling of the basin consists of Neogene and Quaternary deposits; Upper Miocene conglomerates, calcarenites and marls, and Pliocene and Quaternary alluvial sediments, lacustrine and peat bog deposits (Sanz de Galdeano et al., 1998; Delgado et al., 2002; Domingo et al., 1983). Vegetation in the Padul area is dominated by *Q. rotundifolia* (and in less amounts *Q. faginea*), which is normally accompanied by *Pistacia terebinthus*. Shrub species in the area include *Juniperus oxycedrus*, *Crataegus monogyna*, *Daphne gnidium* and *Ruscus aculeatus*. Creepers such as *Lonicera implexa*, *Rubia peregrina*, *Hedera helix*, *Asparagus acutifolius* also occur in this area and some herbs, such as *Paeonia broteroi*. *Quercus coccifera* also occurs in crests and very sunny rocky outcrops. *Retama sphaerocarpa* and *Genista cinerea* subsp. *speciosa* and the *Thymo-Stipetum tenacissime* series also occur in sunny areas and in more xeric soils. Nitrophilous communities occur in soils disrupted by livestock, pathways or open forest, normally related with anthropization (Valle, 2003).

The Padul peat bog is an endorheic area with a surface of approximately 4 km^2 placed in the Padul basin that contains a sedimentary sequence mostly characterized by peat. The basin fill is asymmetric, with thicker peat infill to the northeast (~100 m thick; Domingo-García et al., 1983; Florschütz et al., 1971; Nestares and Torres, 1997) and disappearing to the southwest (Alfaro et al., 2001). The main source area of the sediments in the Padul peat bog is Sierra Nevada, which is characterized at higher elevations by Paleozoic siliceous metamorphic rocks (mostly mica-schists and quartzites) from the Nevado-Filabride complex and, at lower elevations and acting as bedrock, by Triassic dolomites, limestones and phyllites from the Alpujárride Complex (Sanz de Galdeano et al. 1998). Geochemistry in the Padul sediments is influenced by detritic materials coming from the neighboring mountains, mainly the Sierra Nevada mountain range (Ortiz et al., 2004). In addition, groundwater inputs into the Padul basin are the main reason why there is a wetland in this area. These inputs come from the Triasic carbonates aquifers (N and S edge to the basin), the out flow of the Granada Basin (W) and the conglomerate aquifer to the east edge (Castillo Martín et al., 1984; Ortiz et al., 2004). The main water output is by evaporation and evapotranspiration, water wells and by canals ("madres") that drain the water to the Dúrcal river to the southeast (Castillo Martín et al., 1984). Climate in the Padul area is characterized by a mean annual temperature of 14.4 ºC and a mean annual precipitation of 445 mm (http://www.aemet.es/). The Padul-15-05 drilling site was located around 50 m south of the present-day Padul lake shore area. This basin area is presently subjected to seasonal water level fluctuations and is principally dominated by *Phragmites australis* (Poaceae). The lake environment is dominated by aquatic and wetland communities with *Chara vulgaris*, *Myriophyllum spicatum*, *Potamogeton pectinatus*, *Potamogetum coloratus*, *Phragmites australis*, *Typha dominguensis*, *Apium nodiflorum*, *Juncus subnodulosus*, *Carex hispida*, *Juncus bufonius* and *Ranunculus muricatus* between others (Pérez Raya and López Nieto, 1991). Some sparse riparian trees occur in the northern lake shore, such as *Populus alba*, *Populus nigra*, *Salix* sp., *Ulmus* minor and *Tamarix*. At Present *Phragmites australis*, lands bordering the lake are cultivated and the main crops are wheat (*Triticum* spp.) and other species of Poaceae, *Prunus dulcis* and *Olea europea*."

The description of the "vegetation in the Padul area" (line 194) seems to concern potential vegetation as, looking on “google earth” I observe that the surrounding of the site is on large almost totally cultivated: this agricultural activity (and maybe its historical) could be described. Concerning the vegetation on and around the lake, the floristic list, is a description of different assemblages possible? One of them could constitute a modern analogue to the pollen spectra in PAZ 3 and 4a? *Study site:*

Ok, we believe that the reviewer refers to line 154 - about the “vegetation in the Padul area”. The Padul area was cultivated since historical times as we indicated in the text (line 640-641). We agree with the reviewer that this information could be better presented and we added some more information about the agricultural activities in the Padul area at Present (see modification in answer to question 1). The species cultivated in the past might have changed through time but there are not historical records available for a deep review and our pollen data could provide with a clearer image of what happened in the past. See modifications in section of “human activities” concerning Cichorioideae and other nitrophilous taxa that could have possibly related with livestock or agricultural activities.

Now it says:

Line (627 Human activities section): “This is deduced by a significant increase in nitrophilous plant taxa such as Cichorioideae, Convolvulaceae, Polygonaceae and *Plantago* and the increase in some NPP such as *Tilletia*, coprophilous fungi and thecamoebians (Unit 2; Pollen Zone 4; Fig. 4). Most of these pollen taxa and NPPs are described in other southern Iberian paleoenvironmental records as indicators of land uses, for instance, *Tilletia* and covarying Cichorioideae have been described as indicators of farming (e.g. Carrión et al., 2001b). Thecamoebians undiff. also show a similar trend and have also been detected in other areas being related to nutrient enrichment as consequence of livestock (Fig. 8). The stronger increase in Cichorioideae have also been described as indicators of animal grazing in areas subjected to intense use of the territory (Mercuri et al., 2006). Interestingly, these taxa began to decline around ca. 400 cal yr BP (~1550 CE), coinciding with the higher increase in detritic material into the basin. We could then interpret this increase in Cichorioideae by higher livestock activity in the surroundings of the lake during this period, which is supported by the increase in these other proxies related with animal husbandry. ”

Line (638): “This higher increase in detritic material occurred during an increase in other plants related with human land uses such as Polygonaceae, Amaranthacea, Convolvulaceae, *Plantago*, Apiaceae and Cannabaceae-Urticaceae type (Land Use Plants; Fig. 8) and the increase in Poaceae.”

A paper by Pons and Reille (1988) mentions a peat exploitation: It would be of interest to know the connection between this exploitation and its potential impact on the lake beside the coring point.

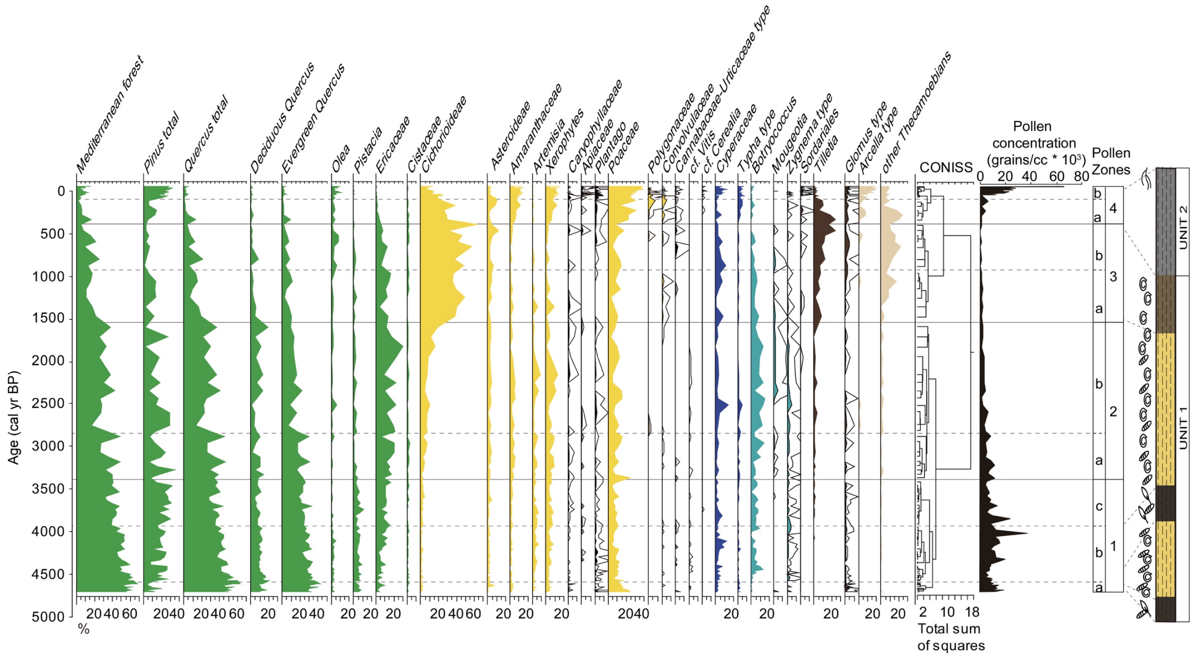
We do not quite understand the question. The Padul-15-05 core was drilled nearby but outside the peat exploitation area, and thus in a different location than the previous cores (e.g. Pons and Reille 1988; Ortiz et al., 2004) that were taken directly from the peat mine. This is the reason why the first (Late Holocene) part of the sediment record was not previously studied as it was lacking from that area. This information is given in lines 79-83.

2/ Line 218: Lycopodium tablets are mentioned here but the changes in pollen concentrations not discussed later? It would be of interest to know if the transition from unit 1 to Unit 2 is marked by a major change in pollen concentrations?

Yes, thank you for the suggestions. We inserted the pollen concentration in the text and pollen diagram (Fig. 4). As you indicated a decrease in pollen concentration occurred in the transition from Units 1 and 2, which could be explained by the decrease in organic matter from a shallow water lake to an ephemeral environment.

Modification in the text (line 269-270): “Four pollen zones (Fig. 4) were visually identified with the help of a cluster analysis using the program CONISS (Grimm, 1987). Pollen concentration was higher during Unit 1 with a decreasing trend in the transition to Unit 2 and a later increase during the pollen subzone 4b. Pollen zones are described below:"

Figure 4:



3/ Line 220: It would be of interest to mention the state of preservation of the pollen grains as far as some authors (Bottema) suggested that a high amount of the very resistant grains of Cichorioideae coud be due to a differential destruction of pollen grains.

That is a good question. We also firstly thought the idea of a major degradation in the pollen during this arid period. However, other proxies such as the increase in other nitrophilous plants and other NPP as *Tilletia* (covarying with Cichorioideae) are indicative of livestock or agricultural activities. In addition, a decrease in this taxon happened since ca. 1500 CE when an increase in clastic material occurred, not supporting a preservation issue.

To clarify this we modified the text between lines (502):

"…Algae component and higher Si and MS and lower TOC values (Unit 1; Figs. 6 and 7). Humans probably also contributed to enhancing deforestation and erosion in the area during this last ca. 1550 cal yr BP. The significant change during the transition from Unit 1 to Unit 2 with a decrease in the pollen concentration and the increase in Cichoroideae could also be due to enhanced pollen degradation as Cichoroideae have been found to be very resistant to pollen deterioration (Bottema, 1975). However, the occurrence of other pollen taxa (e.g. *Quercus*, Ericaceae, *Pinus,* Poaceae, *Olea*) showing climatic trends and a maximum between ca. 1500-400 cal yr BP and a decrease in this taxon in the last ca. 400 cal yr BP when an increase in clastic material occurred, do not entirely support a preservation issue (see section of Human activity; 5.4)."

4/ Line 269 (fig. 4). It would be of interest to recall the lithology beside the pollen zones (even if the scale refers to ages).

Ok, this is a good idea. We added the lithology to the pollen diagram (Fig. 4).

5/ Line 288: this increase in Mediterranean forest types is far to be evident!

Thank you, we modified this line. Now it says: "The principal characteristics that differentiate these subzones is marked by the increasing trend in deciduous *Quercus* and Ericaceae".

6/ lake level, lines 322-331: At a time when human impact is evident together with a high minerogenic influx it is difficult to decide if it is a lake level lowering or simply an infilling.

What we are seeing in this record is a progressive trend in somerization of the lake environment and that is the reason we believe it is mostly due to lake level lowering. In the discussion we explain the environmental evolution of the shallow water lake to an ephemeral lake and then to an emerged environment (line 396-403) with a maximum in clastic and MS values in the last ca. 400 cal yr BP.

To clarify this we modified the text between lines 396-403: "This natural progressive aridification is confirmed by the increase in siliciclastics pointing to a change towards ephemeral (even emerged) environments and became more prominent since the last ca. 1550 cal yr BP and then enhanced again in the last ca. 400 cal yr BP to Present. *Glomus*, a spore from mycorrhizal fungi that occur in soils (van Geel et al., 1989), follows a similar pattern of change, which probably points to enhanced soil erosion in the catchment area related with the decrease in forest in the surroundings during the last 1550 cal yr BP. A clear increase in human land use is also observed during the last 1500 cal yr BP (see below), which shows that humans were at least partially responsible for this sedimentary change."

7/ discussion p.9,

Line 58-360: it could simply mean that Bothryococcus greatly suffers in ephemeral lakes

Yes, for this reason we calculated two different correlations of *Botryococcus* with temperature record from Bond et al (2001): one for the total record and another for only the first (oldest) part, during the deeper shallow water lake phase, where we appreciated a higher correlation.

Line 373: clastic input could simply be linked with increasing land use in the catchment leading to more active erosion!

Yes, we agree with the reviewer, but in this sentence we are talking about the interpretation of variation in detritics in lake environments without any human disturbances – we specified this in the text. Later on, in the discussion, we try disentangling the natural vs. human-induced causes for enhanced erosion, which is sometimes difficult and that is why we give some possible explanations (natural vs human induced).

To clarify this we add more information in the text Line 387: "Nevertheless, in natural environments with potential interactions with human activities the increase in clastic deposition related with other indications of soil erosion (e.g. *Glomus sp.*) may be assigned to intensification in land use (Morellón et al., 2016; Sadori et al., 2016)."

Line 377: it would be of interest to connect this evidence with local historical and archaeological data on the land use around the site across time.

That would be great, however there is a lack of published historical records from the area for a deep review.

Line 492: this increase in Bothryococcus starts quite at least 500 years before the beginning of IRHP: the argument is faint.

The increase in *Botryococcus* started around ca. 3.1 cal ka BP with an increasing trend towards a higher water lake reaching a *Botryococcus* maximum during the IRHP.

Line 506: Cichorioideae! First try to identify the ecosystem (or the disturbance) which generates this incredible amount of Cichorioideae!

We agree that some further discussion must be added about this matter. See answer to question 1 and

3.

Line 603: I am not a statistician but I am afraid by this suggestion of periodicity bases on honest but rather low pollen and algae counts (260 terrestrial).

We are aware of the limited amount of terrestrial pollen counted, however the data show clear cyclical patterns that are not random and are statistically sound (above confidence levels). These results are confirmed by replication of the same patterns through statistical treatments in the TOC%. Therefore we are quite confident that these results are not an artifact.

Line 618: human impact; my feeling is that a part of the information provided here could be included in the initial presentation of the site.

Yes, we agree and included some Human impact information in the initial presentation of the site (see answer to questions 1).