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Corrigendum to “Pollen-based paleoenvironmental and paleoclimatic change at Lake Ohrid (south-eastern Europe) during the past 500 ka” published in Biogeosciences, 13, 1423–1437, 2016

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Abstract. In this corrigendum we report an updated pollen record from the Lake Ohrid DEEP site spanning the past 500 ka whereby we have reprocessed and re-analyzed 104 samples affected by chemical procedure problems that occurred in one palynological laboratory. Firstly, these samples were affected by the use of wrong containers, causing inadequate settling of particles at the set centrifuging speed. Secondly, HCl and HF treatments were combined without the prescribed intermediate centrifuging and decanting steps. The inaccuracy in the protocol resulted in the loss of smaller pollen grains and in the overrepresentation of bisaccate ones in most of the re-analyzed samples. We therefore provide an updated set of figures with the new data and have revised the description of the results, discussion and conclusions reported in Sadori et al. (2016) where necessary. We stress that the majority of the original results and conclusions remain valid, while the records’ reliability and resolution have improved as 12 samples that had been omitted in the original study because of low count sums are now included in the revised dataset (Sadori et al., 2018).

1 Introduction

Lake Ohrid is situated in the Balkan Peninsula (southeastern Europe). The Scientific Collaboration on Past Speciation Conditions in Lake Ohrid (SCOPSCO) international science team carried out a deep drilling campaign in spring 2013 within the framework of the International Continental Scientific Drilling Program (ICDP). The first results of the campaign focusing on the past 500 ka have been reported in a special volume (see the overview in Wagner et

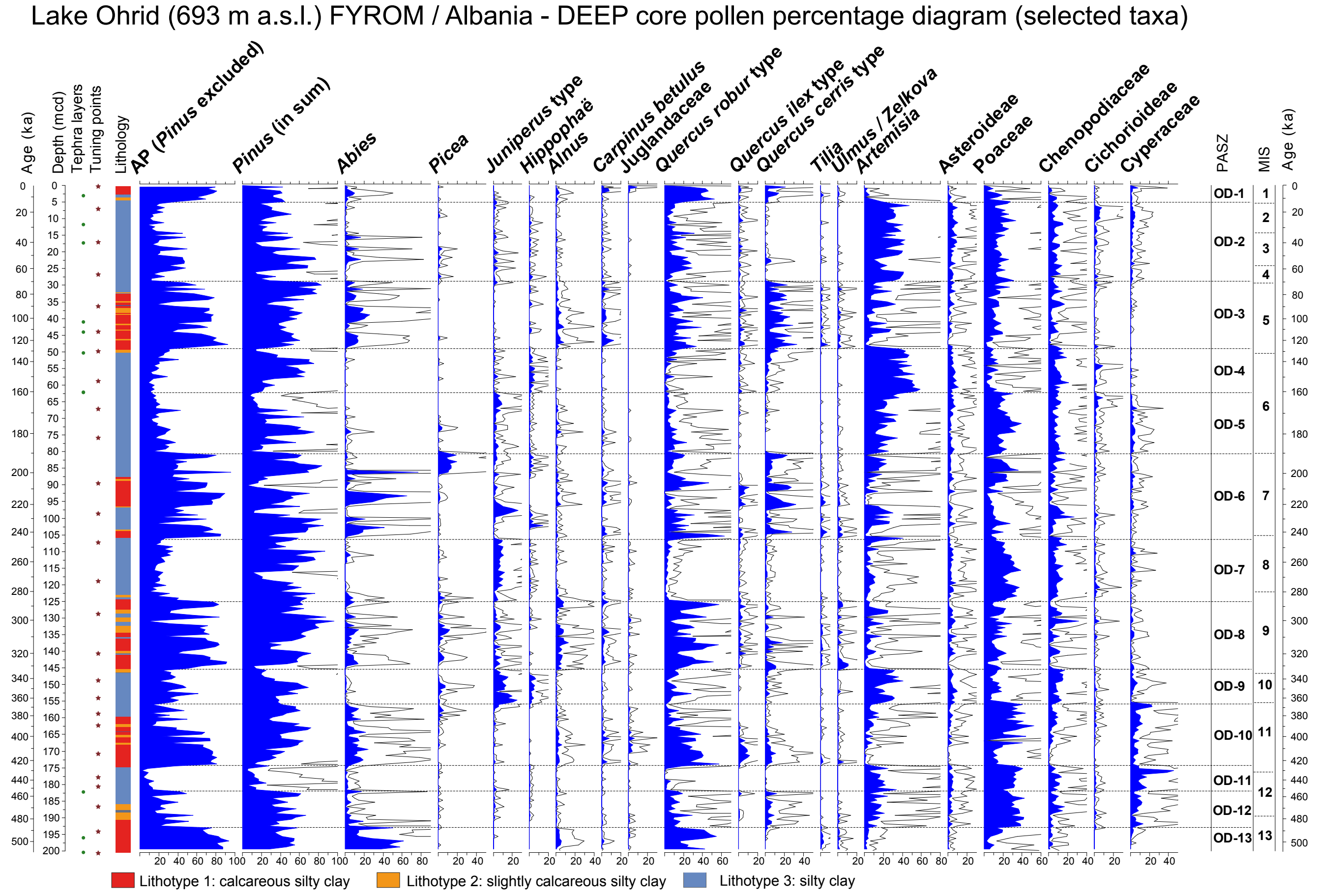

Figure 1. Lake Ohrid and location of the DEEP core. Pollen percentage diagram of selected taxa against depth scale (mcd, meters composite depth). Exaggeration 5×. Lithology, tephra layers and tuning points adapted from Francke et al. (2016).

al., 2017). Palynology is a key element of the DEEP stratigraphic record showing a sensitive response of vegetation to glacial–interglacial climate variability (Sadori et al., 2016). The published pollen record is the result of a cooperative work (Bertini et al., 2016) in which the SCOPSCO pollen group shared expertise, responsibility and work. However, after publication of the pollen diagrams (Sadori et al., 2016) a bias in pollen distribution was identified, probably caused by incorrect application of the processing procedure in sets of samples. Here we discuss this bias and present a correction of the figures represented by Sadori et al. (2016) based on partly reprocessed and recounted samples.

After the establishment of a protocol for pollen extraction, samples have been shared among different laboratories. The Utrecht pollen laboratory took on the burden of processing many samples (around 1/3 of the total), also for colleagues at the moment unable to carry out the chemical treatment.

Most levels of the published diagram showed dominance of large, bisaccate, pollen grains of conifers. This was a common feature of the last 500 ka (Sadori et al., 2016). Bisaccate pollen grains of *Pinus* dominate most samples, peaking at 80 %, including the warm Marine Isotope Stage (MIS) 5 (Sinopoli et al., 2018) and MIS 11 (Kousis et al., 2018). This was first misinterpreted and ascribed to geological taphonomic biases similar to the “Neves effect” reported by Traverse (2007, Fig. 18.1, p. 550). As such, *Pinus* pollen was kept out from the pollen percentage sum. A further factor contributing to the late discovery of the procedural error is that an alternation between forested and non-forested phases, i.e., interglacial/interstadial and glacial/stadial periods, was found to be in good agreement with the general trends of other terrestrial Balkan (Wijmstra, 1969; Wijmstra and Smit, 1976; Tzedakis, 1994; Okuda et al., 2001; Tzedakis et al., 2006; Pross et al., 2015) and ocean global (Lisiecki and Raymo, 2005) records.

High-resolution analysis of MIS-11 (pollen samples were processed in an independent laboratory) revealed that the originally published “skeleton samples” showed offsets with respect to the abundance of larger pollen grains. To confirm this offset, randomly selected samples were reprocessed and underwent cross-check analyses (i.e., by a different analyst to the original samples). As a result, samples with re-

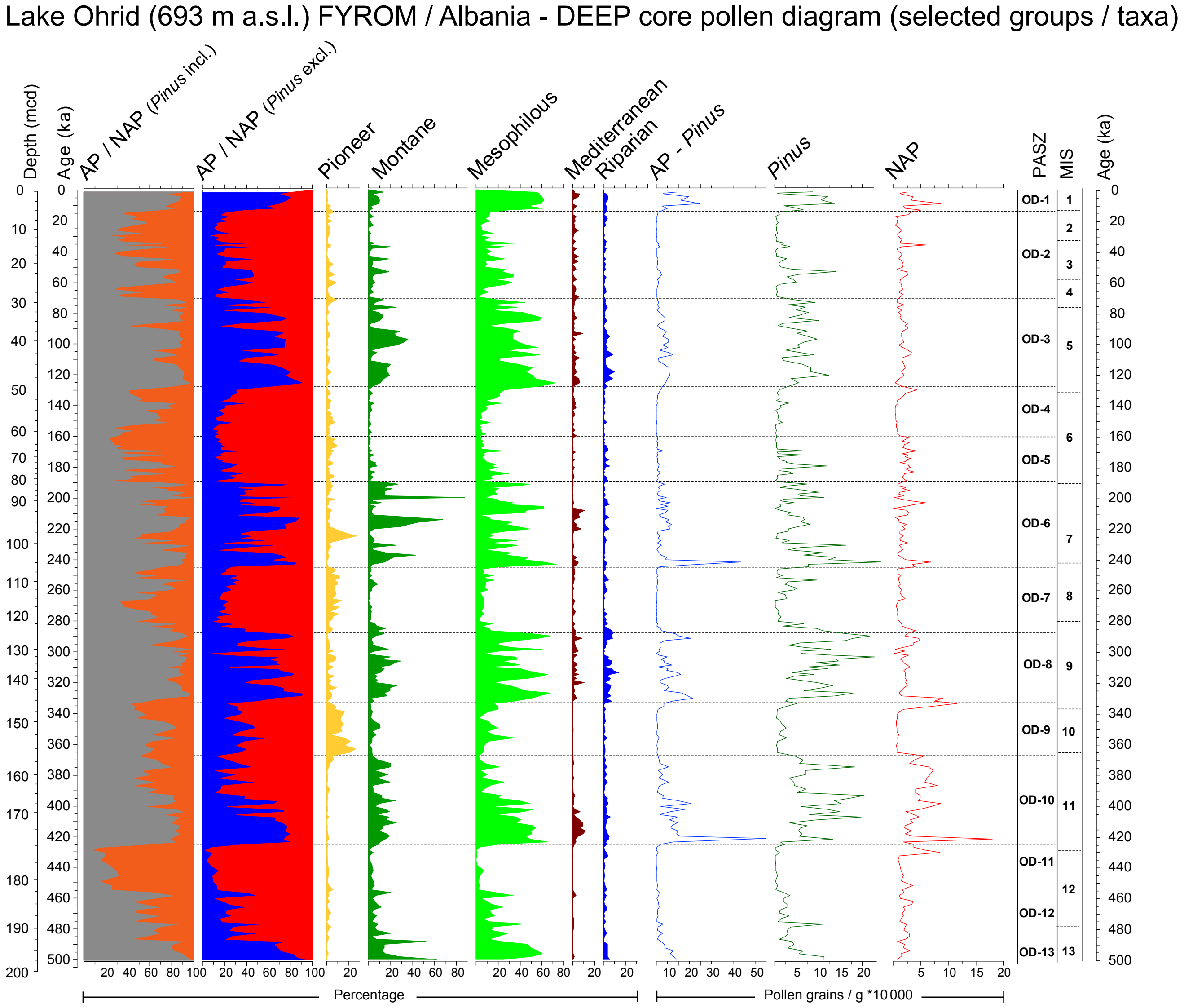

Figure 2. Lake Ohrid (FYROM), DEEP core. Pollen diagram of selected ecological groups (%) and concentration curves (pollen grains per gram dry sediment) against chronology (Francke et al., 2016). Ecological groups: montane trees (*Abies*, *Betula*, *Fagus*, *Ilex*, *Picea*, *Taxus*); mesophilous trees (*Acer*, *Buxus*, *Carpinus betulus*, *Carya*, *Castanea*, *Celtis*, *Corylus*, *Fraxinus excelsior*/*oxycarpa*, *Hedera*, *Ostrya*/*Carpinus orientalis*, *Pterocarya*, *Quercus cerris* type, *Quercus robur* type, *Tilia*, *Tsuga*, *Ulmus*, *Zelkova*); Mediterranean trees (*Arbutus*, *Cistus*, *Fraxinus ornus*, *Olea*, *Phillyrea*, *Pistacia*, *Quercus ilex* type, *Rhamnus*); riparian trees (*Alnus*, *Platanus*, *Populus*, *Salix*, *Tamarix*); pioneer shrubs (*Ephedra*, Ericaceae, *Hippophaë, Juniperus* type).

markably high values of *Pinus*, *Abies* and *Picea* pollen were traced back to a single technician temporarily employed at the palynological laboratory of Utrecht University who had not followed the correct processing protocol. These samples were affected by the use of wrong containers, causing inadequate settling of particles at the set centrifuging speed. In addition, HCl and HF treatments were combined without the prescribed intermediate centrifuging and decanting steps, potentially leading to formation of silicate gels. This processing violated both the Ohrid group and the internal Utrecht University laboratory procedures and especially caused loss of smaller palynomorphs in the affected samples.

The Ohrid palynology group has common responsibility for this error. At the same time, the cooperation within this group has allowed the discovery and complete correction of this specific error. As not all samples from Utrecht were processed by the same technician, comparison with the unaffected samples has triggered the initial identification of the problem. Subsequent cross-checking of samples, ongoing high-resolution analyses, and a detailed documentation of processing steps in the Utrecht laboratory have brought

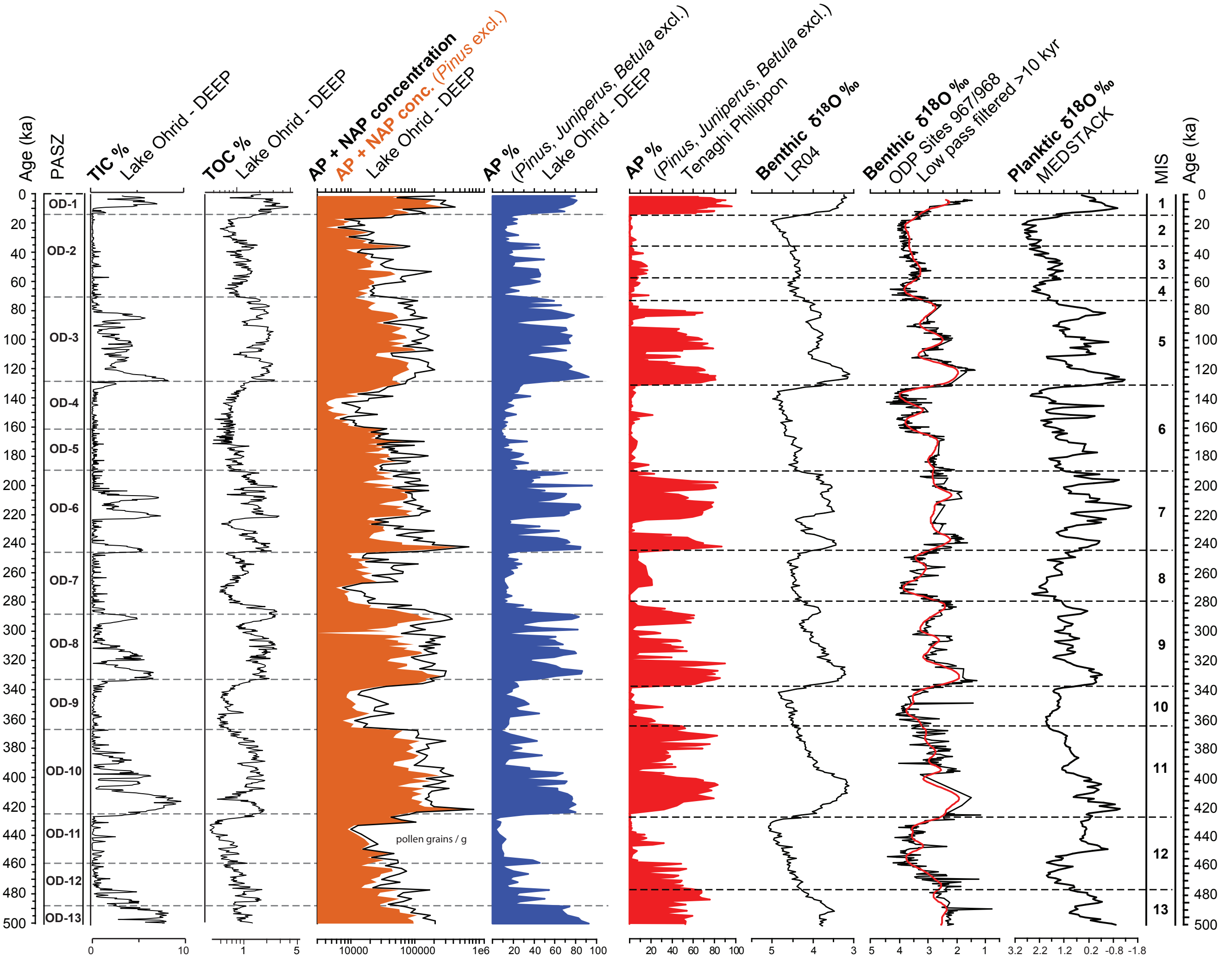

Figure 3. Comparison of selected proxies from Lake Ohrid with other records spanning the last 500 ka drawn against their original age models. Lake Ohrid: total organic carbon (TOC) and total inorganic carbon (TIC; Francke et al., 2016); total pollen concentration (pollen grains per gram dry sediment) of terrestrial plants (AP, pollen of arboreal plants + NAP, pollen of non-arboreal plants) and the same without *Pinus*, AP percentages (this study). Tenaghi Philippon: AP percentages excluding *Pinus*, *Betula* and *Juniperus* (Wijmstra, 1969; Wijmstra and Smit, 1976; age model from Tzedakis et al., 2006). Marine records: LR04 δ^{18}O benthic stack (Lisiecki and Raymo, 2005); stacked benthic δ^{18}O data for ODP sites 967 and 968 from the eastern Mediterranean (Konijnendijk et al., 2015); MEDSTACK planktic δ^{18}O data (Wang et al., 2010).

the issue to light. Crucially, the cooperative work of the Lake Ohrid pollen group was very effective not only in identifying the processing bias, but also in rapidly reprocessing and recounting the affected samples.

2 Recount approach

After reprocessing of test samples from core catcher sediment from the affected interval at the same laboratory, strictly following the processing protocol as reported in Sadori et al. (2016), pollen yield was much improved and comparable to test samples processed in other labs. The affected samples, representing (parts of) MIS 7, 10, 11, and 12, in total 104, were distributed among partners, reprocessed and recounted, and additionally several low-count sums from unaffected samples in MIS 4–2 were increased. The updated diagrams are plotted against the original chronology of Francke et al. (2016).

2.1 Recount results

With the improved pollen yield, no samples had to be excluded from the diagram due to low pollen sums. The corrected diagram is composed of 308 samples with a mean terrestrial pollen sum (AP, arboreal pollen + NAP, non-arboreal

Table 1. Main vegetational features of Lake Ohrid DEEP core pollen assemblage zones (OD-PASZ) and related chronological limits. The basis sum for AP and NAP taxa does not include *Pinus*. The depth is expressed in mcd (meters composite depth).

PAZ	Zone description
OD-1 depth limits (m) 5–0 age limits (ka) 14–0 duration (ka) 14 pollen samples no. 9 mean pollen count 231	Mesophilous tree taxa prevail. Forests are characterized by *Quercus robur* type (22–53 %) and *Quercus cerris* type (2–21 %). Montane taxa are quite scarce and mainly represented by *Abies* and *Fagus*. Riparian and Mediterranean trees are also rare. Poaceae are the dominant herbs. Pollen concentration is high.
OD-2 depth limits (m) 28–5 age limits (ka) 69–14 duration (ka) 55 pollen samples no. 36 mean pollen count 168	Open vegetation (steppe) with low/medium values of *Pinus* (13–77 %) and sparse presence of many montane and mesophilous taxa. Among them *Q. robur* type is the most abundant. *Artemisia* dominates and is accompanied by other herbs like Poaceae, Chenopodiaceae and Cyperaceae. Pollen concentration shows medium values.
OD-3 depth limits (m) 49–28 age limits (ka) 129–69 duration (ka) 60 pollen samples no. 32 mean pollen count 338	Alternation of periods characterized by mesophilous/montane trees and open vegetation. Forests are mainly characterized by expansion of *Q. cerris* type (1–33 %) and *Q. robur* type (3–39 %) together with *Abies* and *Fagus*, the latter reaching the highest values of the diagram in this zone. Riparian and Mediterranean trees are present. *Artemisia*, Poaceae and Chenopodiaceae characterize the open vegetation. Pollen concentration is high.
OD-4 depth limits (m) 62–49 age limits (ka) 160–129 duration (ka) 31 pollen samples no. 21 mean pollen count 262	Open vegetation (steppe) with medium/high values of *Pinus* (14–75 %). *Juniperus* (0–4 %) and *Hippophaë* (0–5 %) are important woody taxa. Mesophilous taxa are present in low values. Herbs are dominant: *Artemisia* shows a sudden increase, while Poaceae and Cyperaceae are reduced; Chenopodiaceae are abundant. Pollen concentration shows medium values.
OD-5 depth limits (m) 81–62 age limits (ka) 191–160 duration (ka) 31 pollen samples no. 29 mean pollen count 203	Open vegetation with medium values of *Pinus* (6–76 %), *Juniperus* (0–9 %) and *Hippophaë*. Many mesophilous taxa are present in low values. Herbs are dominant: Poaceae, *Artemisia*, Chenopodiaceae and Cyperaceae are abundant. Pollen concentration has medium values.
OD-6 depth limits (m) 106–81 age limits (ka) 244–191 duration (ka) 53 pollen samples no. 39 mean pollen count 287	Alternation of coniferous and mesophilous forests with grassland (steppe) formations. Main conifer taxa are *Pinus* (5–85 %), *Abies* (0–77 %) and *Picea* (0–20 %); *Q. cerris* type (< 1–32 %) and *Q. robur* type (0–63 %) are the dominant mesophilous taxa. Poaceae are accompanied by high values of Chenopodiaceae, Cichorioideae and *Artemisia.* Pollen concentration is quite variable, oscillating from almost the highest to almost the lowest values of the record.
OD-7 depth limits (m) 125–106 age limits (ka) 287–244 duration (ka) 43 pollen samples no. 28 mean pollen count 242	Open vegetation with high values of pioneer taxa (mainly *Juniperus*). *Pinus* is very abundant (10–87 %). Poaceae are very abundant, accompanied by Chenopodiaceae and *Artemisia*. Pollen concentration is very low.
OD-8 depth limits (m) 145–125 age limits (ka) 333–287 duration (ka) 46 pollen samples no. 32 mean pollen count 225	Mesophilous tree taxa prevail. The main conifer taxa are *Pinus* (11–96 %) and *Abies* (0–14 %) Forests are characterized by *Q. robur* type (5–57 %) and *Q. cerris* type (0–18 %) with the important contribution of Riparian and Mediterranean trees. Poaceae are the dominant herbs. Pollen concentration is high.
OD-9 depth limits (m) 156–145 age limits (ka) 367–333 duration (ka) 34 pollen samples no. 16 mean pollen count 207	Open vegetation with relatively high values of pioneer taxa. *Pinus* (20–69 %), *Juniperus* type (1–25 %) and *Hippophaë* (0–7 %) are abundant. *Picea* (0–8 %) is mainly found in the middle of the zone. Peaks of mesophilous taxa are also observed. Poaceae, Chenopodiaceae, Asteroideae, Cichorioideae and *Artemisia* are very abundant. Pollen concentration is low.

Table 1. Continued.

OD-10 depth limits (m) 174–156 age limits (ka) 424–367 duration (ka) 57 pollen samples no. 29 mean pollen count 318	Mixed conifer–temperate forests dominated by *Q. robur* type (2–57 %) and *Abies* (2–24 %). *Pinus* is abundant. Poaceae are the dominant herbs. Pollen concentration is high.
OD-11 depth limits (m) 183–174 age limits (ka) 459–424 duration (ka) 35 pollen samples no. 14 mean pollen count 319	Open vegetation is dominated by Poaceae, Cyperaceae, Chenopodiaceae, Asteroideae, Cichorioideae and *Artemisia*. *Pinus* (5–61 %) and *Q. robur* type (0–19 %) are the most common trees. *Abies* (0–17 %) is mainly found in the lowermost samples of the zone. Pollen concentration is the lowest of the entire record.
OD-12 depth limits (m) 193–183 age limits (ka) 487–459 duration (ka) 28 pollen samples no. 15 mean pollen count 212	Forests dominated by *Pinus* (26–67 %), *Q. robur* type (3–29 %) and *Abies* (< 1–19 %) are alternating with open vegetation dominated by Poaceae, Cyperaceae, Chenopodiaceae, Cichorioideae and *Artemisia*. Pollen concentration is relatively low.
OD-13 depth limits (m) 198–193 age limits (ka) 502–487 duration (ka) 15 pollen samples no. 8 mean pollen count 181	Mesophilous and montane tree taxa prevail, with *Abies* (11–61 %) and *Q. robur* type (15–54 %) being the dominant tree taxa. Poaceae are the dominant herbs. Pollen concentration is high.

pollen) count of 508 grains, *Pinus* included, and 251 grains, *Pinus* excluded. The results, updated per pollen zone, are summarized in Table 1 and in two figures, Figs. 1 and 2 (respectively amending Figs. 2 and 3 of Sadori et al., 2016). The AP curve changed only slightly after recounting; however, the striking similarities to other proxy records from the DEEP core and to other records remain virtually unchanged, as evidenced in Fig. 3 (amending Fig. 4 of Sadori et al., 2016).

As the main difference with the original diagrams is the strong relative reduction of large bisaccate pollen grains such as *Abies, Picea*, and *Pinus* (see Table 1), principal increases are seen in the main taxa: *Artemisia* (OD-9, 11, and 12), Poaceae (OD-10), and *Quercus robur* type (OD-6 and 10). Overall, smaller size grains were much underrepresented in the original counts.

The original pollen zonation OD-1–13 was not affected by the reanalysis, with the exception of the OD-10/11 transition, which was changed from 428 to 426 ka (175 to 174.83 mcd). The taxa *Alnus* and *Carpinus betulus* were also added to Fig. 1 (the revision of Fig. 2, Sadori et al., 2016) to account for their more prominent appearance throughout the entire profile, although both taxa do not exceed 5 % abundance. Other minor changes include the representation of the pollen concentration on a logarithmic scale (Fig. 2), and a correction of anomalous high abundances of pioneer taxa in zone OD-4 due to a spreadsheet error in the *Juniperus* type raw data.

3 Implications

Key results and most of the conclusions presented in Sadori et al. (2016) have remained essentially valid. The fact that we had found anomalous very high values of pine pollen led us to use the AP curve with *Pinus* excluded. This prevented errors in the general interpretation of arboreal and non-arboreal phases. The overrepresentation of *Pinus* in Zones OD-9 to -12, as reported by Sadori et al. (2016), is clearly less prominent than before, but still present. The transition based on montane trees between the relatively cool/humid interglacial conditions prior to 288 ka (i.e., MIS 11 to 7) to warmer and drier recent interglacial periods in the last 130 ka (i.e., MIS 5 to 1) is, however, much less marked than before (Figs. 1 and 2). The decrease in *Abies* is less prominent, but still a clear feature of the succession. The relatively high abundance of *Picea* in OD-6 (end of MIS 7) has been verified. The transition from wetter to drier glacial periods in the same time interval remains substantially unchanged. From the bottom to the top of the diagram, the decrease in Poaceae and Cyperaceae and the increase in *Artemisia* during the last two glacial cycles remain clear but slightly more gradual. The suggested plant refugium function of the site (Sadori et al., 2016) is still valid, and seems strengthened by more consistent recorded presence of angiosperm tree taxa during glacial phases in the lower half of the current record (Fig. 1).

The updated record strengthens the relation between vegetation composition at Lake Ohrid and regional benthic and planktic isotope data, particularly in OD-10 (MIS 11) and

OD-12 (MIS 12/13 transition) (Fig. 2). While an extensive data error had to be corrected, it is evident that the team approach to the study of the long record has enabled recognition of the processing problem, which in the case of a single lab might have gone unnoticed, as well as effective and rapid correction of the data.

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