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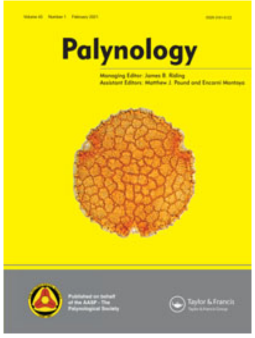

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Long-term persistence of steppe vegetation in the highlands of Arasbaran protected area, northwestern Iran, as inferred from a pollen record

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ABSTRACT
Palynological analysis and radiocarbon dating of a short sediment core from a high-altitude mire in the Arasbaran area of northwestern Iran reveals long-term vegetation dynamics, climate change and anthropogenic impact. Our findings indicate the prevalence of semi-desert steppe vegetation, with a variety of Asteraceae – mainly Lactuceae – species from 3000 to 1440 cal yr BP. This period is followed by a higher occurrence of *Artemisia* spp. and Brassicaceae (1440–1330 cal yr BP), a re-expansion of Lactuceae (1330–1030 cal yr BP) and Brassicaceae (1030–330 cal yr BP) and, finally, Caryophyllaceae species (since 330 cal yr BP). The reconstructed millennia-long dry climate in the highlands of northwestern Iran is in good accordance with climate reconstructions from other east Mediterranean sites. Two phases of moister conditions between 2100–1400 and 1000–350 cal yr BP would correspond to altitudinal *Quercus–Carpinus* forest expansion in the Arasbaran area. The earliest indication of anthropogenic activity in the area dates back to the onset of the record, around 3000 cal yr BP. The occurrence of small maxima of *Juglans regia*, *Corylus avellana* and *Cornus mas* pollen at around 1350 cal yr BP is interpreted to reflect a temporary expansion of fruit cultivation. For the last millennium the occurrence of pollen attributable to *Polygonum*, *Euphorbia*, *Plantago* and *Rumex* suggests a diversification of steppe vegetation, which may reflect intensified agropastoral activities in the Arasbaran highlands. Based on our pollen record, the regional vegetation in the Kalan area remained largely stable over the last three millennia. However, changes in local hydrology caused substantial changes in wetland vegetation.

KEYWORDS
East Mediterranean; Irano-Turanian steppe; late Holocene; palaeoclimate; vegetation history

1. Introduction

The Irano-Turanian region is one of the largest floristic regions of the world, covering some 30% of the surface of Eurasia. The region represents one of the hotspots of biodiversity in the Old World, and served as a source of xerophytic taxa for neighbouring regions (Manafzadeh et al. 2017). Still, little is known about the role of climate and human activity in floristic and vegetational evolution of this important phytogeographical region, particularly of its semi-arid highlands.

Northwestern Iran along with eastern Turkey and the Caucasus constitute the core region of the Arabia–Eurasia collision zone. The mountain ranges in the northwest, including Qara Dagh (or Qareh Dagh), Bozghosh and Ghosha Dagh, consist of Mesozoic to Cenozoic rocks (Allen et al. 2011; Zamani and Masson 2014). Remnants of predominantly deciduous broadleaf forest, the 'Arasbaran forests', cover the mid- to high-elevation ridges of the Qara Dagh range, which within the Euxino-Hyrcanian phytogeographical province (sensu Zohary 1973; Figure 1) forms the southeastern extension of the Caucasus Biodiversity Hotspot (Myers et al. 2000; Nakhutsrishvili et al. 2011).

In 1976, UNESCO designated 72,460 ha (56%) of the Arasbaran Protected Area (APA), one of the nine UNESCO Biosphere Reserves in Iran (Jalili et al. 2003). This biosphere reserve, while comprising less than 0.05% of Iran's land surface, holds nearly 15% of the flora of Iran (7300–7500 plant species, Akhani 2006; Prof. Hossein Akhani pers. comm. 2016), i.e. 1071 plant taxa (451 genera; 89 families), including 18 endemic taxa, such as *Alcea flavovirens* (Boiss. & Buhse) Ilgin and *Cousinia gigantolepis* Rech. (Hamzeh'ee et al. 2010). Furthermore, the following woody taxa of the Iranian flora grow almost exclusively in this disjunct floristic area: *Cornus mas* L., *Cotinus coggygria* Scop., *Juniperus foetidissima* Willd. and *Juniperus oblonga* M. Bieb. The area is the home of many west Eurasian faunal taxa, such as Caucasian black grouse (*Tetrao mlokosiewiczi*), brown bear (*Ursus arctos*), leopard (*Panthera pardus*), wild boar (*Sus scrofa*), Eurasian lynx (*Lynx lynx*), wild goat (*Capra aegagrus*) and roe deer (*Capreolus capreolus*) (Sagheb Talebi et al. 2014).

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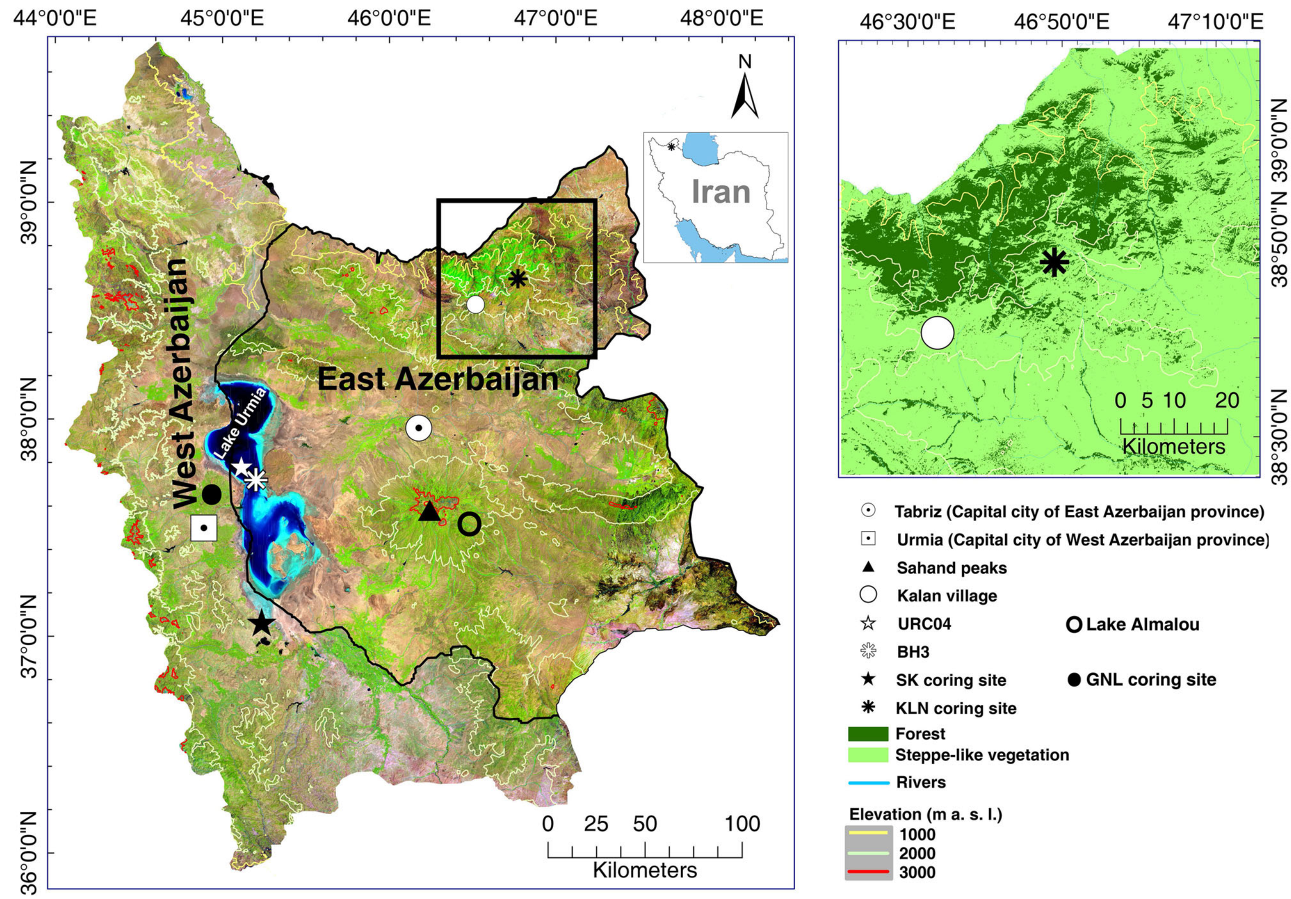

Figure 1. The position of Kalan peatland in northwestern Iran, along with other sites discussed in this study. The map was produced using Landsat imagery in an ArcGIS environment.

This high biodiversity may be explained by the area's diverse topography and strong elevational gradients along with the fact that the flora is composed of elements from three distinct phytogeographical regions, i.e. the Euro-Siberian, the Irano-Turanian and the Mediterranean Regions (Hamzeh'ee et al. 2010) (see Section 2.4 for further details).

Recent palynological studies have considerably elucidated the Late Pleistocene and Holocene environmental conditions of the adjacent Hyrcanian region (e.g. Ramezani et al. 2008, 2016; Leroy et al. 2013; Shumilovskikh et al. 2016) and other landscapes in the northwest (e.g. Djamali et al. 2008, 2009; Ponel et al. 2013; Talebi et al. 2016). In contrast, data on the past vegetation and climate of the Arasbaran area are still missing, which is mainly due to the scarcity of palaeo environmental archives in this rather dry, rugged, mountainous landscape. The above-mentioned studies indicate that, like other parts of the eastern Mediterranean and western Asia, northwestern Iran has been subject to a long history of agro-pastoral activities (Djamali et al. 2009), whereas climate also has played an important role in changing its natural vegetation (Van Zeist and Bottema 1991). Palynological analysis of sediment cores from Lake Urmia (Djamali et al. 2008; coring sites BH3 and URC04 in Figure 1) shows the prevalence of steppe-like vegetation with a dominance of *Artemisia* and Amaranthaceae (and occasionally Poaceae) during glacials/stadials and the expansion of woody taxa, namely various species of *Quercus* and *Pistacia* in the northern Zagros Mountains and *Juniperus excelsa* in the highlands of the Azerbaijan Plateau during the interglacials/interstadials.

This first palaeoecological study in the APA provides insights into the role of climate and humans on late Holocene vegetation development in this biosphere reserve. Our study addresses the following research questions: (i) How stable have vegetation composition and structure been in the highlands of the APA during the late Holocene? (ii) How did climate and human activity contribute to vegetation change in the area? (iii) Did the timberline during the late Holocene ever reach the altitude of our study site?

2. Material and methods

2.1. Study area

The study site [2470 m above sea level (asl); 38°46′46.6″N, 46°50′20.2″E] is a 0.2–0.3 ha mire in Kalan District in the Arasbaran area, northwestern Iran. The site is located northeast of Tabriz, the capital of East Azerbaijan province, and close to the border with the Republic of Azerbaijan (Figure 1).

2.2. Geology

The rocks in the study area are mainly of Cretaceous origin with limestones, schists and conglomerates as the main constituents. Soils of the high elevations of the APA are predominantly calcareous clayey (Jalili et al. 2003).

2.3. Climate

The precipitation regime in the Arasbaran area is controlled by the Caspian Sea in the east, the Mediterranean Sea in the west and the Siberian low-pressure fronts from the north. The mean annual rainfall is 300–600 mm. However, fog, as hidden precipitation, provides an effective additional water supply, particularly at elevations between 1000 and 2000 m (Sagheb Talebi et al. 2014).

2.4. Vegetation

Dependent on elevation, slope, edaphic conditions and degree of human impact, three vegetation zones can be distinguished (Jalili et al. 2003; Hamzeh'ee et al. 2010), as follows.

The low- to mid-elevation zone (265–1250 m asl) can be subdivided into two parts. The lower section (265–600 m asl) encompasses the banks of the Aras River up to the foothills of the Qara Dagh Mountains. Long-term intensive use (Jalili et al. 2003; Sagheb Talebi et al. 2014) has caused this zone to consist mainly of abandoned agricultural lands with secondary vegetation types of mostly Irano-Turanian origin. Among the dominant and abundant plant species are *Artemisia fragrans* Willd., *Bothriochloa ischaemum* (L.) Keng, *Astragalus gossypinus* Fisch., *Atraphaxis spinosa* L., *Chrysopogon gryllus* Trin., *Paliurus spina-christi* Mill., *Punica granatum* L., *Satureja macrantha* C.A.Mey and *Rhamnus pallasii* Fisch & C.A.Mey. At elevations between 600 and 1250 m, secondary woodlands, which developed following the cessation of clear-cutting and burning in the last few decades, constitute the main contemporary vegetation. Here, dense stands of thorny shrubs, particularly of *Paliurus spina-christi*, dominate the landscape. These pioneers are gradually being replaced by individuals of *Quercus petraea* (Matt.) Liebl. subsp. *iberica* (Steven ex M.Bieb.) Krassiln and other later-successional hardwoods (Hamzeh'ee et al. 2010; Sagheb Talebi et al. 2014; first author pers. obs. 2012–2015). Another notable vegetation type, which was possibly more widely distributed and abundant in former times, is formed by sparse populations of *Juniperus foetidissima* in combination with *Ephedra procera* Fisch. & C.A.Mey.

The forest zone (mainly 1000 to 1800 m asl) is the least impacted zone of the APA in terms of human activity and/or pasture pressure. The principal tree species are *Carpinus betulus* L. (frequently as coppice regrowth), *Quercus petraea* subsp. *iberica* (below 1500–1600 m) and *Q. macranthera* Fisch. & C.A.Mey. ex Hohen (from 1600 m upwards). The main accompanying woody taxa include *Acer campestre* L., *Fraxinus excelsior* subsp. *coriariifolia* (Scheele) A.E.Murray, *Cerasus avium* (L.) Moench, *Ulmus glabra* Huds., *Sorbus torminalis* (L.) Crantz, *Celtis caucasica* Willd., *Acer hyrcanum* Fisch. & C.A.Mey. and *Viburnum lantana* L. Stands of *Carpinus betulus* and *Taxus baccata* L. (understory) occur mainly on more humid and deeper soils at elevations of 1100–1300 m.

The alpine zone (1800–2700 m asl) can be split into dwarf scrub grasslands and pure grasslands. The former communities consist of spiny, cushion-shaped dwarf shrubs including *Astragalus* spp., *Onobrychis cornuta* (L.) Desv. and *Juniperus oblonga* together with numerous forbs and grasses. Among the main components of the more or less pure grasslands are *Festuca sulcata* (Hack.) Beck., *F. ovina* L., *Thymus* spp., *Alchemilla sericata* Rehb., *Agrostis gigantea* Roth and *Bromus adjaricus* Sommier & Leivier. The vegetation composition of this zone suggests that it is made up of both the Irano-Turanian and Euro-Siberian floras and that it forms a transitional zone where the two elements are intermingled.

Apart from the above-mentioned species, ample moisture-loving plant taxa grow along brooklets and similar wet places, including *Aconitum pubiceps*, *Anthriscus nemorosa*, *Carex atrata*, *C. panicea*, *C. spicata*, *C. vulpina*, *Calamagrostis epigejos*, *Catabrosa capusii*, *Dactylis glomerata*, *Deschampsia caespitosa*, *Doronicum macrophyllum*, *Epilobium tetragonum*, *Geranium pratense*, *Glyceria arundinacea*, *Mentha longifolia* and *Primula auriculata*.

Ten plant families are richest in terms of species diversity in Arasbaran Biosphere Reserve (Table 1) (Hamzeh'ee et al. 2010). The main plant communities of the landscapes surrounding the Kalan peatland have an Irano-Turanian character (the alpine zone; see above). The surface of the mire consists predominantly of graminoids, i.e. Poaceae and Cyperaceae, accompanied by forbs such as *Ranunculus*, *Prunella* and *Trifolium*.

2.5. Palynology

A 220-cm-long core was retrieved from the central part of the site in 2013 using a Russian chamber corer. Palynological samples (2 cm^3) were taken at 10-cm intervals along the core and prepared following the method of Faegri and Iversen (1989) which includes treatment with hydrochloric acid (HCl) and potassium hydroxide (KOH), sieving (125 um), treatment with hydrofluoric acid (HF), acetolysis and mounting in silicon oil. Sample preparation was carried out in the Laboratory of Palynology and Climate Dynamics, University of Göttingen (Germany).

Counting was carried out using an Olympus CX31 light microscope with 400× magnification. Pollen-morphological types are presented in the text using SMALL CAPITALS to clearly distinguish them from plant taxa (Joosten and de Klerk 2002). Pollen and spores were identified and named following Moore et al. (1991, M), Beug (2004, B) and Van Zeist and Bottema (1977, ZB), and by consulting the reference slide collection of the Faculty of Natural Resources, Urmia University, Iran.

The computer program Tilia 2.0.41 (Grimm 1992–2015) was used for calculating and presenting the palynological data. The pollen diagram was subdivided into pollen assemblage zones using CONISS for square-root transformation of the percentage data, followed by stratigraphically constrained cluster analysis (Grimm 1987).

Microfossil percentages were calculated relative to a pollen sum consisting of pollen types that are assumed to

Table 1. The most abundant plant taxa in Arasbaran Biosphere Reserve (Hamzeh'ee et al. 2010).

Taxon	Number of genera	Number of species and/or subspecies
Asteraceae	52	121
Poaceae	51	114
Fabaceae (subfamily Faboideae)	19	91
Lamiaceae	25	68
Rosaceae	23	65
Caryophyllaceae	16	50
Brassicaceae	28	47
Apiaceae	31	40
Scrophulariaceae	10	36
Boraginaceae	16	33
Sum	**271**	**665**

originate from trees and shrubs (arboreal pollen, AP) and dryland (i.e. well-drained upland) herbs (non-arboreal pollen, NAP). Pollen of presumable wetland plants, Cyperaceae and Poaceae, were excluded from the sum to prevent (extra)local overrepresentation in the pollen record.

2.6. Dating

As no datable plant remains could be found at the specific depths examined, dating of three bulk sediment samples was performed by accelerator mass spectrometry (AMS) at NTUAMS (Taiwan) and Poznań Radiocarbon Laboratory (Poland) (Table 3). Clam package version 2.3.2 (Blaauw 2019) and the calibration curve IntCal13 (Reimer et al. 2013) were used in R (version 3.5.2) to calibrate radiocarbon ages to calendar years BP (cal yr BP) and to plot a classic age–-depth model.

3. Results

3.1. Lithology

Table 2 presents a simplified lithostratigraphical description of the KLN core. The lower two-thirds of the profile consists mainly of rather coarse, granular clastic material (sand/pebbles) with some clay. Hardly any plant remains were observed in this section of the core. The upper 45–50 cm of the core mainly consist of (dark) brown slightly to moderately decomposed peat intermixed with clay.

3.2. Radiocarbon dating

The results of radiocarbon dating (Table 3) suggest a ca. 2980 cal yr old record. The age–depth model (Figure 2) is roughly in accordance with the changes in lithology (Table 2).

3.3. Palynology

The KLN pollen record (Figure 3) has been ordered into terrestrial, i.e. AP + NAP, and wetland types groups. The former represents pollen taxa presumably originating from upland vegetation, and, therefore, forms the basis of calculating the pollen percentages. Also included in this group are Asteraceae, Brassicaceae, Umbelliferae (Apiaceae) and Caryophyllaceae, as the abundance of corresponding producers in the modern upland vegetation suggests a predominantly regional upland rather than local wetland origin.

The KLN pollen diagram (Figure 3) is mainly composed of Chenopodiaceae and Amaranthaceae and, to a lesser extent, Lactuceae, Brassicaceae, Caryophyllaceae, Artemisia and Polygonum aviculare type. Overall, the arboreal pollen (AP) curve shows low values. Among the wetland pollen types, Cyperaceae and Poaceae prevail in most spectra, particularly in the upper 80 cm of the record. Four pollen assemblage zones (PAZs) and four subzones were identified (Table 4).

4. Discussion

4.1. Age–depth model

The radiocarbon dates have a consistent stratigraphical order. A possible source of age error, however, could be the hard-water effect that may have produced too-old dates, as the strong reaction with HCl suggests a significant content of carbonate in the deposits (Table 2). However, neither the lithology of the core nor the pollen record indicates that the mire has ever been inundated by water, so a 'reservoir effect' is improbable (but not totally impossible).

Although the low number of radiocarbon dates precludes the construction of a robust age–depth model, the model is roughly in accordance with the sedimentological record (Figure 2), with low and continuous sedimentation rates in the organic fine sediments of the upper part, and more rapid rates in the gravel unit of the core.

4.2. Regional and local vegetation dynamics

In arid and semi-arid regions of the world, seasonal water-table fluctuations have a profound impact on the preservation of pollen in sediments: The resulting oxidation leads to a bias towards more resistant pollen types. Even a concentration of pollen of taxa with an entomophilous mode of pollination such as Asteraceae has frequently been reported (Bottema 1975, Talebi et al. 2016; Mokarizadeh et al. 2017).

The dominance of NAP types in the Kalan pollen record may lead to the conclusion that steppe vegetation prevailed and persisted in the highlands of the APA throughout the last three millennia. Our findings also indicate that during this period the alpine timberline, which is nowadays at about 2000 m asl in the Arasbaran area (Hamzeh'ee et al. 2010), did not approach Kalan. However, two phases of altitudinal forest expansion may be deduced from the distinct, though

Table 2. Lithological characteristics of the KLN core.

Depth (cm)	Chemical reaction with hydrochloric acid	Lithology
9–15	High	Slightly decomposed brown radicel peat with some clay
15–45	High	Moderately to highly decomposed dark brown peat with some clay
45–75	High	Brown sandy clay sediment with some plant remains
75–100	Low	Brick-red sandy clay sediment with tiny plant remains
100–125	Low	Brick-red sand/pebbles with some clay; no plant remains
125–150	Low	Brick-red sand/pebbles; no plant remains
150–164	Low	Pale brown sandy clay sediment; few plant remains
164–168	High	Dark brown sandy clay, few plant remains
168–183	High	Reddish brown sand/pebbles with some clay; few plant remains
183–190	High	Dark brown sandy clay; few plant remains
190–214	High	Reddish brown sandy clay; no plant remains

Table 3. Results of radiocarbon dating and calibrated ages of core KLN (Arasbaran, northwestern Iran).

Lab code	Depth (cm)	^{14}C Age (yr BP)	Calibrated age (cal yr BP) Best date (min–max)
NTUAMS-2708	92	1258 ± 37	1200 (1080–1275)
NTUAMS-2706	182	1542 ± 28	1451 (1364–1521)
Poz-85947	212	2785 ± 30	2882 (2794–2957)

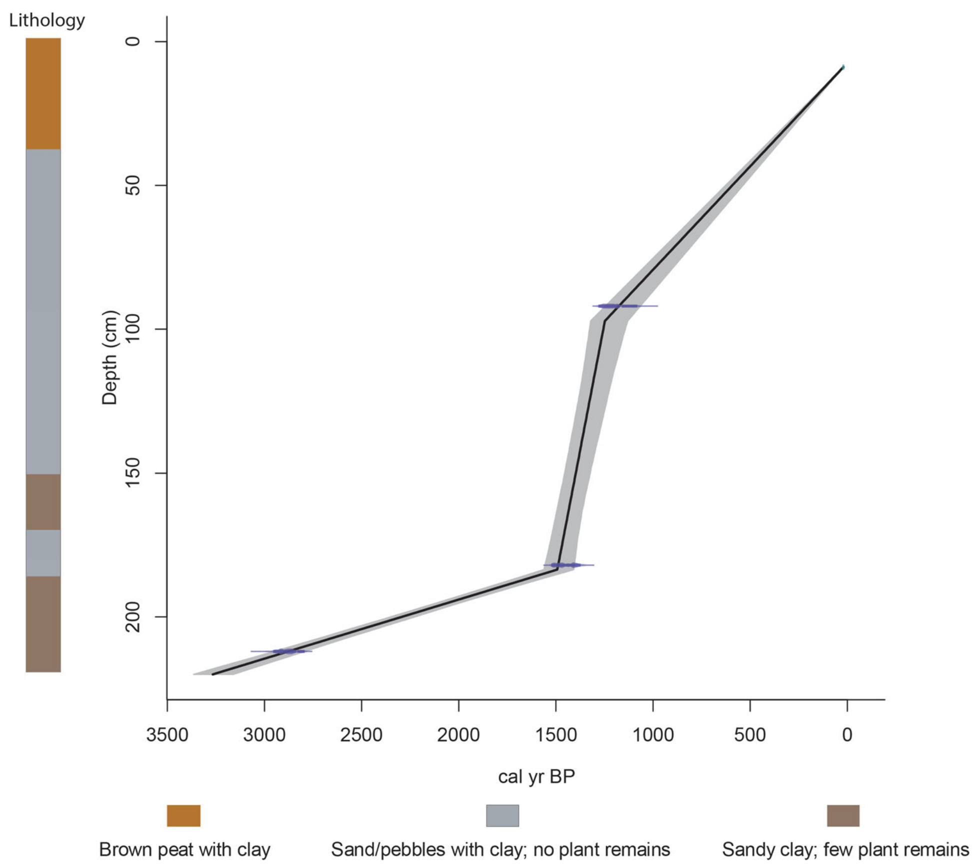

Figure 2. Age–depth model for the KLN pollen record plotted by linear interpolation in CLAM.

small, rise of Quercus and Carpinus pollen at specific periods (see below). Long-distance pollen transport is evident from the frequent occurrence of pine pollen in the Kalan pollen diagram (Figure 3) as the nearest natural pine populations are located in Turkey and the Caucasus. Comparable values of pine pollen have been encountered in other pollen records from northwestern Iran (e.g. Djamali et al. 2009; Talebi et al. 2016).

Amaranthaceae (including Chenopodiaceae; cf. APG III) constitute the original natural vegetation of the Eastern Mediterranean (Zohary 1973). Members of this family are representative of steppe vegetation and adapted to arid and/or saline environments (El-Moslimany 1990; Akhani 2004; Roberts et al. 2011). El-Moslimany (1990) claims that in the gradient from desert via steppe to mesic forest-steppe sites in the Middle East, 'above a minimal amount of precipitation, the percentage of Chenopodiaceae pollen is inversely related to precipitation'.

The predominance of Chenopodiaceae and Amaranthaceae (with overall mean values of more than 44%) in the Arasbaran record, however, may not be taken as an assertion for the abundance of its pollen producers in the surrounding vegetation. Amaranthaceae species produce pollen grains in great abundance, which are transported over large distances

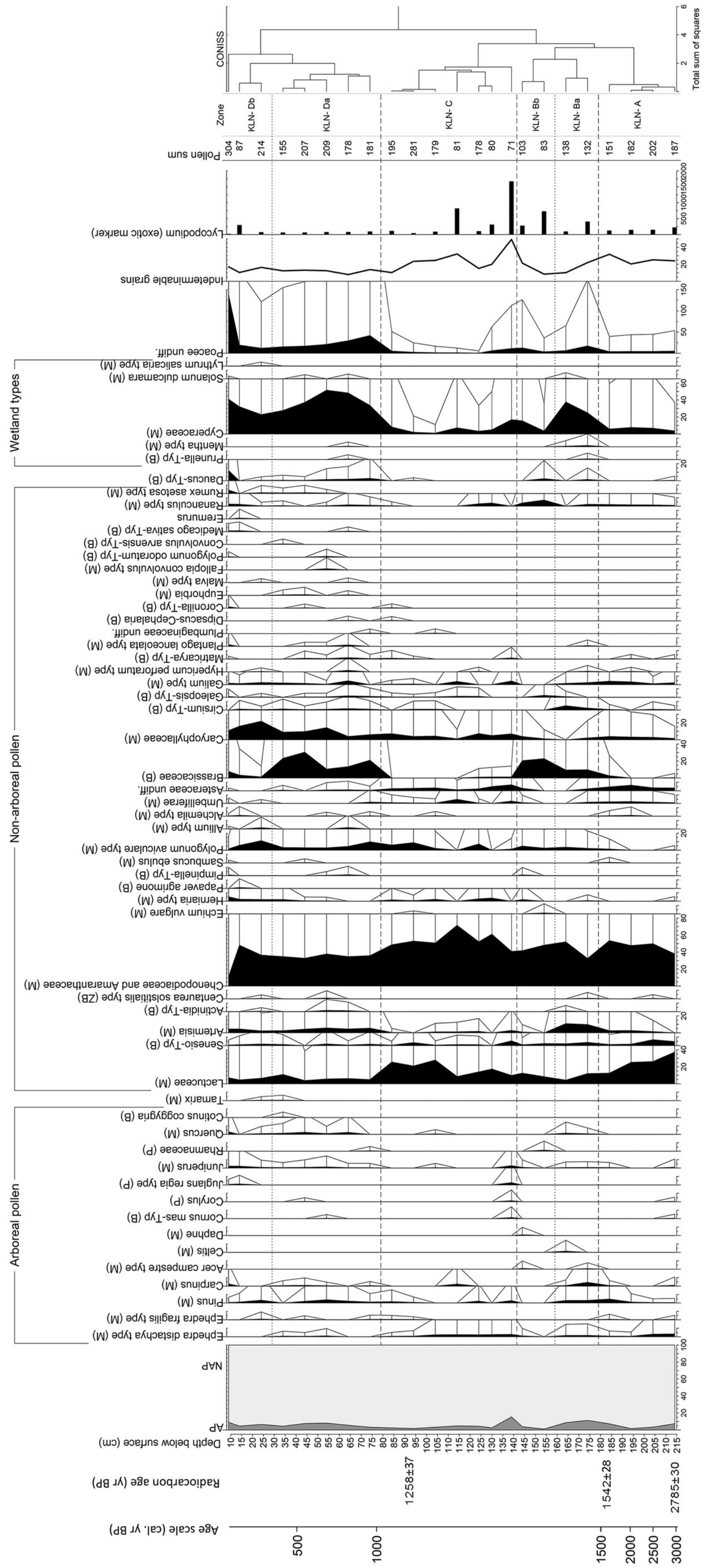

Figure 3. Pollen percentage diagram of KLN mire (Arasbaran), showing percentage values (closed curves) of selected arboreal (AP), non-arboreal (NAP) and wetland types, with 10-times exaggeration (open curves with depth bars). The first two groups are used as the basis for pollen sum calculations. *Lycopodium* values are divided by 10.

Table 4. Depth, age range and important features of pollen assemblage zones (PAZ) of the Kalan (KLN) pollen diagram.

PAZ	Depth (age)	Pollen zone features
KLN-A	214–179 cm (3000–1440 cal yr BP)	Arboreal types (AP) mainly consist of EPHEDRA DISTACHYA TYPE and PINUS pollen, with values up to 3.2 and 4.6%, respectively. CHENOPODIACEAE AND AMARANTHACEAE (38–54%) is the predominant pollen type. LACTUCEAE is the second most abundant pollen type; however, its values progressively decline towards the upper boundary of the zone. Another feature of this zone is the modest values of e.g. CYPERACEAE, POACEAE, UMBELLIFERAE, GALIUM and RANUNCULUS TYPE.
KLN-B	179–142 cm (1440–1340 cal yr BP)	This zone is divided into two subzones: KLN-Ba (179–159 cm; 1440–1390 cal yr BP) and KLN-Bb (159–142 cm; 1390–1340 cal yr BP). The first subzone is characterised by a slight increase in the values and diversity of AP types (e.g. CARPINUS, JUNIPERUS and QUERCUS). Among the non-arboreal pollen (NAP) types, CHENOPODIACEAE AND AMARANTHACEAE markedly declines in the lower part of the zone but recovers thereafter. ARTEMISIA notably increases. A substantial increase of CYPERACEAE and a slight increase of POACEAE characterise this subzone. The characteristic features of KLN-Bb include high values of CHENOPODIACEAE AND AMARANTHACEAE, the disappearance of ARTEMISIA and a marked increase of BRASSICACEAE.
KLN-C	142–79 cm (1340–1025 cal yr BP)	Among the AP group, EPHEDRA DISTACHYA TYPE is omnipresent throughout the zone with values up to 2.8%. Single grains of JUGLANS, CORYLUS AVELLANA and CORNUS MAS TYPE pollen were encountered. BRASSICACEAE and ARTEMISIA show low values while CHENOPODIACEAE AND AMARANTHACEAE, as the main pollen type, peaks in the middle of the zone. Another important constituent is LACTUCEAE, particularly in the upper half of the zone. CARYOPHYLLACEAE and POLYGONUM AVICULARE show moderate values.
KLN-D	79 cm to the mire surface (since 1025 cal yr BP)	This zone is divided into two subzones: KLN-Da (79–29 cm; 1025–340 cal. yr BP) and KLN-Db (29 cm to the mire surface; since 340 cal yr BP). The main features of the first subzone include the relatively continuous curves of a few AP types, namely QUERCUS, JUNIPERUS, PINUS and, to a lesser degree, CARPINUS. Of NAP types,CHENOPODIACEAE AND AMARANTHACEAE is the most abundant pollen type of the subzone, followed by fluctuating values of BRASSICACEAE and CARYOPHYLLACEAE. ARTEMISIA slightly increases while LACTUCEAE decreases. For wetland types, CYPERACEAE and POACEAE substantially increase. Subzone KLN-Db is characterised by increased CARYOPHYLLACEAE, a small peak of POLYGONUM AVICULARE, A noticeable decline of BRASSICACEAE and constant values of RUMEX ACETOSA TYPE. CYPERACEAE remains high and POACEAE produces a remarkable peak in the topmost sample.

and preserved well in sediments (El-Moslimany 1990; Messager et al. 2013). Furthermore, even highly damaged grains are rather easily recognisable. Surface sample studies in western (Wright et al. 1967), northeastern (Moore and Stevenson 1982) and north-central Iran (Dehghani et al. 2017) have shown high representation of wind-pollinated Amaranthaceae. Dehghani et al. (2017) furthermore claim that pollen representation in this family differs along taxonomic groups and that the euhalophytic chenopods produce far more pollen compared to species in ruderal or xeric habitats.

We postulate that the high and rather stable curve of CHENOPODIACEAE AND AMARANTHACEAE reflects the larger scale vegetation cover in northwestern Iran and that the main source area for this pollen type in the Kalan record will have been outside the APA. Source areas may have included the marshlands along the Aras River or even the distant salt marshes along the eastern coasts of Lake Urmia to the west and/or the Aralo-Caspian lowlands to the east (Figure 1), which are two out of four main distribution areas of Irano-Turanian halophytes in Iran (Akhani 2004). Regional over-representation of Amaranthaceae pollen is frequently recorded from a wide array of wetlands/lakes in neighbouring regions (e.g. Caucasus: Connor 2011).

At a finer scale, changes in the composition of the late Holocene steppe vegetation of the alpine zone in the Arasbaran area are evident from substantially fluctuating values of the main pollen types, e.g. ASTERACEAE, BRASSICACEAE and CARYOPHYLLACEAE. The overall long-term vegetation succession in the area is characterised by the dominance of a variety of Asteraceae, mainly belonging to the tribe Lactuceae (during the period 3000–1440 cal yr BP), followed by a vegetation with *Artemisia* spp. and Brassicaceae (1440–1330 cal yr BP), a re-expansion of Lactuceae (1330–1030 cal yr BP) and Brassicaceae (1030–330 cal yr BP) and, finally, Caryophyllaceae (since 330 cal yr BP). Surface sample studies in arid and semi-arid regions (e.g. Moore and Stevenson 1982) have shown that some of these insect-pollinated taxa, such as Asteraceae and Brassicaceae, are quite well represented in modern pollen assemblages.

Various observations indicate the presence of an extensive semi-desert steppe in the area over the period 3000–2100 cal yr BP. These observations particularly include the virtual absence of forest tree pollen and the rather high values of EPHEDRA DISTACHYA TYPE of which the producers normally represent (extremely) dry climatic conditions (Prentice et al. 1996; Wick et al. 2003; Zhao et al. 2012). A further indication of a dry steppe environment during this period is the abundance of a variety of Asteraceae–Lactuceae taxa (Figure 3). Also, the roughly synchronous pollen record of GNL peatland in suburban Urmia in west Azerbaijan province (Figure 1) suggests, for the period 2650–2350 cal yr BP, the presence of a dry steppe, as indicated by negligible values of QUERCUS along with high values of the CHENOPODIACEAE/ARTEMISIA ratio (Zavvar et al. 2017).

This inferred dry period corresponds with a well-known Near-East Aridification Phase (Ocakoğlu et al. 2016). A wealth of lake data in Turkey show arid conditions during the period 3000 to 2100/2000 cal yr BP (Roberts et al. 2001, 2008; Schilman et al. 2001; Wick et al. 2003; Kaniewski et al. 2007; Finné et al. 2011; Ocakoğlu et al. 2016). A deforestation phase and expansion of a steppic environment starting at around 3000 cal yr BP, and driven by climate and human impact, have been reported from the southern Caucasus (Messager et al. 2013).

The increasing abundance and diversity of tree pollen (e.g. CARPINUS, JUNIPERUS and QUERCUS) and a notable decrease of LACTUCEAE and CHENOPODIACEAE AND AMARANTHACEAE during the period 2100–1400 cal yr BP may suggest slightly wetter conditions that may have been associated with an elevated alpine timberline in the APA. The autecology of *Artemisia* species in northwestern Iran may provide more insight into the climatic conditions of the area as inferred from the Kalan record. Compared to Amaranthaceae, *Artemisia* species tend to occur in less dry situations (El-Moslimany 1990; Roberts et al. 2011). More specifically, the highlands of northwestern Iran are inhabited by quite a number of orophytic *Artemisia*, such as *A. haussknechtii*, *A. persica* and *A. austriaca*, which require relatively high moisture (Zavvar et al. 2017). We may accordingly take the corresponding rise of ARTEMISIA pollen (Figure 3) as an indication of rather humid conditions. Studies in the United States (e.g. Meyer 2008) propose successful seed germination of many *Artemisia* species under snow cover. In the Alpine/subalpine zone of northwestern Iran, the values of ARTEMISIA pollen may thus be positively correlated with snowfall (and the ensuing soil water content in spring and summer months).

Also, the increased values of wetland types, particularly CYPERACEAE, could have resulted from rising local (i.e. wetland) water tables possibly associated with a regional less dry period. Talebi et al. (2016) ascribe a substantial rise of the spores of *Riella*, an aquatic submerged liverwort, in the Lake Urmia record (site SK in Figure 1) at around 2100–1850 cal yr BP to an increased lake level. Other eastern Mediterranean records (Finné et al. 2011; Ocakoğlu et al. 2016) show synchronous climatic amelioration (i.e. wetter conditions). A high-resolution lake-level record of the late Holocene Dead Sea suggests wetter conditions around 2100 cal yr BP, based on a lake-level high-stand, which is further supported by historical and archaeological evidence from the area (Bookman et al. 2004).

The overall pollen composition for the period 1400–1020 cal yr BP implies the recurrence of severe drought, with the regional prevalence of steppe-like vegetation composed mainly of Amaranthaceae, Asteraceae, Caryophyllaceae, *Ephedra* spp. and *Polygonum* spp. This protracted dry period was possibly interspersed with a decadal-scale less dry climate as the moderate peak of the AP curve, centred at 1330 cal yr BP, suggests (see below).

At a local scale, the wetland must have been desiccated over this period, as can be inferred from the virtual disappearance of sedge and grass pollen. The increased values of POLYGONUM AVICULARE TYPE pollen may be another indicator of a lowered water table in this period. This postulate arises from the fact that the curves of CYPERACEAE and POLYGONUM AVICULARE TYPE pollen tend to behave oppositely in the KLN pollen diagram. Djamali et al. (2009) found colonies of *Polygonum* cf. *aviculare* in the eulittoral zone of Lake Almalou in the northwest of Iran. Further evidence for a rather dry wetland are the high values of sand and pebble input in the basin at the corresponding depths (Table 2) and the curve of indeterminable grains (Figure 3). A dry period is also recorded from Lake Mirabad in western Iran at 1500 cal yr BP (Stevens et al. 2006).

In line with our findings from the Arasbaran area, a dry period lasting from 1700 to 1000 cal yr BP is proposed by Ehrmann et al. (2007) for the north and south catchments of the Aegean Sea. In addition, pollen-, stable isotope- and diatom-based palaeoclimate reconstructions in Anatolian lakes suggest centennial-scale dry climatic conditions for at least part of the period 1800–1300 cal yr BP (Ocakoğlu et al. 2016 and references therein). Sea-level reconstruction for the Dead Sea (Bookman et al. 2004) suggests low lake levels in the period 1950–1450 cal yr BP, briefly interrupted by a high-stand at around 1600 cal yr BP, i.e. during the Byzantine period.

Our pollen record indicates minor re-expansion of lower elevation oak and hornbeam forests in the APA, particularly between 1000 and 350 cal yr BP. This, along with decreased values of LACTUCEAE and CHENOPODIACEAE AND AMARANTHACEAE and increased values of ARTEMISIA (decreased CHENOPODIACEAE/ARTEMISIA ratio), may point to less dry climatic conditions. Wetter conditions may be inferred from the substantial rise of pollen of Cyperaceae and Poaceae, which could have expanded following a rise in ground water table in the Kalan wetland. The lithology of the core (see Figure 3 and Table 1) shows the accumulation of highly organic materials largely corresponding to this period. This period correlates with the Mediaeval Climatic Anomaly (MCA) through the Little Ice Age (LIA). Some areas experienced prolonged droughts during the MCA, while other areas received exceptional rainfall (Bradley et al. 2003). In central Turkey, diatom analysis of Lake Nar sediments (Woodbridge and Roberts 2011) indicates a relatively wet phase for the MCA (950 to 1400 AD). A roughly synchronous wet period has also been inferred for the eastern Mediterranean marine sediments from the Dead Sea (Bookman et al. 2004) and southern Oman (Fleitmann et al. 2004).

Based on palynological studies (e.g. Djamali et al. 2009), during the LIA northwestern Iran would have experienced lower annual temperatures and 'episodic increases in the annual precipitations'. Whereas a clear distinction in the frequencies of the upland vegetation between the MCA and LIA is hardly detectable by our pollen record, the wetland vegetation, i.e. Cyperaceae and Poaceae, must have reacted in more or less the same fashion to different local hydrology. The Kalan pollen record suggests that wetalnd taxa were in general favoured by the (inferred) raised water table in both periods, particularly during the MCA.

4.3. Anthropogenic activity

Evidence for human interference with the landscape surrounding the Kalan wetland is vaguely present throughout the pollen record. We may interpret the occurrence of Corylus avellana, Cornus mas and Centaurea solstitialis type in the lowermost spectra (see Figure 3) as the earliest indication of anthropogenic activity in the highlands of the APA (see Djamali et al. 2009). High values of Lactuceae may reflect grazing pressure in the area (see Behre 1981). Pollen producers of C. solstitialis type are, in the circum-Mediterranean and Near Eastern regions, normally associated with cereal cultivation (Bottema and Woldring 1990; Djamali et al. 2009).

Both *Corylus avellana* (hazelnut) and *Cornus mas* (Cornelian cherry) are natural constituents in the low- to mid-elevations of the Arasbaran area. Small populations of hazelnut are normally encountered along river/brook valleys (800–1200 m asl) on north- to northeast-facing slopes. *Cornus mas* is a small tree or shrub intermixed with a variety of broad-leaved taxa on warm and dry slopes at an elevation between 800 and 1400 m (Ghanbari Sharafeh et al. 2010; Sagheb Talebi et al. 2014; Ahmad Alijanpour pers. comm. 2017). Both taxa are nowadays of socio-economic and medicinal value (e.g. Kyriakopoulos and Dinda 2015). Fruit production of *C. mas* is around 900 kg/ha (Ghanbari Sharafeh et al. 2010). Flower and fruit production of both taxa are favoured where the forest canopy is opened up. Therefore, local inhabitants frequently eliminate other broad-leaved species in support of *C. mas*. Given the insect-pollinated nature of this species, even its sporadic occurrences in Kalan area may correlate with human impact in Arasbaran.

A rather strong human-induced signal dates back to around 1350 cal yr BP, where the curves of Juglans regia, Corylus avellana and Cornus mas show small peaks. Like *C. avellana*, *Juglans regia* grows in wet valleys far away from our study site. We interpret the occurrence of these taxa as an indication of the expansion of fruit cultivation in the Arasbaran area. The dating concurs rather well with the Sassanid period, when fruit cultivation flourished for over two centuries (Djamali et al. 2009).

The past millennium is characterised by a diversification of steppe vegetation in the highlands of the APA (Figure 3), as reflected by the presence of hitherto absent or very rare pollen types, including Polygonum aviculare type, Euphorbia, Plantago lanceolata type and Rumex acetosa type. In their palaeoecological study of Almalou peatland, northwest Iran, Djamali et al. (2009) considered the cumulative curve of P. lanceolata type, R. acetosa type, and C. solstitialis type pollen as an indication of intensified agropastoral activities. P. lanceolata type and R. acetosa type are frequently taken as indicators of low-intensity grazing (Behre 1981; Djamali et al. 2009; Connor 2011).

5. Conclusion

This study provides a record of the late Holocene vegetation dynamics of the 'alpine zone' in the APA under the (combined and interacting) influence of climate change and human impact.

We postulate that the regional vegetation in Kalan area has remained largely stable over the last three millennia, with some minor fluctuations. Forest vegetation has never approached the elevation of Kalan peatland and its surroundings within the time span covered by our record. However, substantial changes in local (wetland) vegetation, as driven by changes in local hydrology, are indicated in the record (Figure 3). Drier periods may have corresponded with the expansion of Lactuceae and other Asteraceae (except *Artemisia*, probably), whereas periods of higher water tables may be reflected by the expansion of Cyperaceae and Poaceae.

Amaranthaceae and an array of Asteraceae, in particular Lactuceae and *Artemisia*, must have been the major constituents of the regional vegetation in Arasbaran during the late Holocene, while sedges and grasses are shown to have been the most abundant wetland plant taxa.

The inferred climatic events in our study correspond reasonably well with similar events deduced from other east Mediterranean records. Any inter-site differences could be due to chronological imprecision (cf. Roberts et al. 2011), unfavourable preservation status of the pollen and/or local differences in topography and hydrology.

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No potential conflict of interest was reported by the authors.

Author Contributions

ER, AS and BH conceptualized the study; TT performed pollen analysis under the supervision of ER; ER led the writing of the manuscript; KA prepared Fig. 1 and the age-depth model. The paper has benefited greatly by valuable remarks of all co-authors.

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