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Vegetation, climate and environmental history of the last 4500 years at lake Shkodra (Albania/Montenegro)

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Abstract

Three parallel overlapping cores have been taken in the Albanian side of Lake Shkodra (Albania/Montenegro). The chronological frame of the record, spanning approximately the last 4500 years, has been assessed using four radiocarbon dates and four well-known tephra layers of Italian volcanoes. Multidisciplinary analyses turned out to be decisive to understand environmental, climatic changes and human impact. Here, we focus on palynology. The humidity at Shkodra was always enough to allow the developing of a luxuriant arboreal vegetation. The pollen percentage diagram does not record important changes in terrestrial plants percentages. Arboreal pollen (AP) shows only a rather slight decrease, with 'natural forests' replaced by intensive cultivation of chestnut and walnut in the last seven/eight centuries. The rather minimal changes in composition and dominance are because of the fact that the pollen rain comes from different vegetation belts, from the Mediterranean to the alpine one. Two major periods of humidity are found, one at the base of the pollen concentration and influx diagram, before 4100 yr BP, the other at 1300 yr BP. Minima in pollen influx and concentration occurred soon before 4000, at ca. 2900 and at ca. 1450 yr BP These minima, interpreted as aridity crises, show a temporal coincidence with the so-called Bond events 1-3 already found in other central and eastern Mediterranean records. The minimum in AP occurring after 500 yr BP could represent the record of the 'Little Ice Age', even if it could be the effect of a strong land use.

Keywords

Bond events, climate and environmental changes, human impact, Lake Shkodra, Mediterranean, mid to late Holocene, Palynology

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Introduction

In the present-day debate concerning the possible effects on biodiversity of the on-going climate change and of human impact, the understanding of the environmental feedback on past climatic and environmental variations is of fundamental interest. Although significant papers retrace in detail the recent vegetation and climate history of central-eastern Mediterranean (e.g. Combourieu-Nebout et al., 2013; Djamali et al., 2013; Di Rita and Magri, 2009, 2012; Jahns, 2005; Jahns and Van den Bogaard, 1998; Karkanas et al., 2011; Kouli and Dermitzakis, 2008, 2010; Noti et al., 2009; Sadori et al., 2010a, 2011, 2013; Tinner et al., 2009) within the increasing interest of climatic and environmental evolution under Mediterranean conditions, most is still to be known.

In particular, the Balkan region features a number of wide natural lakes that record Pleistocene and Holocene palaeoenvironmental history. Climate and vegetation history for upper Pleistocene and Holocene sediments (Lake Ohrid and Lake Prespa) has been described in many recent papers (Aufgebauer et al., 2012; Leng et al., 2010; Panagiotopoulos et al., 2013; Wagner et al., 2009, 2010). Lacustrine sediments of Lake Dojran and Lake Butrint have been characterized and used to understand environmental changes (Ariztegui et al., 2010; Francke et al., 2013). Denèfle et al. (2000) and Bordon et al. (2009) investigated the vegetation history and climate interpretation of former Lake Maliq.

The role in the past of either environmental or human forcing in shaping the present landscape is still a matter of discussion. Anyway, it is becoming clear that a synergy between climate changes and human agency took place in different ways in different time periods and ecosystems (Bowes et al., in press; Di Pasquale et al., 2014; Kouli, 2012, in press; Magny et al., 2013; Mercuri and Sadori, 2014; Mercuri et al., 2011, 2013, 2014; Pepe et al., 2013; Sadori et al., 2004, 2010b, in press; Zanchetta et al., 2013). Whether human societies adapted to climate changes or collapsed is still matter of debate.

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Recently, several authors discussed the late-Holocene sedimentology, palaeolimnology and tephrochronology of Lake Shkodra (Mazzini et al., 2014; Sadori et al., 2012; Sulpizio et al., 2008; Van Welden et al., 2008; Zanchetta et al., 2012b).

Our contribution focuses on palynology and aims to provide new insights about the palaeoenvironmental history of the area. Moreover, in this study, we try to understand whether and at which extent human history has potentially interacted with environmental factors in one of the best-preserved area of the Balkans.

Site setting

Lake Shkodra, Liqeni i Shkodrës in Albanian, Skadarsko Jezero in Montenegrin, is the largest natural freshwater lake in the Balkan region (Figure 1). It is a transboundary lake located at the Albania/Montenegro border (42°21′54″, 19°09′52″ in the North, 42°03′15″, 19°30′00″ in the South, 42°03′15″, 19°30′00″ in the East, 42°21′19″, 19°01′28″ in the West). The lake surface is only at ca. 5–10 m.a.s.l., being quite variable through the years as not only the rainfall but also numerous rivers and subterranean springs abundantly feed the lacustrine water (Jacobi, 1978). The lake, of tectonic-karst origin, has a sub-elliptical shape and is ca. 45 km long and ca. 15 km wide. It has a coastline (including islands) 207 km long, and an average depth between 5 and 6 m. It is surrounded by NW-SE elongated reliefs (up to 2750 m.a.s.l.) parallel to the Adriatic Sea. To the southwest, the chain of the Tarabosa and Rumia mountains, from 10 to 15 km wide, peaks up to 1600 m. They separate the lake from the Adriatic Sea coast. The catchment (ca. 5500 km^2) mainly consists of carbonate rocks (limestones and dolomites), with minor exposures of siliciclastic rocks. The main tributary of the lake is the Moraca River, and the Bojana River is the only outflow, draining water towards the Adriatic Sea.

The lake area, depending on water level fluctuations, is quite variable, ranging from 353 km^2 (at a minimum lake level of 4.6 m.a.s.l.) to 500 km^2 (at a maximum lake level of 9.8 m) (Beeton and Karaman, 1981; Lasca et al., 1981; Van Welden et al., 2008).

Although the climate of the area is Mediterranean, with pronounced summer aridity (<50 mm of rainfall in July), very high rainfall amounts are recorded on the mountains surrounding the lake. For the period 1970–1990 at the meteorological stations of Podgorica and Shkodra, the measured rainfall is between 2000 and 2800 mm/yr, even if some areas received over 3000 mm annually. It is remarkable that humidity is never lower than 50% as sunshine hours and temperature in summer are high, causing a high evaporation (Keukelaar et al., 2006). In Shkodra, the mean annual air temperature is between 14 and 16°C, with the highest average temperature recorded in August (21.4–27.5°C) and the lowest average in January (0.5–6.5°C) (APAWA and CETI, 2007). Temperature in winter is low because of the high elevations and predominant easterly and northerly winds. Wind activity is determined by cyclonic factors of the Mediterranean and Balkan areas, but also by local factors.

The lake and its surroundings are among the richest reservoirs of plant and animal life of all Europe, so the region is considered as a biogenetic reserve of European importance (Keukelaar et al., 2006). In the watershed of the lake, Dhora (2005) surveyed a very high number of botanical and animal species: 1900 vascular plants (147 aquatic ones), 1100 microalgae (420 diatom ones), 57 mammals (3 aquatic ones), 282 birds (112 aquatic), 54 fishes, 6 amphibians, 28 reptiles (4 aquatic ones), 6000 insects (210 aquatic ones) and 54 freshwater molluscs. Considering the aquatic microfauna, Petkovski (1961) described 9 species of ostracods from the Montenegro side. Pulevic et al. (2001) found 12 species. A detailed study on the present-day ostracods of the lake is on-going (Mazzini et al., 2014).

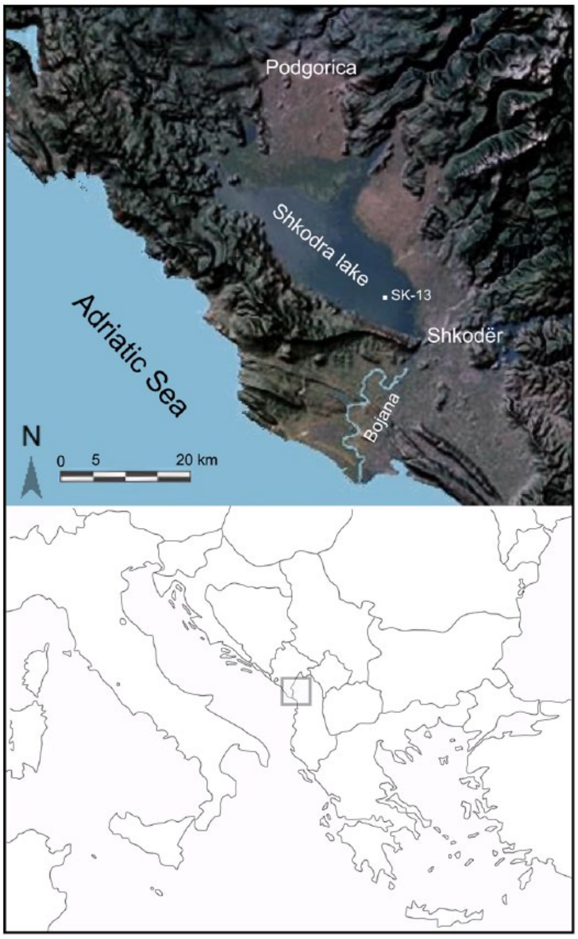

Figure 1. Location map of Lake Shkodra and of coring site (source: esri landsat shaded basemap).

Concerning the flora, the Mediterranean and Balkan elements predominate, but several species of Central Europe have their southern distribution limit in the area, giving to the region a special phytogeographic interest. In fact, the geographic, geomorphological and climatic features of the lake basin, in particular the proximity to the sea and the presence of high mountains around the lake, favour the spread of rich and diversified vegetation. The vegetation is organized in altitudinal belts, from the lake level to top mountains, ranging from evergreen Mediterranean vegetation to alpine pasturelands. Besides aquatic and riparian species, the vegetation is mainly composed of Mediterranean shrubs, mixed oak woodlands and beech forests mixed with conifers. Among the last, fir, spruce and pines are quite common. Stands of willows grow as small forests or as randomly scattered trees, mainly on the northern shore and in the flooding area. Shkodra's oak (*Quercus robur* L. ssp. *scutariensis* Čer.) forests can be found only in few small stands with *Fraxinus oxycarpa* M. Bieb. ex Willd. and *Periploca greca* L. The *shibljak* vegetation (the local name for the evergreen Mediterranean scrubland) is found up to 300–500 m.a.s.l. It is mainly constituted by evergreen trees and shrubs like *Quercus ilex* L., *Phillyrea latifolia* L., *Juniperus oxycedrus* L., *Erica arborea* L., *Olea europea* L., *Arbutus unedo* L. and *Laurus nobilis* L. They are accompanied by many deciduous species like *Pistacia terebinthus* L., *Carpinus orientalis* Mill., *Crataegus monogyna* Jacq., *Paliurus spina-cristi* Mill., *Fraxinus ornus* L. From about 300 up to 700 m of altitude, the oak zone is found, with deciduous and semi-deciduous oaks like *Quercus trojana* Webb, *Quercus cerris* L., *Quercus petraea* (Matt.) Liebl., *Quercus frainetto* Ten. and *Quercus pubescens* Willd. At higher altitude, between ca. 600 and 1700 m, the beech belt is found. Common trees of this zone are *Fagus sylvatica* L., *Acer* *pseudoplatanus* L. and *Sorbus graeca* (Spach) Kotschy. In some areas, beeches are mixed with pines and may reach 1900 m. Among pines, the most common species are *Pinus leucodermis* Antoine and *Pinus nigra* J.F.Arnold. Alpine pastures cover the areas over 1800–1900 m of the lake basin. The only spread shrub of this zone is *Juniperus sabina* L. (APAWA and CETI, 2007; Keukelaar et al., 2006).

The fact that Lake Shkodra is a shallow lake favours the development of a rich aquatic flora with great variety. The total number of aquatic macrophytes for the whole area is 164 species belonging to 66 genera and 43 families. The phytoplankton population is mainly composed of diatoms (Keukelaar et al., 2006).

There is very little available archaeological and historical information about past human impact on the watershed. Unpublished data (Michael Galaty, personal communication) seem to date the start of prehistoric occupation in the watershed around 3000 years BC, with archaeological sites mainly located on the hills at that time. A detailed field survey concerning pottery was led, in the frame of the Shkodra archaeological project (PASH, Projekti Arkeologjike i SHkodres) 2010, by Maria Grazia Amore in the area at the southeast of the lake. PASH is directed by Lorenc Bejko and Michael Galaty. Preliminary data show that the pottery dated to Post-Medieval/Modern Period is overwhelming, especially in the plain, the Hellenistic/Roman Period is the second best represented, but with predominance in the hills. The same pattern of the last is followed by the pottery dated to the Classical Period. The important town of Shkodra, located to the southwest of the lake and 10 km apart the drilling point, was the capital of Illyria (mid-3rd century BC) conquered by Romans during the 2nd century BC. It soon became an important trade and military route. During the first years of 7th century AD, with Barbarian populations menacing the empire, the city was given by Byzantine emperors to Serbs which ruled, fighting against Bulgarians and Byzantines and giving hospitality to crusaders (the Serbian King Bodin welcomed the Provençal leaders in 1096), until 14th century when Shkodra surrendered to Venice, in order to have protection from the Ottoman Empire. After two sieges, the town became an Ottoman territory in AD 1479. Shkodra was a major city under Ottoman rule in southeast Europe until the early 20th century. This importance was because of its geo-strategic position connected through land-routes to Prizren, the other important Ottoman centre, and through the Adriatic Sea to the Italian ports. The city was an important meeting place of diverse cultures from other parts of the Empire, as well as influences coming westwards, by Italian merchants. Shkodra's importance as a trade centre in the second half of the 19th century was owed to the fact that it was an important trading centre for the entire Balkan peninsula and the whole Mediterranean. Over the last 100 years, Shkodra lost the economic autonomy it had enjoyed in previous centuries (Hoti, 1999; http://www.albanianhistory.net/texts20_1/AH1916_2.html).

Materials and methods

Three parallel overlapping sediment records cored down to the depth of 7.26 m (Van Welden et al., 2008) have been used for a multidisciplinary research. The cores were recovered in the Albanian side of the lake (Figure 1), and one composite sediment record was obtained using palaeomagnetic and sediment constraints. Tephra, geochemical, stable isotopes results have been published (Sulpizio et al., 2010; Zanchetta et al., 2012b). Ostracod results are in publication (Mazzini et al., 2014). Here, we focus on palynology. For pollen and microcharcoal analyses, a total of 56 samples was chemically processed at a fairly regular pace, once the record was dated. The chronological framing of the core (Figure 1), spanning approximately the last 4500 years, has been assessed using four radiocarbon dates and four well-known and well-dated tephra layers (Sulpizio et al., 2010). Two are from Somma-Vesuvius (Pollena, AD 472; Avellino, ca. 3800 cal. yr BP), one from Etna (FL, ca. 3300 cal. yr BP) and one from Campi Flegrei (AMS, Agnano Mt. Spina ca. 4400 cal. yr BP). In the text, ages are expressed as calendar years BP or AD.

For each palynological sample, 1/1.5 g of dry sediment was chemically processed with strong acids, HCl (37%) and HF (40%), and hot NaOH (10%). In order to estimate the pollen and microcharcoal concentration, a tablet containing a known amount of *Lycopodium* spores (Stockmarr, 1971) was added. To draw the pollen percentage diagram, different pollen basis sums have been used, following the criteria listed by Berglund and Ralska-Jasiewiczowa (1986).

Concerning the genus *Quercus*, three oaks pollen taxa have been distinguished following Smit (1973): *Quercus robur* type, which comprehends all deciduous oaks, *Quercus ilex* type including all the evergreen oaks, and *Quercus cerris* type, comprehending all semi-deciduous oaks. Oleaceae are broken down into *Fraxinus* cf. *oxycarpa, Fraxinus ornus, Phillyrea* and *Olea*. *Fraxinus* cf. *oxycarpa* includes *Fraxinus oxycarpa* Bieb. and *Fraxinus excelsior* L. as their pollen grains cannot be distinguished (Punt et al., 1981). As concerns hornbeams, they were morphologically separated in two pollen taxa: *Ostrya carpinifolia*/*Carpinus orientalis* and *Carpinus betulus*. As far as *Pinus*, all pollen grains were tentatively ascribed to 'montane' species on the basis of their size (Roure, 1985). *Pediastrum* colonies belong to different species, the most represented being *Pediastrum simplex*. The different species were not anyway routinely discriminated.

Charcoal particles were counted in pollen slides, measuring their shortest axis and sorting them in three dimensional fractions: 10–50, 50–125 and >125 µm. Particles between 10 and 50 µm provide an indication of regional fire; fragments between 50 and 125 µm give an image of fire occurrence at landscape/regional scale, while the occurrence of fragments >125 µm is generally taken as an evidence of local fire (Whitlock, 2001).

Pollen concentration (PC) has been used to elaborate influx data, once the chronology was assessed. Pollen and microcharcoal influx data are an estimation of the amount of pollen grains and charcoal fragments deposited in a given time (Berglund and Ralska-Jasiewiczowa, 1986). Pollen influx (PI) data depend on plant biomass. Charcoal influx data depend on the burnt biomass and are obtained from concentration data. These last are normalized into influx data using sedimentation rates.

Pollen percentages, concentrations and influx data are presented as single curves and 'ecological' groups together with microcharcoal data (concentration and influx) curves of the three dimensional fraction in Figures 2 and 3. The diagrams have been drawn (Tilia software, Grimm, 2011) with taxa curves against both time and depth scales. A dendrogram created using CONISS (included in TILIA software) was used to identify the four pollen assemblage zones (Figures 2 and 3).

Pollen results

Pollen of arboreal plants (AP) and pollen of non-arboreal plants (NAP) percentage, concentration and influx values of selected groups and taxa are shown in diagrams (Figures 2 and 3). AP is on average slightly over 84% (Figure 2a). From ca. 4500 (bottom core) to 800 yr BP, AP is on average 87%, ranging from 80% (at 3100 yr BP) to 94% (at 1950 yr BP). In the last seven centuries, AP% is ca. 74% on average with a minimum (68%) centred at around three centuries ago. PC values of AP (Figure 2b) are rather stable with minima at ca. 4000, 2900, 1450 and at 370 yr BP. PI values (Figure 2c), even if showing a similar trend and minima at the same ages, are less stable with important expansions at 4300 and 1300 yr BP.

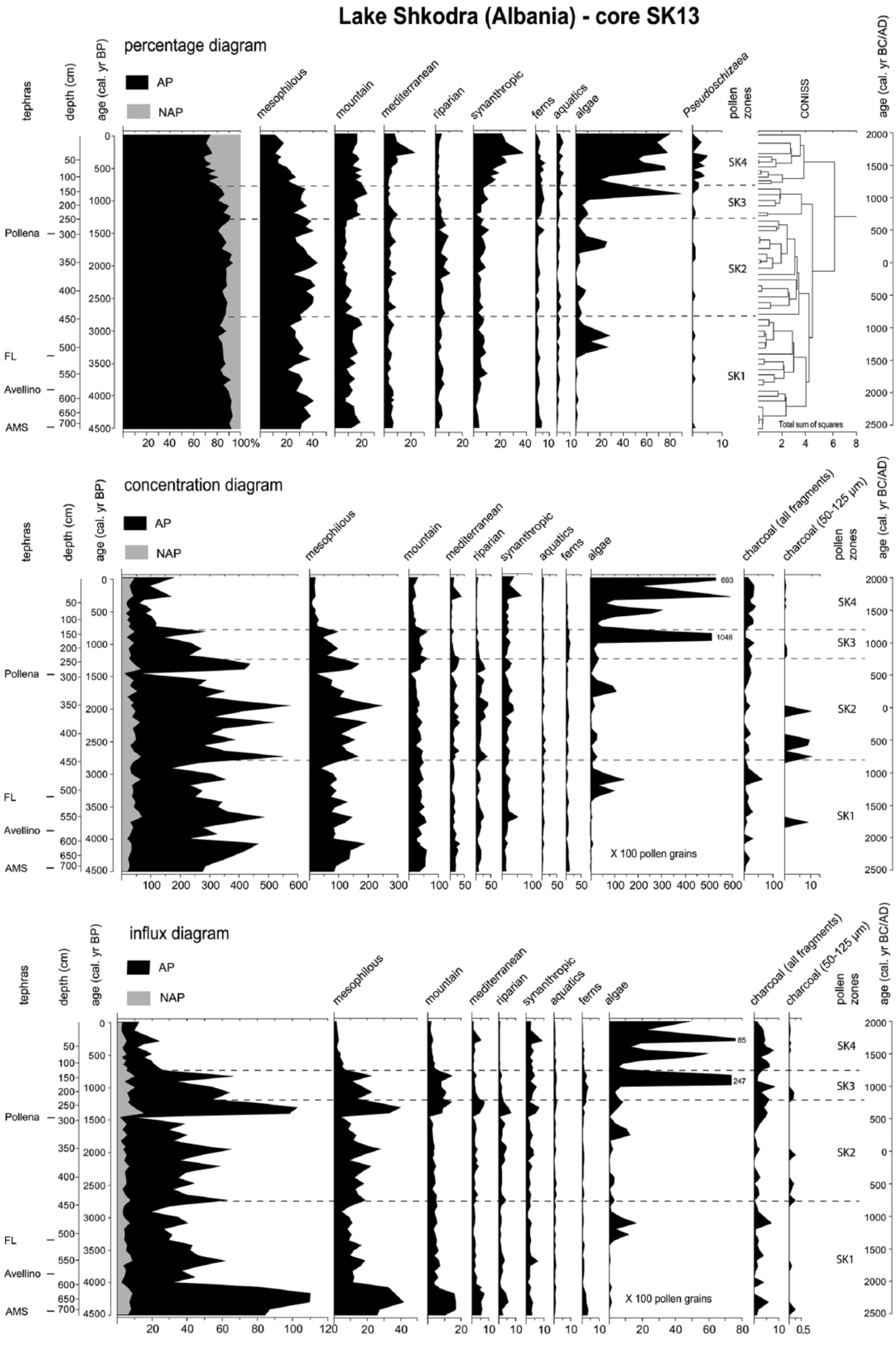

Figure 2. Pollen percentage (a, top), concentration (b, middle) and influx (c, bottom) diagrams of plant groups and algae. Mesophilous plants: *Quercus robur* type, *Quercus cerris, Carpinus betulus, Corylus, Castanea, Acer, Fraxinus oxycarpa, Ostrya/Carpinus orientalis, Tilia, Ulmus, Hedera*. Mediterranean plants: *Quercus ilex* type, *Olea*, Ericacee, *Fraxinus ornus, Pistacia, Rhamnus, Phillyrea, Ephedra*. Montane plants: *Pinus, Betula, Fagus, Abies, Picea*. Riparian plants: *Alnus, Salix, Populus*, Synanthropic plants: *Castanea, Juglans, Olea, Vitis*, Asteroideae, Chenopodiaceae, Cichorioideae, Leguminosae, *Plantago, Rumex*, cereals, *Secale*, Urticaceae. Aquatic plants: *Alisma, Myriophyllum alterniflorum, Myriophyllum spicatum*, Nympheaceae, *Sparganium, Typha*, Algae: *Pediastrum, Botryococcaceae, Cosmarium, Spirogyra, Zygnema*.

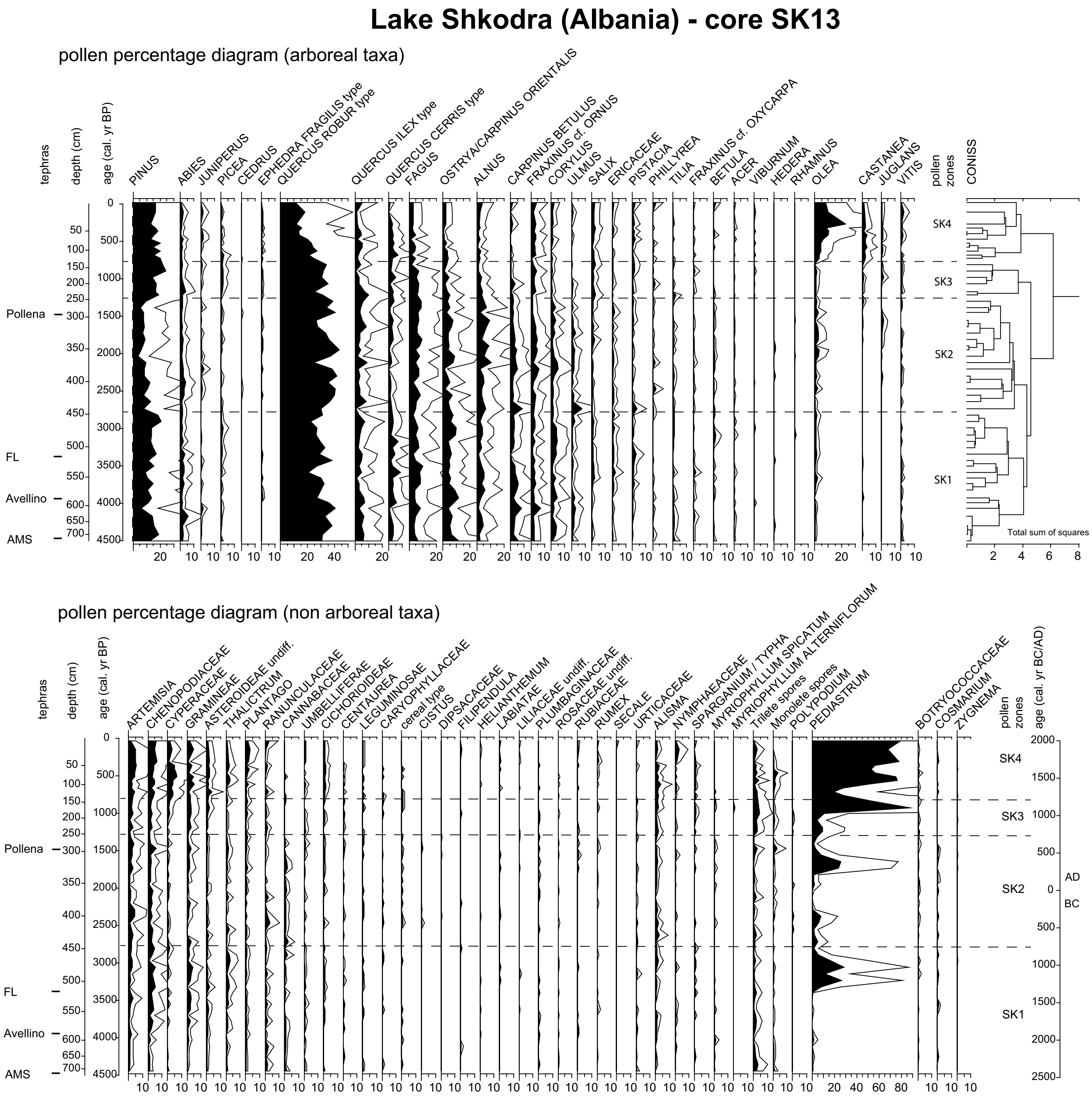

Figure 3. Pollen percentage diagrams of arboreal (a, top) and non-arboreal (b, bottom) selected taxa. Curve magnification 5×.

Main arboreal taxa (Figure 3a) typical of different vegetation belts that contribute to the pollen rain such as *Quercus robur* type (deciduous oaks), *Pinus, Fagus, Ostrya/Carpinus orientalis, Quercus ilex* type (evergreen oaks) and *Quercus cerris* type (semi-deciduous oaks) are the most represented. *Olea*, present from bottom core, increases in the last two millennia, with an important expansion (reaching 23% at 270 yr BP) since ca. 700 yr BP. Among riparian trees, *Alnus* is dominant. *Artemisia*, Chenopodiaceae, Gramineae and Cyperaceae are the most abundant herbaceous taxa, even if none of them ever exceeds 7% (Figure 3b). Algal remains are mainly concentrated in the last 1000 years (Figure 2), and the bulk is formed by *Pediastrum* colonies. Fires are never strong, as indicated by concentration and influx curves of microcharcoals between 50 and 125 mμ. The vegetation history is described using the four pollen assemblage zones.

Zone SK1 (4495–2818 yr BP/2545–868 years BC): AP% are between 80 and 93, total PC between 16,500 and 48,000 (pollen grains per gram) and total PI between 1900 and 11,000 (pollen grains per year): the highest AP% matches the highest AP influx value at ca. 4300 yr BP. Mesophilous taxa are the most abundant (Figures 2a and 3); between them, *Quercus robur* type (21–40%) is overwhelming. *Pinus* (6–21%), *Fagus* (3–10%), *Ostrya/Carpinus orientalis* (4–12%), *Carpinus betulus* (0–6%), *Quercus cerris* type (1–9%), *Quercus ilex* type (2–7%), *Alnus* (2–6%), *Corylus* (1–5%) and *Fraxinus ornus* (1–7%) are worth of mention. Herbs are quite rare (Figures 2b and 3), among them Chenopodiaceae are the most abundant (0–6%). An expansion of algae, mainly *Pediastrum* (Figures 2 and 3), is recorded from 3300 to 2900 yr BP, when riparian trees show a decrease (Figure 2a). Microcharcoal influx values show one peak at ca. 4200 yr BP in correspondence with an increase of total PI (Figure 2c). The second episode of fire is found at ca. 2900 yr BP. The most prominent peak of synanthropic taxa is found together with an AP influx and concentration peak at ca. 3700 yr BP.

Zone SK2 (2731–1299 yr BP/781 years BC–AD 651 years): AP% are between 81 and 94, total PC between 5300 and 57,000 (pollen grains per gram) and total PI between 1200 and 10,000 (pollen grains per year): the lowest total PC and influx, AP% and Mediterranean taxa percentage are recorded at 1400 yr BP. Mesophilous taxa are the most abundant in percentages and reach their maxima in this zone (Figures 2 and 3a); between them, *Quercus robur* type (25–43%) is overwhelming. *Pinus* is between 4% and 12%. The first occurrence of *Juglans* dates back to 2400 yr BP. *Olea*, present since bottom diagram, has a slight expansion between 2000 and 1600 yr BP. Large charcoal fragments (Figure 2) are recorded between 2700 and 2400 yr BP and again at 2000 yr BP. Algae, mainly constituted by *Pediastrum*, peak (25–26%) around 1700 yr BP.

Zone SK3 (1214–811 yr BP/AD 736–1139 years): AP% are between 81 and 91, total PC between 14,000 and 32,000 (pollen grains per gram) and total PI between 3300 and 7600 (pollen grains per year). *Pinus* increases (14–24%) and *Quercus robur* type shows a weak tendency to decrease (25–34%, Figure 3a). Important changes are not found in other taxa percentages, apart from trilete spores from ferns increasing with pine. At 900 yr BP there is a blooming of *Pediastrum*.

Zone SK4 (726 to −24 yr BP/AD 1224–1974 years): AP% are between 69 and 81, total PC between 6000 and 17,500 (pollen grains per gram) and total PI between 500 and 2400 (pollen grains per year). *Quercus robur* type (11–27%) shows a clear decrease and, together with *Pinus* (13–20%), is the most abundant taxon, followed by Mediterranean taxa (Figures 2 and 3a). Among the last, *Olea* (between 3–10% shows a peak of 23% at 270 yr BP), increases since bottom zone, mirroring the curve of *Quercus robur* type. *Castanea* (1–3%) shows an increase in this zone. Cyperaceae (1–7%) are rather abundant and many other herbs that belong to synanthropic taxa increase. In the last 500 years, *Pediastrum* is blooming, with percentage between 50% and 80%. Among aquatic plants *Alisma* and Nympheaceae are the most abundant. *Pseudoschizaea* (Figure 2a) has an expansion in this zone.

Interpretation and discussion

The percentage pollen diagrams do not record important changes in terrestrial plants all over the investigated period (Figure 3). The AP% curve (Figure 2) is showing only a rather slight decreasing trend from bottom to top diagram, with meaningful changes only in the last 700/800 years. Before 800 yr BP, AP% is always over 80% (average 87%), and subsequently shows an average value of 74%. Changes occurring in the last seven centuries can be ascribed to human impact and evidenced mainly by olive, but also by chestnut and walnut, plantation and a general clearance of 'natural forests' replaced by intensive cultivation of fruit trees. A confirmation of enhanced land use comes also from *Pseudoschizaea*, a NPP (non-pollen palynomorph) whose presence indicates erosion in the catchment (Pantaleón Cano Villanueva, 1997). Regional fires (all fragments) are quite important at ca. 4200, 3000 yr BP and in the last 1600 years. Traces of local fires/use of fire (50–125 μm) are found at ca. 4400, between 2750 and 2100, and between 1300 and 1200 yr BP. Only at 4400 yr BP, fire seems to be linked to the available fuel (plant biomass), as a peak of charcoal matches high AP influx and concentration values. In all the other cases, a relation between fire and trees is not found at Shkodra. The intensification of fire occurring in Classical and Roman times and in the early Middle Ages could be an evidence of human activity in the area as indicated by historical data.

A simple explanation for the rather low changes occurring in this record is that the pollen rain preserved in the Lake Shkodra sediments is coming from quite different altitudes (5–2000 m.a.s.l.). In the last 4500 years, the forests around the lake, organized in vegetation belts as today, showed minimal changes in composition and dominance (Figures 2 and 3). In the case of a climate change, plants could in fact migrate to an upper or lower vegetation belt. As a matter of fact, the humidity at Shkodra was probably always enough to allow the development of luxuriant arboreal vegetation and a 'simple' migration of the vegetation belts in altitudes. If this is a good point in explaining the high present-day biodiversity, it is rather disappointing for the study of climate changes that we know occurred in the second half of the Holocene. Such panorama is also not of great help in understanding changes in vegetation and landscape.

The rapid and significant changes recorded in PC and influx diagrams are of difficult interpretation but can represent the evidence of climate and environmental changes. These curves should in fact reflect changes in the plant biomass, the first being the 'raw data' and the second representing the data 'cleaned' using sedimentation rates (Berglund and Ralska-Jasiewiczowa, 1986). Minima of PC and PI can be considered as moments of forest opening.

Under this light, important changes happened soon before 4000, at ca. 2900 and 1450 yr BP, in correspondence with minima in PI and PC probably because of strong decrease in humidity. These minima show a temporal coincidence with the so-called North Atlantic Bond events 1-3 (Bond et al., 1997), found also in other central and eastern Mediterranean records (Sadori et al., 2011, in press).

Considering the PI record of AP, two major periods of humidity are found, one at the base of the diagram, before 4100 yr BP, the other at 1300 yr BP. Both these periods have a correspondence in the $\delta^{18}O$ record (Figure 3 in Zanchetta et al., 2012b). According to archaeological data, there is no evidence of early Bronze Age settlements by the lake (the lake was at that time a marsh, see Figure 12 in Mazzini et al., 2014), while Serbs ruled the city of Shkodra since 7th century AD. The minimum in AP PI occurring after 500 yr BP (centred at 370 yr BP) could represent the record of the 'Little Ice Age' (LIA), even if it has possibly a different explanation, as this could be also the effect of an increasing land use under the Ottomans.

Beside the use of concentration and influx data, another way to interpret pollen data is to use cumulative curves of vegetation types, depicting possible 'migration' of vegetation belts (Figure 2) caused by changes in precipitation and temperature. Of course, the first climatic parameter is the main limiting factor in Mediterranean environment and the easier one to detect.

Mesophilous vegetation is overwhelming along the recorded 4500 years, with slight changes of difficult interpretation. Maxima in mesophilous vegetation (influx and concentration) are found at 4100 yr BP (between AMS and Avellino tephras) and at 1300 yr BP. The $\delta^{18}O$ record (Figure 4 and Zanchetta et al., 2012b) evidences the presence of a humid period before 4100 yr BP. This was also found in the lacustrine sediments of Lake Dojran (Francke et al., 2013). Triantaphyllou et al. (2013) found a warm and humid phase recorded in the Levantine Sea and Aegean Sea sediments between 5500 and 4000 yr BP. In one of the records (NS14, near Kos Island, Figure 1), there is an expansion of deciduous oaks (the bulk of mesophilous vegetation at Shkodra) between 5200 and 4100, with a decrease at 4300 yr BP. A decrease in humidity at ca. 4300 yr BP is also found to the Southeast of Shkodra both in speleothems (Soreq cave, Bar-Matthews and Ayalon, 2011) and in archaeobotanical records (Arslantepe, Masi et al., 2013a, 2013b, 2014). Falls of AP centred at ca. 4200 yr BP were found in other central and eastern European pollen records (Di Rita and Magri, 2009; Sadori et al., 2004, 2011, 2013). Also other proxies, such as lake level records and glacier advances (e.g. Giraudi et al., 2011; Magny et al., 2009; Zanchetta et al., 2012a), indicate changes in humidity in the same period.

At Shkodra, montane vegetation is the second in importance and has a percentage reduction in zone SK2, between ca. 2700 and 1300 yr BP (Figure 2). This seems to be a warm period with

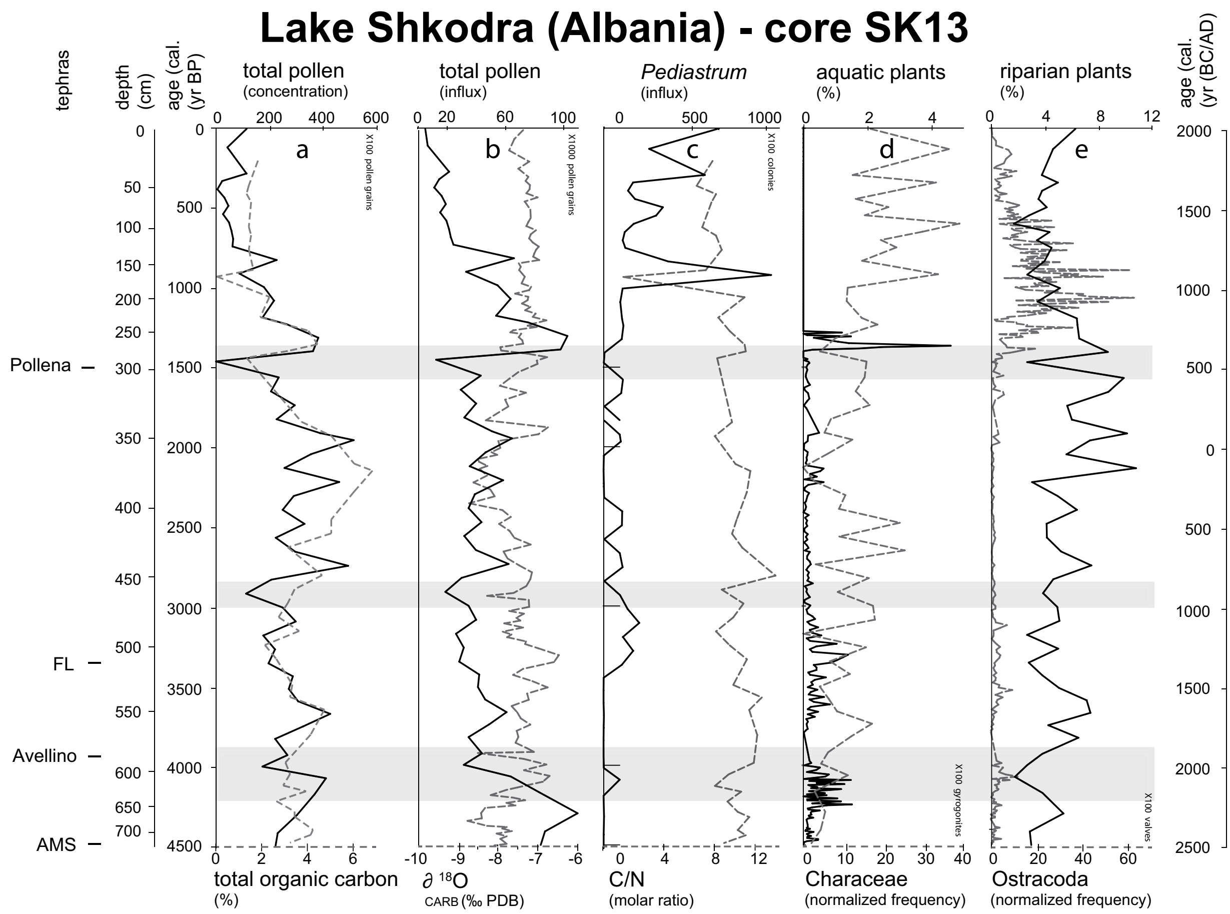

Figure 4. Comparison between pollen, continuous line (this paper), and other proxies, dotted line (Mazzini et al., 2014; Zanchetta et al., 2012b). The light grey rectangles mark arid phases roughly corresponding to the ages of Bond events 1-3 (Bond et al., 1997).

humidity as high as that recorded before 4100 yr BP. The $\delta^{18}O$ curve from the same sediment record (Zanchetta et al., 2012b and Figure 4b) registers maximum humidity between 2700 and 1200 yr BP, apart from a dry episode around 1850–1900 yr BP. Another important change in the vegetation physiognomy occurs at ca. 1200 yr BP, with mesophilous, Mediterranean and riparian trees decreasing, while montane ones and ferns increase (Figure 2). The increase of montane vegetation is mainly because of 'montane' pines pollen and the meaning of this environmental change is difficult to interpret.

Analyses of ostracods and Characeae contained in the sediment core indicate that a sharp change in the water environment happened around 1200 yr BP (Figure 4e and f). The interpretation of this phenomenon (Mazzini et al., 2014) is at the same time simple and complex, confirmed by historical sources and consists in the hypothesis of a transition from a marsh to a lake only around 1200 cal. yr BP. A climatic cause for this environmental change is excluded, and could be related to hydrological changes in the emissary of the lake (Mazzini et al., 2014). Pollen data confirm the non-climatic origin of this change.

In Figure 4, some curves are coupled according to either particular parallelism (PC vs total organic carbon (TOC)) or apparent dissimilarity (PI versus $\delta^{18}O$; *Pediastrum* colonies versus Carbon Nitrogen ratio (C/N); pollen of water plants (WP) versus Characeae gyrogonites, pollen of riparian plants (RP) versus ostracods frequency).

The climate signal (Figure 4a and b) obtained by PC and PI is in good agreement with geochemical indicators (TOC and $\delta^{18}O$). The amount of pollen preserved in the sediments has a quite similar trend to that of organic carbon, with the clear meaning that plant biomass is strongly influencing the quantity of carbon deposited in the lake. Indeed, such a good similarity is not found between 2500 and 2000 years ago.

Arid phases are indicated by both PI (high values) and $\delta^{18}O$ (low values) in the two quite specular curves (Figure 4). They are marked by grey shaded rectangles and show a good correspondence with Bond events (Bond et al., 1997). Between ca. 2400 and 2000 years ago, the correspondence between the two curves is always amazing, but less effective.

The C/N curve shows a strong decrease just before the blooming of *Pediastrum*, a colonial alga (Figure 4c). This minimum can be easily explained. It is well known that C/N ratios help to distinguish between algal and land-plant origins of sedimentary organic matter. This distinction arises from the absence of cellulose in algae and its abundance in vascular plants and the consequent relative richness of proteinaceous material in algae, and it is largely preserved in sedimentary organic matter (Jasper and Gagosian, 1990; Meyers, 1994). The minimum found in the curve C/N matches the minima found in PC and PI values of terrestrial plants. The three peaks of *Pediastrum* occurring in the last millennium could have been also favoured by water pollution because of agriculture and livestock (Janssen, 1968). Between the 11th and 13th century, the passage of the crusaders in Albania and in the region of Shkodra could be an explanation for this rising impact occurring since the 11th century (Elsie, 2010).

Comparing WP percentages and Characeae occurrence (Figure 4d), it appears clear that when the first ones increase, the last show minima. This pattern occurs until ca. 1300 yr BP. After this date, Characeae disappear and WP increase. This could find a proper explanation in an increase of lake level (Mazzini et al., 2014).

In the last diagram (Figure 4e), we compare ostracods and RP. The two curves are often specular, generally suggesting that if the lake level rises, the ostracods increase and the shoreline becomes more distant. This is indicated by a reduction of riparian trees. The most important change seems to occur at ca. 1300 yr BP.

Conclusion

In the investigated pollen record, no important changes in plant physiognomy are found, probably because of the environmental features of the lake catchment (orography). Forests, mostly deciduous ones, are dominant all over the investigated period. In the case of a climate change, vegetation could have migrated to different altitudes and plants typical of all the vegetation belts found at present could have been able to survive. The fact that the lake area has a very high total biodiversity (species–area relationship = 0.875, Keukelaar et al., 2006) finds a confirmation on the vegetation history depicted by palynology. In the last 4500 years, the aridity was never enough to prevent the presence of luxuriant vegetation.

The last millennium is an exception to the previous pattern, with a strong increase of Mediterranean and cultivated trees and use of fire, because of very high human impact. This land-use change can be easily explained as in the mentioned period, many populations contended the supremacy of Shkodra, the town located 10 km to the southeast of the coring site. Increasing impact is visible since AD 1200 (the crusaders of 1101 were there and Venetians obtained from Byzantine to rule the area in the 14th century AD) and indicated also by NPP as *Pseudoschizaea*. The vegetation belt most affected by this important land use (olive tree and chestnut cultivations in particular) is the mesophilous one. This quite late human impact is in agreement with the (scarce) archaeological and historical data that suggest a quite late use of the plains surrounding the lakes. Following Mazzini et al. (2014), the lake was a swampy area until Middle Ages. A close comparison of palaeoenvironmental and archaeological data is in progress and will hopefully provide a key to understand such complex human and environmental dynamics.

Climate changes are detected in AP concentration and influx diagrams, with minima indicating meaningful forest openings. The major changes are recorded at ca. 4000, soon after 3000 and at ca. 1500 yr BP. These are in good agreement with geochemical data from the same core ($\delta^{18}O$ and TOC, Zanchetta et al., 2012b). There is also a good correspondence between forest openings at Shkodra and temperature decreases in northern Atlantic cores (Bond et al., 1997). The traces of 'Medieval Warm Period' (MWP) and of the LIA are not visible in the pollen record, probably masked by a strong human impact.

Environmental changes are easily detected through a strict comparison with palaeolimnological data (ostracods and Characeae, Mazzini et al., 2014). Pollen data (see Figure 4e, RP versus ostracods) are in agreement with the hypothesis of a lake level increase at ca. 1300 yr BP. The fact that there is a contemporary percentage decrease of deciduous elements and an increase of montane taxa could reinforce this hypothesis: in the case of an increase of both the lake level and surface, the flat lands could have been submerged. In the pollen percentage diagram, this would imply a decrease in mesophilous taxa (mainly oaks) previously widespread there. Pollen analyses confirm that there is not a climatic cause for this change that, as expected, is not visible in the $\delta^{18}O$ record.

The multidisciplinary approach followed in the study, although enhancing the difficulties in the interpretation of existing links between single proxies, once again proved to be a precious tool in distinguishing the different signatures occurring in the sediment. In fact, palynology alone as well as ostracodology or geochemistry could not disentangle three fundamental aspects: climate change, environmental change and human impact.

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