Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

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

Laura Sadori[1*], Marco Giardini[1], Elsa Gliozzi[2], Ilaria Mazzini[3], Roberto Sulpizio[4], Aurelien van Welden[5], Giovanni Zanchetta[6]

[1] Dipartimento di Biologia Ambientale, Università "La Sapienza", Roma, Italy
[2] Dipartimento di Scienze della Terra, Università Roma3, Roma, Italy
[3] Istituto di Geologia Ambientale e di Geoingegneria, CNR, Monterotondo (Roma), Italy
[4] Dipartimento di Scienze della Terra e Geoambientali, Università degli Studi di Bari, Bari, Italy
[5] Geological Survey of Norway (NGU) 7491, Trondheim, Norway
[6] Dipartimento di Scienze della Terra, Università di Pisa, Pisa, Italy
* corresponding author: laura.sadori@uniroma1.it

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

Abstract

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

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. Comborieu 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 (lakes Ohrid and 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 Dorjan and 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

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

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., 2014; Di Pasquale et al., 2014; Kouli, 2012, 2014; Magny et al., 2013; Mercuri et al., 2011, 2012, 2014; Mercuri and Sadori, 2014; Pepe et al., 2013; Sadori et al., 2004, 2010b; 2014; Zanchetta et al., 2013). If human societies either adapted to climate changes or collapsed is still matter of debate.

Recently, several authors discussed the late Holocene sedimentology, palaeolimnology and tephrochronology of Shkodra Lake (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 if and at which extent human history have potentially interacted with environmental factors in one of the best-preserved area of the Balkans.

Site setting

Shkodra lake, 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 to ca. 10 m asl, 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

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

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 asl) 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 asl) 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/year, 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 14ºC - 16ºC, with the highest average temperature recorded in August (21.4ºC – 27.5ºC) and the lowest average in January (0.5º C – 6.5º C) (APAWA and CETI, 2007). Temperature in winter is low, due to 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

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

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), 54 freshwater molluscs. Considering the aquatic microfauna, Petkovski (1961) described 9 species of ostracods from the Montenegro side. Pulevic and colleagues (2001) found 12 species. A detailed study on the present-day ostracods of the lake is on-going (Mazzini et al. 2014).

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 asl. 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*

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

cerris L., *Quercus petraea* (Matt.) Liebl., *Quercus frainetto* Ten. and *Quercus pubescens* Willd. At higher altitude, between ca. 600 up to 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) seems 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 lead, in the frame of the Shkodra archaeological project (PASH, Projekti Arkeologjike i SHkodres) 2010, by Maria Grazia Amore in the area at the south east 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 3th cent. BC) conquered by Romans during the 2nd cent. BC. It soon became an important trade and military route. During the first years of 7th cent. AD, with Barbarian populations menacing the empire, the city was given by Byzantine emperors to Serbs which ruled, fighting against

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

Bulgarians and Byzantines and giving hospitality to crusaders (the Serbian King Bodin welcomed the Provençal leaders in 1096), until 14th cent. when Shkodra surrendered to Venice, in order to have protection from the Ottoman Empire. After two sieges the town became an Ottoman territory in 1479 AD. Shkodra was a major city under Ottoman rule in Southeast Europe until the early 20th century. This importance was due to 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 center 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 lose 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, 472 AD; Avellino, ca. 3800 cal. years BP), one from Etna (FL, ca. 3300 cal. years BP) and one from Campi Flegrei (AMS,

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

Agnano Mt. Spina ca. 4400 cal. years 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): *Q. robur* type, which comprehends all deciduous oaks, *Q. ilex* type including all the evergreen oaks, and *Q. cerris* type, comprehending all semideciduous oaks. Oleaceae are broken down into *Fraxinus* cf. *oxycarpa*, *F. 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 *P. 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 µm, 50-125 µm, 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 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 & Ralska-

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

Jasiewiczowa, 1986). Pollen influx 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 1992) 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 2-3).

Pollen results

AP (pollen of arboreal plants) and NAP (pollen of non arboreal plants) percentage, concentration and influx values of selected groups and taxa are shown in diagrams (Figures 2-3).

AP is on average slightly over 84% (Figure 2a). From ca. 4500 (bottom core) to ca. 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. Pollen concentration values of AP (Figure 2b) are rather stable with minima at ca. 4000, 2900, 1450 and at 370 yr BP. Pollen influx 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.

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

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

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 BC): AP % are between 80 and 93, total pollen concentration between 16500 and 48000 (pollen grains per gram) and total pollen influx between 1900 and 11000 (pollen grains per year): the highest AP % matches the highest AP influx value at ca. 4300 yr BP. Mesophilous taxa are the most abundant (Figure 2a, 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 (Figure 2b, 3), among them Chenopodiaceae are the most abundant (0-6%). An expansion of algae, mainly *Pediastrum* (Figure 2, 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 pollen influx, (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 yr BC – 651 yr AD): AP % are between 81 and 94, total pollen concentration between 5300 and 57000 (pollen grains per gram) and total pollen influx between 1200 and 10000 (pollen grains per year): the lowest total pollen concentration and influx, AP%, and Mediterranean taxa % is recorded at 1400 yr BP.

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

Mesophilous taxa are the most abundant in percentages and reach their maxima in this zone (Figure 2, 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 / 736 – 1139 yr AD): AP % are between 81 and 91, total pollen concentration between 14000 and 32000 (pollen grains per gram) and total pollen influx between 3300 and 7600 (pollen grains per year). *Pinus* increases (14-24%), *Quercus robur* type shows a weak tendency to decrease (25-34%, Figure 3a). Important changes are not found in other taxa percentages, apart trilete spores from ferns increasing with pine. At 900 yr BP there is a blooming of *Pediastrum*.

Zone SK4 (726 – -24 yr BP / 1224 – 1974 yr AD): AP % are between 69 and 81, total pollen concentration between 6000 and 17500 (pollen grains per gram) and total pollen influx 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 (Figure 2, 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 *Q. 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 % 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

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

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 years BP AP % is always over 80 (average 87%), and subsequently shows an average value of 74%. Changes occurring in the last 7 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 ys 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 ys BP. Only at 4400 ys BP fire seems to be linked to the available fuel (plant biomass), as a peak of charcoal matches high arboreal pollen 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 Shkodra lake sediments is coming from quite different altitudes (5-2000 m asl). In the last 4500 years the forests around the lake, organized in vegetation belts as today, showed minimal changes in composition and dominance (Figure 2-3). 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

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

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 pollen concentration 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", the second representing the data "cleaned" using sedimentation rates (Berglund and Ralska-Jasiewiczowa, 1986). Minima of pollen concentration and influx 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 pollen influx and concentration probably due to 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; 2014).

Considering the pollen influx 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 cent. AD. The minimum in AP pollen influx 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

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

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 Dorjan lake (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 record (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 et al., 2011) and in archaeobotanical records (Arslantepe, Masi et al., 2013a,b, 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 years BP (Figure 2). This seems to be a warm period with 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 a dry episode around 1850-1900 yr BP. Another important change in the vegetation physiognomy occurs at ca. 1200 years BP, with mesophilous, Mediterranean and riparian trees decreasing, while montane ones and

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

ferns are increasing (Figure 2). The increase of montane vegetation is mainly due to "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 years BP (Figure 4e, 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 years 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 (pollen concentration - PC - versus Total Organic Carbon - TOC) or apparent dissimilarity (pollen influx - 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 pollen concentration and influx (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

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

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 et al., 1990; Meyers, 1994). The minimum found in the curve C/N matches the minima found in pollen concentration and influx values of terrestrial plants. The three peaks of *Pediastrum* occurring in the last millennium could have been also favoured by water pollution due to 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 water plants 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 years BP. After this date Characeae disappear and water plants 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 riparian plants. 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.

Conclusions

In the investigated pollen record no important changes in plant physiognomy are found,

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

probably due to 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, due to 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 1200 AD (the crusaders of 1101 were there and Venetians obtained from Byzantine to rule the area in the 14th cent. 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 and colleagues (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 arboreal pollen 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 years 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

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

decreases in northern Atlantic cores (Bond et al., 1997). The traces of Medieval Warm Period (MWP) and of the Little Ice Age (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 Fig. 4e, riparian plants versus ostracods) are in agreement with the hypothesis of a lake level increase at ca. 1300 years 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.

Acknowledgments

We are in debt with archaeologists working in the area (PASH project), namely Michael Galaty, Lorenc Bejko and Maria Grazia Amore. Professor Rexep Kochi (Institute of Geosciences, Energy, Water and Environment, Polytechnic University of Tirana) provided useful literature and constant assistance during field surveys.

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

References

APAWA (Association for Protection of Aquatic Wildlife of Albania) and CETI (Center for Ecotoxicological Research of Montenegro), 2007. The Strategic Action Plan (SAP) for Skadar/Shkodra lake Albania & Montenegro. Ministry of Tourism and Environment of Montenegro (MoTE), Ministry of Environment, Forests and Water Administration of Albania (MEFWA).

Ariztegui D, Anselmetti FS, Robbiani J-M, Bernasconi SM, Brati E, Gilli A and Lehmann MF (2010) Natural and human-induced environmental change in southern Albania for the last 300 years — Constraints from the Lake Butrint sedimentary record. *Global and Planetary Change* 71: 183–192.

Aufgebauer A, Panagiotopoulos K, Wagner B, Schaebitz F, Viehberg FA, Vogel H, Zanchetta G, Sulpizio R, Leng MJ and Damaschke M (2013) Climate and environmental change in the Balkans over the last 17 ka recorded in sediments from Lake Prespa (Albania/F.Y.R. of Macedonia/Greece). *Quaternary International* 274: 122-135.

Bar-Matthews M, Ayalon A (2011) Mid-Holocene climate variations revealed by high- resolution speleothem records from Soreq Cave, Israel and their correlation with cultural changes. *The Holocene* 21: 163-171.

Beeton AM and Karaman GS (1981) Monitoring program for protection of Lake Skadar. In Beeton A.M., Karaman G.S. (eds) The biota and limnology of Lake Skadar, Vol 1: 425-428. Univerzitet "Veljko Vlahovic" Institut za bioloska i medicinska istrazivanja u SRCG Bioloski zavod Titograd, Yugoslavia; Smithsonian Institution Washington, D. C., U.S.A.; Center for great lake studies University of Wisconsin – Milwaukee Milwaukee, Wisconsin, U.S.A., Beograd.

Berglund BE and Ralska-Jasiewiczowa M (1986) Pollen analysis and pollen diagrams. In: Berglund BE (ed.) *Handbook of Holocene Palaeoecology and Palaeohydrology*. Chichester: John Wiley & Sons, pp.455-496.

Bond G, Showers W, Cheseby M, Lotti R, Almasi P, deMenocal P et al. (1997) A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates. *Science* 278: 1257–1266.

Bordon A, Peyron O, Lézine AM, Brewer S and Fouache E (2009) Pollen- inferred Late-Glacial and Holocene climate in southern Balkans (lake Maliq). *Quaternary International* 200: 19–30.

Bowes K, Mercuri AM, Rattigheri E, Rinaldi R, Arnoldus-Huyzendveld A, Ghisleni M, et al. (2014) Palaeoenvironment and land-use of Roman peasant farmhouses in southern Tuscany. *Plant biosystems*, accepted.

Bradzil R, Pfister C, Wanner H, Von Storch H and Luterbacher J (2005) Historical climatology in Europe – The state of the art. *Climatic Change* 70: 363–430.

Combourieu-Nebout N, Peyron O, Bout-Roumazeilles V, Goring S, Dormoy I, Joannin S, Sadori L, Siani G and Magny M (2013) Holocene vegetation and climate changes in the central Mediterranean inferred from a high-resolution marine pollen record (Adriatic Sea). Climate of the Past 9: 2023-2042.

Denèfle M, Lezine AM, Fouache E and Dufaure JJ (2000) A 12,000-year pollen record from Lake Maliq, Albania. *Quaternary Research* 54: 423–432.

Dhora, Dh. 2005. Liqeni i Shkodres [Shkodra Lake]. Camaj-Pipa. Shkoder.

Djamali M, Gambin B, Marriner N, Andrieu-Ponel V, Gambin T, Gandouin E, Lanfranco S, Médail F, Pavon D, Ponel P and Morhange C (2013) Vegetation dynamics during the early to mid-Holocene transition in NW Malta, human impact versus climatic forcing. *Vegetation History and Archaeobotany* 22: 367–380.

Di Pasquale G, Buonincontri MP, Allevato E and Saracino A (2014) Human-derived landscape changes on the northern Etruria coast (western Italy) between Roman times and the late Middle Ages. *The Holocene*, doi:10.1177/0959683614544063.

Di Rita F and Magri D (2009) Holocene drought, deforestation and evergreen veg- etation development in the central Mediterranean: A 5500 year record from Lago Alimini Piccolo, Apulia, southeast Italy. *The Holocene* 19: 295–306.

Di Rita F and Magri D (2012) An overview of the Holocene vegetation history from the central Mediterranean coasts. *Journal of Mediterranean Earth Sciences* 4: 35-52.

Elsie R (2010) *Historical Dictionary of Albania*. 2nd ed. Plymouth: Scarecrow Press.

Francke A, Wagner B, Leng MJ and Rethemeyer J (2013) A Late Glacial to Holocene record of environmental change from Lake Dojran (Macedonia, Greece). *Climate of the Past* 9: 481–498.

Giraudi C, Magny M, Zanchetta G and Drysdale R (2011) The Holocene cli- matic evolution of the Mediterranean Italy: A review of the continental geological data. *The Holocene* 21: 105–115.

Grimm EC (1992) TILIA and TILIA GRAPH: Pollen spreadsheet and graphics program. In *8th International Palynological Congress. Program and Abstracts*. Aix-en-Provence, France, p. 56.

Hoti FR (1999) SHKODRA FREE ZONE. The most adequate option for the economic development of Shkodra region, giving the actual conditions. Shtëpia Botuese "CAMAJ – PIPA" Shkodër, 1999.

Jacobi GZ (1978) Zoobenthos from sublacustrine springs in Lake Skadar, Crna Gora, Yugoslavia. Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte. *Limnologie* 20: 1067-1077.

Jahns S (2005) The Holocene history of vegetation and settlement at the coastal site of Lake Voulkaria in Acarnania, western Greece. *Vegetation History and Archaeobotany* 14: 55–66.

Jahns S and van den Bogaard C (1998) New palynological and tephrostratigraphical investigations of two salt lagoons on the island of Mljet, south Dalmatia, Croatia. *Vegetation History and Archaeobotany* 7: 219–234.

Janssen CR (1968) Myrtle Lake: a late- and post-glacial pollen diagram from nonrthern MInnesota. *Canadian Journal of Botany* 46: 1397-1408.

Jasper JP, and Gagosian RB (1990) The sources and deposition of organic matter in the Late Quaternary Pigmy Basin, Gulf of Mexico. *Geochimica et Cosmochimica Acta* 54: 1117-1132.

Karkanas P, Pavlopoulos K, Kouli K, Ntinou M, Tsartsidou G, Facorellis Y and Tsourou T (2011) Palaeoenvironments and site formation processes at the Neolithic lakeside settlement of Dispilio, Kastoria, Northern Greece. *Geoarchaeology* 26: 83–117.

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

Keukelaar F, de Goffau A, Pradhan T, Sutmuller G, Misurovic A, Ivanovic S et al. (2006) Lake Shkoder Transboundary Diagnostics Analysis Albania & Montenegro. World Bank (IBRD), 178 pp.

Kouli K (2012) Vegetation development and human activities in Attiki (SE Greece) during the last 5,000 years. *Vegetation History and Archaeobotany* 21: 267-278.

Kouli K (2014) Plant landscape and land use at the lake settlement of Dispilió (Macedonia, Northeastern Greece). *Plant Biosystems*, accepted.

Kouli K and Dermitzakis MD (2008) Natural and cultural landscape of the Neolithic settlement of Dispilió: palynological results. *Hellenic Journal of Geosciences* 43: 29-39.

Kouli K and Dermitzakis MD (2010) Contributions to European Pollen Database: Lake Orestiás (Kastoria, northern Greece). *Grana* 49: 154-156.

Lasca NP, Radulovic V, Ristic RJ and Cherkauer DS (1981) Geology, hydrology, climate and bathymetry of Lake Skadar. The Biota and Limnology of Lake Skadar, Titograd, pp 17–38.

Leng MJ, Baneschi I, Zanchetta G, Jex CN, Wagner B and Vogel H (2010) Late Quaternary palaeoenvironmental reconstruction from Lakes Ohrid and Prespa (Macedonia/Albania border) using stable isotopes. *Biogeosciences* 7: 3109–3122.

Magny M, Combourieu Nebout N, de Beaulieu JL, Bout-Roumazeilles V, Colombaroli D, Desprat S et al. (2013) North–south palaeohydrological contrasts in the central Mediterranean during the Holocene: tentative synthesis and working hypotheses. *Climate of the Past 9*: 2043-2071.

Magny M, Vannière B, Zanchetta G, Fouache E, Touchais G, Petrika L et al. (2009) Possible complexity of the climatic event around 4300–3800 cal. BP in the central and western Mediterranean. *The Holocene* 19: 1–11.

Masi A, Baneschi I, Sadori L, Siani AM and Zanchetta G (2013a) Stable isotope analysis of archaeological oak charcoal from eastern Anatolia as a marker of mid-Holocene climate change. *Plant Biology* 15 (suppl. 1): 83-92.

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

Masi A. Sadori L, Balossi Restelli F, Baneschi I and Zanchetta G. (2014) Stable carbon isotope analysis as crop management indicator at Arslantepe (Malatya, Turkey) during the Late Chalcolithic and Early Bronze Age. *Vegetation History and* Archaeobotany 23: 751-760.

Masi A, Sadori L, Zanchetta G, Baneschi I and Giardini M (2013b) Climatic interpretation of carbon isotope content of Mid-Holocene archaeological charcoals from eastern Anatolia. *Quaternary International* 303: 64-72.

Mazzini I, Gliozzi E, Koci R, Soulie-Märsche I, Zanchetta G, Baneschi I et al. (2014) Historical evolution and Middle to Late Holocene environmental changes in Lake Shkodra (Albania): new evidences from micropaleontological analysis. *Palaeogeography, Palaeoclimatology, Palaeoecology,* doi 10.1016/j.palaeo.2014.08.012

Mercuri AM, Bandini Mazzanti M, Florenzano A, Montecchi MC and Rattighieri E (2013) *Olea*, *Juglans* and *Castanea*: The OJC group as pollen evidence of the development of human-induced environments in the Italian peninsula. *Quaternary International* 303: 24-42.

Mercuri AM and Sadori L (2014) 30. Mediterranean culture and climatic change: past patterns and future trends. In: Goffredo S., Dubinsky Z. (eds): The Mediterranean Sea: its history and present challenges. Springer, Dordrecht, pp. 507-527.

Mercuri AM, Allevato E, Arobba D, Bandini Mazzanti M, Bosi G, Caramiello R, Castiglioni E, Carra ML, Celant A, Costantini L, Di Pasquale G, Fiorentino G, Florenzano A, Guido M, Marchesini M, Mariotti Lippi M, Marvelli S, Miola A, Montanari C, Nisbet R, Peña-Chocarro L, Perego R, Ravazzi C, Rottoli M, Sadori L, Ucchesu M and Rinaldi R (2014) Pollen and macroremains from Holocene archaeological sites: a dataset for the understanding of the bio-cultural diversity of the Italian landscape. Review of Palaeobotany and Palynology, DOI: 10.1016/j.revpalbo.2014.05.010.

Mercuri AM, Sadori L and Uzquiano Ollero P (2011) Mediterranean and north-African cultural adaptations to mid-Holocene environmental and climatic changes. *The Holocene* 21:189-206.

Meyers PA (1994) Preservation of elemental and isotopic source identification of sedimentary organic matter. *Chemical Geology* 144: 289-302.

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

Noti R, van Leeuwen JFN, Colombaroli D, Vescovi E, Pasta S, La Mantia T et al. (2009) Mid- and late-Holocene vegetation and fire history at Biviere di Gela, a coastal lake in southern Sicily, Italy. *Vegetation History and Archaeobotany* 18: 371–387.

Panagiotopoulos K, Aufgebauer A, Schäbitz F and Wagner B (2013) Vegetation and climate history of the Lake Prespa region since the Lateglacial. *Quaternary International* 293: 157-169.

Pantaleón Cano Villanueva J (1997) *Estudi palinòlogic de sediments litorals de la provincia d'Almeria. Transformacions del paisatge vegetal dins un territori semiarid*. PhD Thesis, Universitat Autònoma de Barcelona, ES.

Pepe C, Giardini M, Giraudi C, Masi A, Mazzini I and Sadori L (2013) Plant landscape and environmental changes recorded in marginal marine environments: the ancient Roman harbour of Portus (Rome, Italy). *Quaternary International* 303: 73-81.

Petkovski TK (1961) Zur Kenntnis der Crustaceen des Skadar- (Scutari-) Sees. Musei Macedonici Scientiarum Naturalium 8 (2): 29-52.

Pulevic V, Hadžiablahovic S, Kasom G, Rakocevic-Nedovic J, Nikcevic S, Pešic V et al. (2001) Biodiversity database of the Shkodra/Skadar Lake. The Regional Environmental Center for Eastern and Southern Europe, Activity 3.2.1: 1-52.

Punt W, Bas JAA, Hoen PP (1981) Oleaceae. In: Punt W and Blackmore S (eds) *The Northwest European pollen flora*. Amsterdam: Elsevier, VI, pp. 23-47.

Roure JM (1985) Palinología Ibérica. Fam. 1 a 20. Cupressaceae a Betulaceae. *Orsis* 1: 43-69.

Sadori L, Giardini M, Giraudi C and Mazzini I (2010a) The plant landscape of the imperial harbour of Rome. *Journal of Archaeological Science* 37: 3294-3305.

Sadori L, Giraudi C, Petitti P and Ramrath A (2004) Human impact at Lago di Mezzano (central Italy) during the Bronze Age: a multidisciplinary approach. *Quaternary International* 113: 5-17.

Sadori L, Jahns S and Peyron O (2011) Mid-Holocene vegetation history of the central Mediterranean. *The Holocene* 21: 117-129.

Sadori L, Masi A and Ricotta C (2014) Climate driven past fires in central Sicily. *Plant Biosystems*, accepted.

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

Sadori L, Mercuri AM and Mariotti Lippi M (2010b) Reconstructing past cultural landscape and human impact using pollen and plant macroremains. *Plant Biosystems* 144, 940 – 951.

Sadori L, Ortu E, Peyron O, Zanchetta G, Vannière B, Desmet M et al. (2013) The last 7 millennia of vegetation and climate changes at Lago di Pergusa (central Sicily, Italy). *Climate of the Past* 9: 1969-1984.

Sadori L, Zanchetta G, van Welden A, Baneschi I, Drysdale R, Giardini M et al. (2012) Climate changes at Lake Shkodra (Albania): the last 4500 years. *Rendiconti Online della Società Geologica Italiana* 18: 35-38.

Smit A (1973) A scanning electron microscopical study of the pollen morphology in the genus *Quercus*. *Acta Botanica Neerlandica* 22: 655-665.

Stockmarr J (1971) Tablets with spores used in absolute pollen analysis. *Pollen et Spores* 13: 615–621.

Sulpizio R, van Welden A, Caron B, Zanchetta G (2010) The Holocene tephrostratigraphic record of Lake Shkodra (Albania and Montenegro). *Journal of Quaternary Science* 25: 633–650.

Tinner W, van Leeuwen J, Colombaroli D, Vescovi E, van der Knaap WO, Henne PD et al. (2009) Holocene environmental and climatic changes at Gorgo Basso, a coastal lake in southern Sicily, Italy. *Quaternary Science Reviews* 28: 1498–1510.

Triantaphyllou MV, Gogou A, Bouloubassi I, Dimiza M, Kouli K, Rousakis G et al. (2013) Evidence for a warm and humid Mid-Holocene episode in the Aegean and northern Levantine Seas (Greece, NE Mediterranean). *Regional Environmental Change*, DOI 10.1007/s10113-013-0495-6.

van Welden A, Beck C, Reyss JL, Bushati S, Koci R, Jouanne F et al. (2008). The last 500 year of sedimentation in Shkodra Lake (Albania/Montenegro): paleoenvironmental evolution and potential for paleoseismicity studies. *Journal of Paleolimnology* 40: 619–633.

Wagner B, Lotter AF, Nowaczyk N, Reed JM, Schwalb A, Sulpizio R et al. (2009) A 40,000-year record of environmental change from ancient Lake Ohrid (Albania and Macedonia). *Journal of Paleolimnology* 41: 407–430.

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

Wagner B, Vogel H, Zanchetta G, Sulpizio R (2010) Environmental change within the Balkan region during the past ca. 50 ka recorded in the sediments from lakes Prespa and Ohrid. *Biogeosciences* 7: 3187-3198.

Whitlock C (2001) Variations in Holocene fire frequency: a view from the western United States. Biology and environment. *Proceedings of the Royal Irish Academy* 101B: 65–77.

Zanchetta G, Bini M, Cremaschi M, Magny M, Sadori L (2013) The transition from natural to anthropogenic-dominated environmental change in Italy and the surrounding regions since the Neolithic. *Quaternary International* 303: 1-9.

Zanchetta G, Giraudi C, Sulpizio R, Magny M, Drysdale RN and Sadori L (2012a) Constraining the onset of the Holocene "Neoglacial" over the central Italy using tephra layers. *Quaternary Research* 78: 236-247.

Zanchetta G, Van Welden A, Baneschi I, Drysdale R, Sadori L, Roberts N et al. (2012b) Multiproxy record for the last 4500 years from Lake Shkodra (Albania/Montenegro). *Journal of Quaternary Science* 27: 780-789.

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

Figure captions

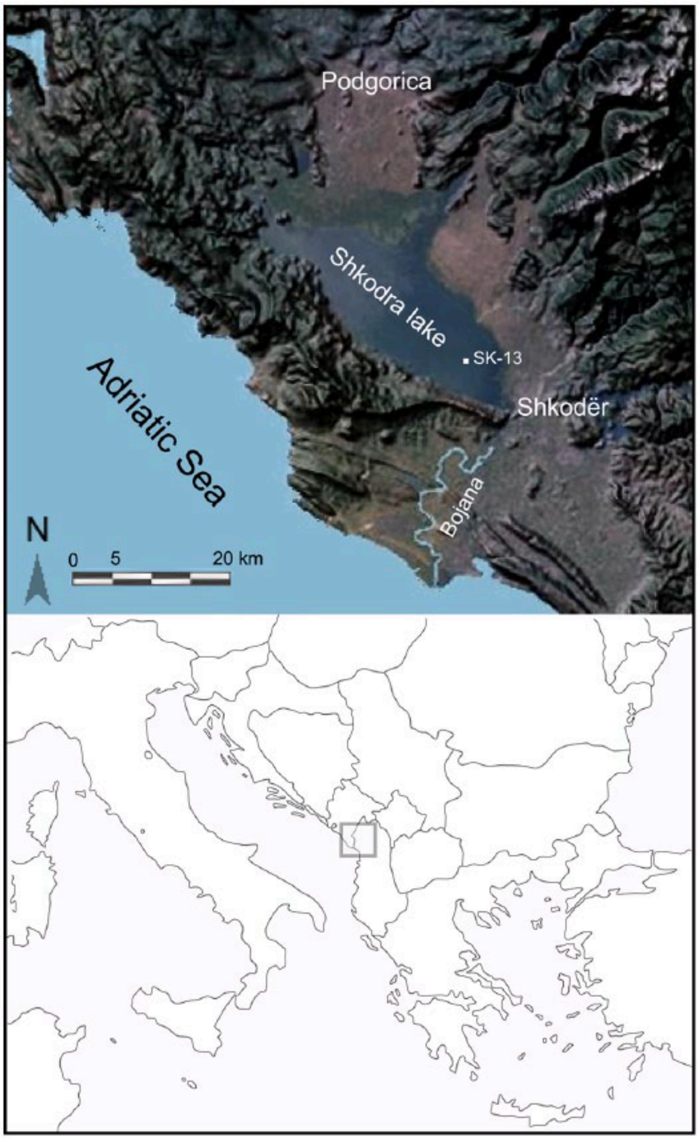
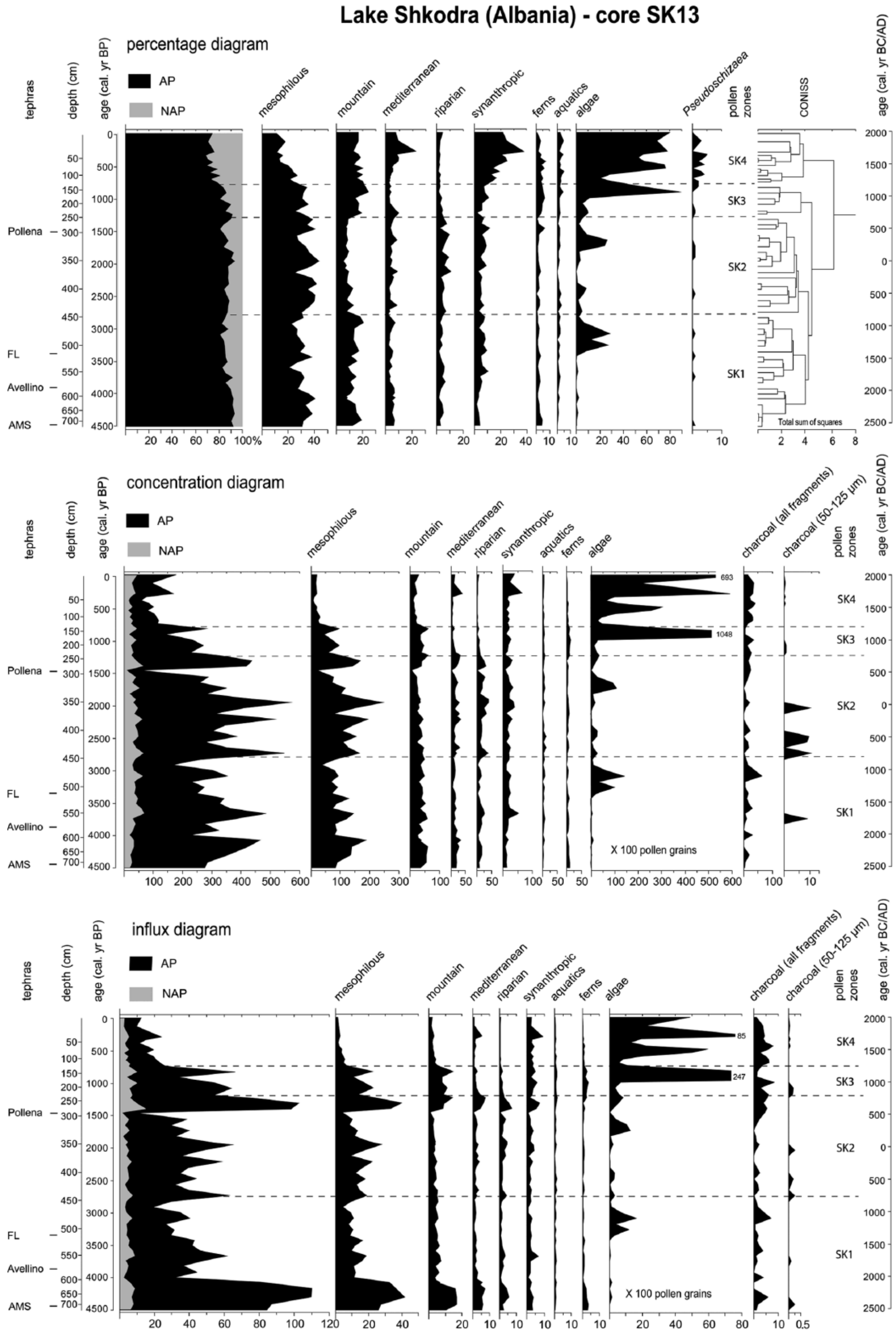


Figure 1. Location map of Lake Shkodra and of coring site (source: esri landsat shaded basemap).

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891



Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

Figure 2. Pollen percentage, concentration and influx 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*.

Published on The Holocene (2015), vol. 25(3), pag. 435-444 - 10.1177/0959683614561891
Paginated version available at https://journals.sagepub.com/doi/10.1177/0959683614561891

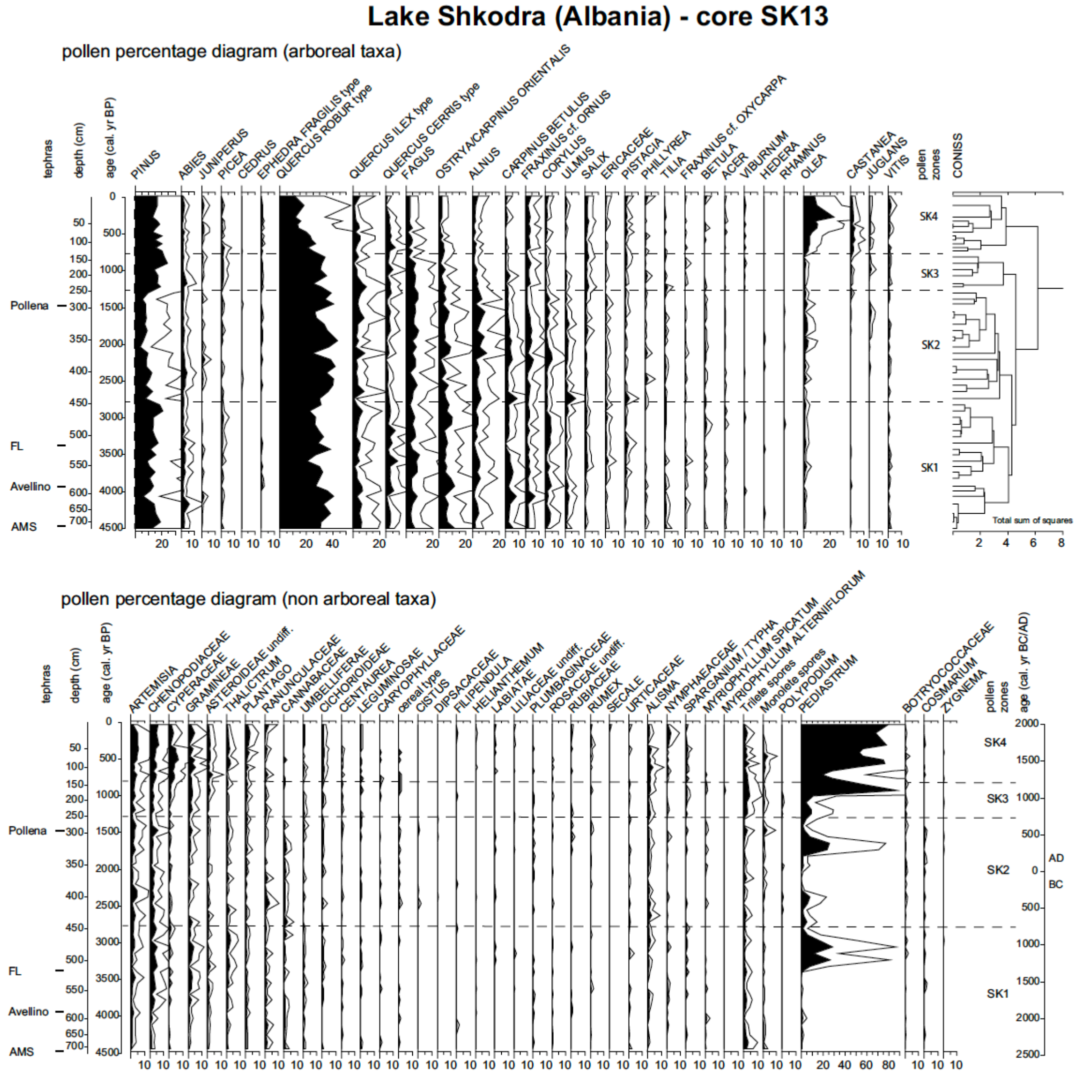


Figure 3. Pollen percentage diagrams of arboreal and non arboreal selected taxa. Curve magnification 5X.

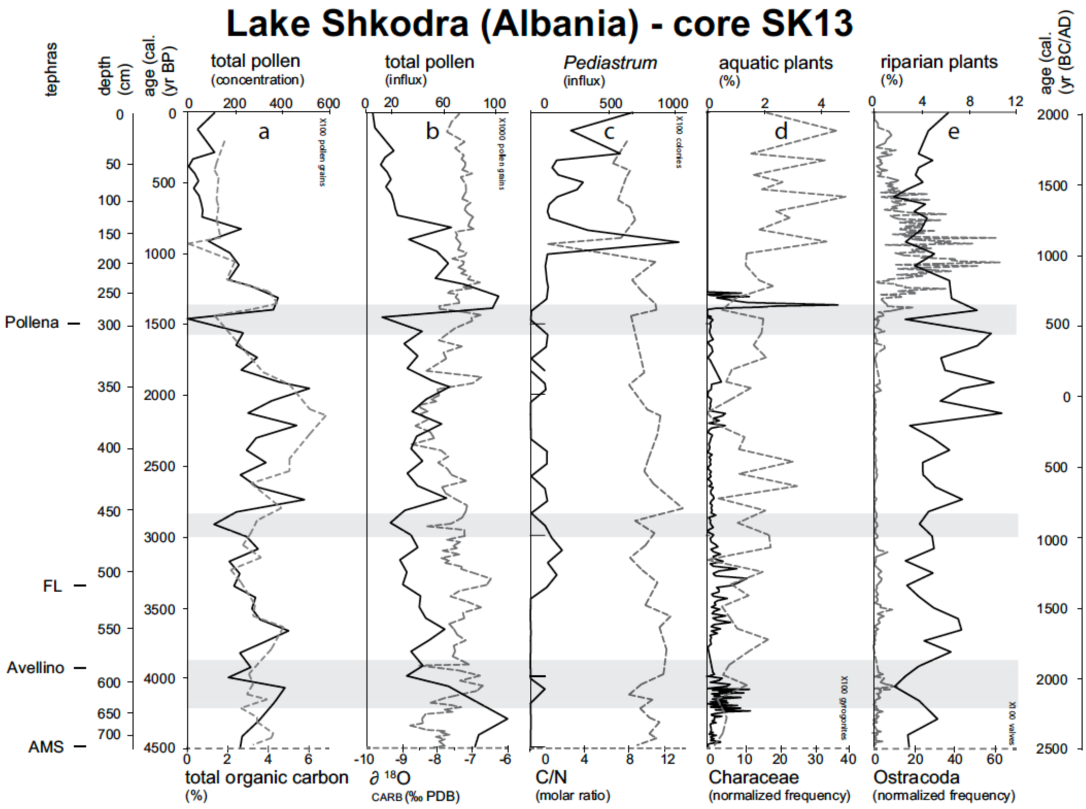


Figure 4. Comparison between pollen, continuous line (this paper) and other proxies, dotted line (Zanchetta et al., 2012b; Mazzini et al., 2014). The light grey rectangles mark arid phases roughly corresponding to the ages of Bond events 1-3 (Bond et al., 1997).