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Abstract: This paper examines the interrelationship between the natural and human history of Sicily over the last 2000 years. It presents a close comparison of the data from the key multi-proxy site of Lago di Pergusa - located inland in the eastern part of Sicily - with the existing archaeological and textual evidence on the socio-economic processes. The article also includes a review of the available natural proxy archives from the Central Mediterranean. On the basis of the isotope and pollen data from the Lago di Pergusa core PRG2, we identified two humid periods (ca. 450-750 AD and ca. 1400-1800 AD) as well as a dry one (ca. 1100-1350 AD); our evidence corresponds closely with other environmental palaeoclimate proxies from the Mediterranean region. In our synthesis of the environmental, historical and archaeological evidence from southern Italy, we argue that during both periods of increased humidity - that is during the late antique-Byzantine times and during the late medieval and early modern periods - intense agricultural use of the Sicilian landscape developed on an unprecedented scale. This in turn contributed to the impressive demographic and economic expansion visible during these periods. A sudden period of aridity followed the first of these eras of humidity-related agricultural growth. This climatic shift, dated to around 750 AD, corresponds to a decrease in synanthropic taxa and a recovery of arboreal vegetation. We argue that in this case a climatic change contributed to socio-economic decline. Moreover, as this change occurred prior to the Arab invasion of Sicily in AD 827, the environmental processes may help to explain the collapse of Byzantine society on Sicily which, in turn made the Muslim conquest possible. After this event, there occurred a longer period of agricultural decline, lasting until around 1000 AD, after which we see the first signs of a slow recovery. Although textual evidence records considerable population losses during the later Middle Ages as a result of the Black Death, the effects of the plague are not obviously apparent in the pollen data, except for some short term fluctuations.

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Highlights

1. In the last 2,000 years we found two humid periods (ca. 450–750 years AD and ca. 1400–1800 years AD) and a dry one (ca. 1100–1350 AD).
2. Very high levels of human activity occurred during both the late Roman and Byzantine period and the early modern period. Both of these periods of agricultural and demographic expansion coincided with periods of increased humidity, which made it possible for agriculture to develop in Sicily on an unprecedented scale.
3. Climate change (a strong drying trend in 750–800 AD) may help to explain the collapse of Byzantine society in Sicily, and the subsequent success of the Arab conquest. This is the only case in which climate can be used to explain a case of socio-economic decline.
4. We identified a close correspondence between the Arabic conquest and a longer-term decline in agriculture.
5. During the later Middle Ages, the impact of the Black Death is not visible in the pollen data, except for short term fluctuations; it did, however, cause considerable population losses throughout Sicily.

Climate, environment and society in Southern Italy during the last 2000 years. A review of the environmental, historical and archaeological evidence

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Abstract

This paper examines the interrelationship between the natural and human history of Sicily over the last 2000 years. It presents a close comparison of the data from the key multi-proxy site of Lago di Pergusa – located inland in the eastern part of Sicily – with the existing archaeological and textual evidence on the socio-economic processes. The article also includes a review of the available natural proxy archives from the Central Mediterranean. On the basis of the isotope and pollen data from the Lago di Pergusa core PRG2, we identified two humid periods (ca. 450–750 AD and ca. 1400–1800 AD) as well as a dry one (ca. 1100–1350 AD); our evidence corresponds closely with other environmental palaeoclimate proxies from the Mediterranean region. In our synthesis of the environmental, historical and archaeological evidence from southern Italy, we argue that during both periods of increased humidity – that is during the late antique-Byzantine times and during the late medieval and early modern periods – intense agricultural use of the Sicilian landscape developed on an unprecedented scale. This in turn contributed to the impressive demographic and economic expansion visible during these periods. A sudden period of aridity followed the first of these eras of humidity-related agricultural growth. This climatic shift, dated to around 750 AD, corresponds to a decrease in synanthropic taxa and a recovery of arboreal vegetation. We argue that in this case a climatic change contributed to socio-economic decline. Moreover, as this change occurred prior to the Arab invasion of Sicily in AD 827, the environmental processes may help to explain the collapse of Byzantine society on Sicily which, in turn made the Muslim conquest possible. After this event, there occurred a longer period of agricultural decline, lasting until around 1000 AD, after which we see the first signs of a slow recovery. Although textual evidence records considerable population losses during the later Middle Ages as a result of the Black Death, the effects of the plague are not obviously apparent in the pollen data, except for some short term fluctuations.

1. Introduction

This article reviews the existing environmental evidence from Southern Italy for the last two millennia and at compares it with the relevant historical and archaeological data. In this way it hopes to integrate the history of climatic and environmental changes with the socio-economic, political and cultural developments that took place in this part of the Mediterranean during the pre-modern period, that is from the Roman Empire until the Unification of Italy.

Such a synthesis is needed in order to fill in an important gap in recent scholarship on the societal impact of climatic fluctuations in the Mediterranean. Although there is a significant scientific literature about the complex interactions between climate and prehistoric societies (Magny et al., 2013; Mercuri and Sadori, 2014; Roberts et al., 2011; Zanchetta et al., 2013), the period covered in this paper has been studied less frequently. Existing studies focus on either the western (Morellón et al., 2011; Pèlachs et al., 2009; Valero-Garcés et al., 2006; Cheyette, 2008) or eastern parts of the Mediterranean (Haldon et al., 2014; Hirschfeld, 2004; Izdebski, 2011; for a rare case of a general overview, see McCormick et al., 2012), but they do not include Italy. Moreover, a recent review of the currently available climate evidence for the last two thousand years (in the following, thousand years=ka) demonstrates that the climate proxies often do not seem to express similar trends, even within the same region (Luterbacher et al., 2012). Therefore, with this paper we wish to establish the pattern of climatic changes that has taken place in Southern Italy over the last two millennia and, at the same time, we also hope to demonstrate the potential of this region for the study of the socio-economic impact of climatic changes in the past.

Many recent articles that have presented environmental data from sites in the Mediterranean assume that modern societies must have been capable of either managing or adapting to climatic change. However this is not an obvious fact, as we will demonstrate in this article, and the reactions of the various societies must be addressed on a case by case basis. Unfortunately, the impact of human life, which has been dominant and extensive throughout the Mediterranean region over the past several millennia, also introduces distortions in estimating recent climate variability with the use of environmental proxies (Roberts et al., 2008, 2011); human activities may thus have may have obscured the true cause of changes in the climate signal. To give a simple example, forest opening can be the result of an arid trend in climate or of intensive land use.

In order to avoid misinterpretation, it is necessary to use the right proxies, that is those which cannot be influenced by humans, such as hydrological proxies. These in turn can then be used to interpret the pollen diagrams, which reflect both climatic and anthropogenic impacts. In the absence of an instrumental physical record of past weather conditions, historical sources are of great importance. Historical documentation allows us to identify extreme events that severely stressed human and natural systems, such as droughts and floods. Variations in the hydrological cycle are very important when discussing the Mediterranean region, as the availability of water has always been crucial for both societies and ecosystems. Unfortunately, well-dated and detailed records of past environmental conditions are rather scarce and are rarely taken into full account when studying the societal impact of climatic changes. There have, as yet, been almost no attempts to integrate the environmental records of the past with the available historical records of extreme events (although see Bersani and Bencivenga 2001, Camuffo and Enzi, 1994, 1995 as they are used in Pepe et al., 2013 and Giraudi 2014).

We have decided, in the present study, to make the inland site of Lago di Pergusa (Enna, central Sicily) our key reference site for all of Sicily and Southern Italy. There are two reasons for this choice. First of all, this lake is particularly sensitive to climatic changes, which is clearly visible in its well-dated high-resolution isotopic data for the last two millennia, which is published here for the first time. Second, the territory around Lago di Pergusa witnessed significant and continuous human occupation over the course of the past two millennia; this, combined with pollen data from Pergusa (Sadori et al., 2013), provides us with an excellent multi-proxy record through which we may investigate the role of climatic fluctuations within the socio-economic history of the region.

The paper begins with a brief overview of the political history of southern Italy during the last two millennia. We then present the data from our reference site, Lago di Pergusa, and compare it with other environmental records from South Italy relevant to our period of study. This comparison will occur in two steps: first we review the palaeoclimate proxies from Italy and the Mediterranean, then we compare the vegetation history of Lago di Pergusa with other pollen records from southern Italy. These analyses are followed by a discussion of the historical and archaeological evidence, including an integrated account of the environmental history of Sicily and southern Italy in the pre-modern era. In this section, we attempt to synthesise data on long-term socio-economic trends that are usually characterised by a relatively low time approximation (rather than specific annual dates that are the case in the study of political history), with environmental events and processes registered in sediments; their temporal resolution is also at times relatively low, as their chronologies are based on radiocarbon dates or tephra layers. Finally, we present our conclusions.

2. History of southern Italy from the Roman Empire to the Unification of Italy: an overview

During most of our period of study, Sicily and the southern part of the Italian peninsula belonged to a single political organisation, either the Roman empire (until the fifth century), the Kingdom of Sicily (twelfth and thirteenth centuries), or the Italian state that was created in the second half of the nineteenth century. During the medieval millennium (ca. AD 500–1500), however, the political and social history of Sicily followed a different trajectory to that of the southern regions of the peninsula. This process of regional differentiation reached its climactic point during the ninth to the eleventh centuries, when Sicily became part of the *dar al-islam*, while the rest of southern Italy remained a part of Christendom, either as a province of Byzantium or as an independent local kingdom. In other words, Sicily and the southern part of the Italian peninsula did not always share the same social history. The diverse political and cultural factors that influenced the southern Italian microregions throughout the Middle Ages resulted in a patchwork of different identities and social structures; these regional differences would, in turn, have led to differing attitudes toward the landscape, as well as a wide range of economic patterns (cf. Davis-Secord, 2010).

Sicily was first united politically with the rest of the peninsula in the late third century BC, when the Romans conquered the island. Roman rule continued without interruption, and in relative peace, until the fifth century AD. With the arrival of the Vandals in North Africa, the Mediterranean was no longer the peaceful internal sea of the Roman Empire, but rather a theatre of military struggle between a declining Roman power and its Germanic successor states. In AD 535, the Eastern Roman Empire – which would later become known as Byzantium – invaded Italy

(Kislinger, 1994). Although the Byzantine conquest was initially successful, its rule did not last long; by AD 568 a new Germanic tribe, the Lombards (also named Langobards), had migrated to Italy and quickly became a dominant political presence (La Rocca and Azzara, 2002). The resulting political fragmentation lasted for several centuries, although Sicily would remain a Byzantine province until the ninth century. In AD 827 the Islamic rulers of North Africa started their conquest of the island, while the south of the peninsula remained divided between the Byzantines and the Lombards (Aḥmad, 1975; Chiarelli, 2011). Southern Italy was once again re-united by the Normans in the twelfth century, but after only 150 years Sicily was separated from the Kingdom of Naples. Only at the very end of the Middle Ages, when the Spanish rulers from the Crown of Aragon gained control over all of southern Italy, the island became permanently united with the southern part of the peninsula (Abulafia, 1997).

3. The key reference site: Lago di Pergusa

3.1. The site, materials and methods

Lago di Pergusa (37°31′N; 14°18′E) is located in the centre of Sicily (Fig. 1) the largest of the Mediterranean islands. The site has been described in detail in previous works (Sadori and Narcisi 2001; Sadori and Giardini 2007; Sadori et al., 2008, 2011, 2013; Zanchetta et al., 2007). Pergusa is an endorheic lake, fed solely by rainfall and groundwater, that has experienced strong lake-level variations related to changes in its hydrological budget. The lake is located 667 metres above sea level, in a hilly area surrounded by the Madonie, Nebrodi and Erean mountain ranges.

The flora of Sicily is rich in endemic taxa, but as the area around the lake has been cultivated extensively, the arboreal vegetation is poorly preserved. Before the regulation of water levels in the present century, the lacustrine vegetation (Fig. 1c, for original data see Calvo et al., 1995) consisted of several concentric belts: a permanent external belt several meters wide (belt a), contained *Phragmites australis* (Cav.) Trin. almost exclusively; an inner discontinuous belt (belt b) contained halophilous plants characterised by *Juncus maritimus* Lam.; and an internal ephemeral zone dependent on lake-level fluctuations (c, d, and e belts), consisted of halophilous and seasonal plant communities, characterised mainly by chenopods suchas *Atriplex latifolia* Wahlenb. (belt c), *Suaeda maritima* (L.) Dumort. (belt d) and *Salicornia patula* Duval-Jouve and many nytrophilous Asteraceae, both Asteroideae and Cichorioideae (belt e).

There has been human activity in central Sicily since prehistoric times. The site of Cozzo Matrice, located at the edge of the catchment area of the lake, dates back to the Eneolithic Age, but was also active during Greek times. During the Bronze and Iron Ages, the area surrounding the lake experienced a strong increase in the number of inhabited sites (Bernabò Brea, 1961; Giannitrapani and Pluciennik, 1998; Tusa, 1992). Under the Romans, Enna (Castrum Hennae, later Castrogiovanni) became a centre of cereal trade, and remained so under the Byzantines, the Arabs, and into the early modern period.

Different cores from Lago di Pergusa have already been investigated palynologically (PRG1, PG2, PEW2) and geochemically (PRG2, PEW2) (Sadori and Narcisi 2001; Sadori and Giardini 2007, 2008; Sadori et al., 2013, 2015b; Zanchetta et al., 2007). Pollen analyses have provided palaeoenvironmental data for the last Glacial and the Holocene periods. The recently published PG2 record (Sadori et al., 2013) overlaps with the PRG1 (Sadori and Narcisi, 2001) for the last 6700 years, showing similar vegetation dynamics, although at a higher resolution.

The published isotopic data (PEW2 and PRG2 cores: Giraudi et al., 2011, Roberts et al., 2008; Sadori et al., 2008, Zanchetta et al., 2007) show that the mid-late Holocene was characterised by strong evaporation of lake water. The oxygen isotope composition from ca. 9000 to 3000 years BP suggests wetter climatic conditions than before. The late Holocene is characterised by a return to the dryer conditions of the Younger Dryas (the last expression of glacial climate before the present interglacial, the Holocene). However the data for the last three millennia is not detailed enough to be correlated with historical events.

In the present paper we present new detailed $\delta^{18}O$ and $\delta^{13}C$ records, along with selected pollen curves for the last 2000 years of PG2 core sediments. In these cases, four tie points were available for the chronology of the last 2000 years (three AMS radiocarbon dates from plant macroremains and the year of coring on top), which offers a reasonably good age control. It is also worth noting that the temporal resolution of the new PG2 core is considerably better than that of the previous one, especially with regard to the last three millennia (Sadori et al., 2013, Fig. 6).

Samples for stable isotopes on bulk carbonate were collected every 6 cm and dried in an oven at 50°C for 48 h. A subsample of each dried sample was gently disaggregated and sieved at 100 μm to separate ostracods and shells from the sediment. The fraction below 100 µm was powdered and homogenised. Carbonate isotopic compositions were determined on CO_2 released by an overnight reaction with 100% H_3PO_4 at 25°C (McCrea, 1950) and purified using cryiogenic traps at the Stable isotope laboratory of the IGG-CNR in Pisa. Mass spectrometric measurements were normalised to the Vienna Pee Dee Belemnite scale using an internal working standard (Carrara Marble), calibrated against the international standards NBS18 and NBS19. For the high ratio between carbonate content and organic matter (Zanchetta et al., 2007 and unpublished data), no pretreatment was performed in order to remove organic contaminant, following the indication of Wierzbowski (2007) and Oehlerich et al. (2013). The average analytical precision (±1σ) for replicate analyses of carbonate was 0.15‰ for both carbon and oxygen.

We do not present methods for pollen as they are already reported in Sadori et al., 2013.

3.2. Results: isotope and pollen data from Pergusa

Of the available environmental evidence relating to the last two millennia, the core from Lago di Pergusa (core PG2) is the only record from the central Mediterranean with three AMS dates obtained from terrestrial plant macroremains; with a mean sample resolution of around 46 years, it is also the record that has been analysed in the greatest detail.

Pollen data has often been misused to assess either the degree of climate change, or the level of human involvement. In fact, the vegetation record is the result of both human and natural factors, and they can be difficult to disentangle using palynology alone. A forest opening, for instance, may have been caused by climate change, but it could just as easily have been the result of wood cutting. In more complicated cases, an increase in ruderal pollen curves may be caused by either a lowering in the lake level or an increase in human activity (Sadori et al., 2013, p. 1980, 1981). By contrast, stable isotopes on lacustrine deposits tend to be less affected by human impact (see discussion in Roberts et al., 2008; 2011; Zanchetta et al., 2012b) and are therefore better indicators of hydrological variability – including evaporation processes – within the catchment area of the lake. It is important to remember that bulk carbonate is chiefly indicative of spring-summer conditions, when algal bloom promotes carbonate precipitation (Leng and Marshall, 2004), even if the isotopic composition of the lake water is also affected by the winter recharge. In the Mediterranean region, it has in fact been demonstrated that the amount of rainfall and the residence time of water in lakes both determine the final oxygen isotope composition of the lake carbonates (e.g., Roberts et al., 2008). Consequently, higher isotopic values are usually considered to indicate drier phases, whereas lower values indicate the opposite (e.g. Zanchetta et al., 1999, 2007, 2012b; Sadori et al., 2008; Roberts et al., 2008; Leng et al., 2010, 2013). Thus, the higher $\delta^{18}O$ values at Pergusa during the last two millennia are indicative of a highly evaporated, terminal lake (Zanchetta et al., 2007; Roberts et al., 2008). The limited amount of clastic contamination has already been challenged by Zanchetta et al. (2007) and will not be further discussed here.

Here we present unpublished isotope data for the last 2 ka of core PG2; a detailed article on the whole record is currently in preparation by Baneschi and Zanchetta.

In Fig. 2, looking from the left, the stable isotope data ($\delta^{18}O$ and $\delta^{13}C$ records) is aligned with the pollen record (arboreal pollen –AP– versus non arboreal pollen –NAP, along with the main arboreal, cultivated, weed and ruderal taxa curves) for the last two thousand years. The stable isotope data shows very high values, suggesting that the lake water evolution was dominated by a low precipitation/evapotranspiration ratio in the catchment area during the last two millennia. Although their amplitude is different, most of the variations in the $\delta^{18}O$ and $\delta^{13}C$ records are consistent, and any shifts occur simultaneously. This suggests a good response of our isotopic record to natural changes. In the present study, we will discuss only the $\delta^{18}O$ curve in detail, while the $\delta^{13}C$ will be the subject of a separate paper.

We were able to identify periods of enhanced humidity during the years 450–750 AD and 1400–1800 AD. The rapid oscillations in $\delta^{18}O$ during the last two centuries also suggest that hydrological changes were taking place in the catchment area, probably due to climatic fluctuations, the effects of which are sometimes magnified in a shallow lake. Botanical chronicles report frequent lowering of the lake level since at least the early twentieth century (Forti, 1933a,b; Battaglia et al., 1991), along with an increase in water salinity. The reduction in water along with the related increase in water salinity should have favoured the blooming of marshy chenopods (Calvo et al., 1995, belts b, c and d, Fig. 1c). However, we can find no clear correspondence between Chenopodiaceae (in AP/NAP diagram) and the $\delta^{18}O$ curves. In the absence of isotope data, the easiest way to interpret the expansions of Chenopodiaceae would be to suggest a decrease in the body of water due to an increase in the precipitation/evapotransipiration ratio in the lake and its catchment. However, since the isotope evidence is available in this case, we may also suggest that the increase of Chenopodiaceae visible at the base of the diagram can be attributed to the presence of ruderal taxa associated with a strong human impact. Many taxa belonging to Chenopodiaceae, whose pollen cannot be distinguished at a specific level, are typical of either marshy environments or ruderal ones. According to this interpretation, the middle of the first century AD would have been a period of strong human disturbance around Lago di Pergusa. It is possible that the relatively low amount of cultivated taxa in the same period are hidden by the high percentage of chenopods. The inconsistency between the pollen and $\delta^{18}O$ records from Lago di Pergusa may therefore be explained by considering pollen as primarily an indicator of human impact and stable isotopes as indicators of changes in hydrological conditions.

Agriculture appears to be well developed throughout our period of study, as indicated by cereals and related weed taxa such as *Papaver* (poppy)and *Centaurea cyanus* (cornflower). *Secale* (rye), a cereal whose pollen can be distinguished from that of *Hordeum* (barley), *Avena* (oat) and

Triticum (wheat), became increasingly abundant from the late antique-Byzantine age (ca. AD 450–750). Interestingly, *Secale cereale* is a crop easily grown at high elevation, and is both more resistant and less demanding than wheat or barley. *Fabaceae* comprise both wild and cultivated plants, such as legumes, so the curve can be taken as an indication of local cultivation. The continuous presence of *Vitis* (grape vine) in the record suggests that it was probably locally cultivated throughout the two millennia studied in this paper.

The three cultivated arboreal taxa deserve special consideration. Both chestnut (*Castanea*) and walnut (*Juglans*) appear during the medieval period: walnut first appears around 750 AD, and is followed by chestnut around 1150 AD. Walnut had been cultivated in the area much earlier, as indicated by two sporadic finds dated to around 850 and 700 BC (Sadori et al., 2013); its pollen, however, was not found in the Pergusa sediments during the Greek and Roman periods, and it reappears only towards the end of the Byzantine rule. Chestnut pollen was found in the record of Pergusa from as early as the Bronze Age, but only a single grain was found for the Greek, Roman and Byzantine periods taken together, at around 60 AD. It becomes a regular presence again after 1150 AD, suggesting that it was newly cultivated — this is not surprising given the importance of chestnut within the economy of medieval Italy (Squatriti, 2013) and its infrequent use in Roman times (Cherubini, 1981, Di Pasquale et al., 2010). Olive tree (*Olea*) pollen is always present in the diagram. Lago di Pergusa is outside the natural distribution area of the wild olive tree (*Olea europapaea* var. *sylvestris*), the pollen of which cannot be distinguished from that of the cultivated olive tree (*Olea europaea* var. *sativa*). Its continuous presence may thus be attributed to long distance transport of pollen – of either the wild or cultivated variety – or to small orchards in the vicinity. There can be no doubt that olive was cultivated during the last two centuries, a time when walnut, cereals and legumes also increased. A recent paper by Mercuri et al. (2013) used the OJC (*Olea*, *Juglans*, *Castanea*) composite curve as an indication of human impact throughout the Mediterranean. Starting from the Bronze Age, these taxa have an early expansion, followed by different regional patterns (Sadori et al., 2004, Magri and Sadori 1999; Comborieu Nebout et al., 2013, Mercuri et al., 2002, Sadori et al., 2015a, Kouli, 2012).

In addition to identifying agricultural activity, pollen may also be used to assess pastoral practices, such as sheep-farming. *Rumex* (sorrel) is a taxon favoured both by natural opening of the forest and by grazing. A similar consideration can also be applied to Cichorioideae (Florenzano et al., 2015), the pollen from which increases in barren areas and lands exploited for animal farming. Moreover, we must also consider that Cichorioideae pollen also increases as the lake level lowers (see Fig. 1, belt e). The parallel curves of *Rumex* and Cichorioideae demonstrate similar trends to the curves of *Plantago* (plantain) and Asteroideae, and also partly to Urticaceae. To the last three plant groups belong herbs favoured by human activity. No trace of *Platanus* (plane) pollen – probably introduced to Italy in ancient times – has yet been found either in Pergusa or in other pollen records from southern Italy (see Rosati et al., 2015).

4. Other environmental records for the last two thousand years

4.1. Palaeoclimate and past vegetation proxies from southern? Italy

Climate records from southern Italy for the last 2000 years with a high resolution are rather scarce, and the chronological control of available environmental records was one of the major problems faced by our study of the last two millennia. As the chronological focus moves closer to the present, it becomes increasingly important that the dating error is reduced to minimum. In the current state of scholarship, an error of many decades (ca. 80–100 years) is unacceptable; rather, the shift between radiocarbon-based chronologies and historical events should be limited to a few decades (ca. 30–50 years). The situation has improved in recent years, as researchers have started to select, whenever possible, macroremains of terrestrial plants for AMS dating (Bisculm et al., 2012, Calò et al., 2012, Noti et al., 2009, Sadori and Narcisi, 2001, Sadori et al., 2013, Tinner et al., 2009). However, many pollen records still do not have a good chronological control for the last two millennia, either because the studies are too old or because the good material for dating was missing

(Lago Battaglia: Caroli and Caldara, 2007; Canolo Nuovo: Grüger, 1977, Schneider, 1985, Urgo di Pietra Giordano: Bertolani Marchetti et al., 1984). Furthermore, until recently, palaeocologists paid little attention to historical periods, and the sample resolution for the last 2000 years remained relatively low.

The $\delta^{18}O$ and $\delta^{13}C$ data from the discontinuous speleothem of Grotta Carburangeli (Frisia et al., 2006) indicates only a high hydrological variability between 600 and 1000 AD. In addition, as pointed out by Magny et al. (2011), the lake level record of a central core (LPB) from Lago Preola (not very detailed for the last couple of millennia), shows similarities with pollen curves from Lago di Pergusa (PRG1) (Sadori and Narcisi, 2001). A more marginal core from the same lake (LPA) indicates that the lake level rose during the last six centuries.

The majority of available environmental data for southern Italy comes from palynology. It is worth stressing once again that such data poses serious problems when used for the purpose of climate reconstruction, and it is for this reason that the availability of independent palaeoclimate information – in this case, the isotopic data from Lago di Pergusa – is of central importance to the hypotheses presented in this paper.

With regard to the spatial distribution of the pollen data (Fig. 1d), the Sicilian coastal sites include Gorgo Basso (Tinner et al., 2009), Lago Preola (Calò et al., 2012 and Biviere di Gela (Noti et al., 2009). In these cases, local lacustrine/marshy vegetation seems to have masked both the human and natural climate signals. Pollen grains of cereal type increase at around 1200 AD at Biviere di Gela, and around 500 AD at Gorgo Basso. On the Sicilian coast, olive is inside its natural distribution area and it is difficult to ascertain whether or not the expansion that started at Biviere di Gela around 1700 AD was due to local cultivation; however, the presence of chestnut pollen at Biviere di Gela might suggest that the expansion of olive was the result of an intensification of agricultural activity. At a coastal site in southern Italy, the Lago Alimini Piccolo in Apulia (Di Rita and Magri, 2009), forest clearance started to occur during Roman times, and a strong expansion of olive is recorded around 800 AD, well before its expansion in coastal Sicily (cf. Arthur et al., 2012).

In the same region, in the northernmost site of the Gargano promontory (Caroli and Caldara, 2007) there is no olive tree expansion corresponding with that found at Lago Battaglia. Recent data from Pantelleria (Calò et al., 2013) and Comino-Malta islands (Carroll et al., 2012) (Fig.1d) to the south of Sicily, show the presence of cultivated and ruderal taxa. The record from Pantelleria covers only the last 1200 years, but the expansion of olive and evergreen oak that occurred between 800 and 1000 AD may be considered evidence of the Medieval Warm Period (MWP).

The inland and mountain sites of Sicily, Calabria and Basilicata show different vegetation histories, probably linked to different modes of land exploitation. Apart from Lago di Pergusa, data is available from Urio Quattrocchi, in the Madonie mountains in Sicily (Bisculm et al., 2012), Lago Grande di Monticchio, the Vulture volcano in Basilicata (Allen et al., 2002) and, from Calabria, Lago di Trifoglietti in the Catena Costiera (Joannin et al., 2012, Brugiapaglia et al., 2013) and Canolo Nuovo in Aspromonte (Grüger, 1977, Schneider, 1985). At Lago Grande di Monticchio, forest opening (due to both beech and deciduous oaks) can be dated to roughly 800 AD; sparse traces of cultivated and other synanthropic taxa are visible, but the time resolution of the record is not good enough for the last millennium. At Lago di Trifoglietti, a decrease in humidity starting around 800 AD and lasting for several centuries may have resulted in a strong reduction in riparian vegetation (alder) (has it anything in common with the olive increase recorded at Pantelleria in the same period?). In every period there is some indication of land use, even if the signal is sometimes quite weak; only in the last four or five centuries does it become stronger. The pollen diagram from Canolo Nuovo (Schneider, 1985) demonstrates a surprising expansion of cultivated taxa, such as olive, chestnut, nut, rye and cerealia-type, during the last 2000 years. Unfortunately, the record was published 30 years ago, and both the dating methods and time resolution are in need of improvement. As the site is outside the natural distribution area of olive, its expansion – which was radiocarbon dated to 785 ± 115 years BP (date obtained by bulk sediment, 20 cm thick) – deserves particular attention. It follows a period during which chestnut had been cultivated on a notable scale and precedes a period which saw an expansion of cereals, in particular rye. However, this last phenomenon does not necessarily indicate just an increase in cereal cultivation. We should consider that *Secale* (rye) is a cereal with a distinct pollen grain, distinguishable from that of the other cereals. Pollen grains of the two species of rye found in the Italian flora (Pignatti, 1982), however, cannot be distinguished. These two species of rye are the cultivated *S. cereale* and the wild *S. stricta*, a Mediterranean mountain species – also known as mountain or wild rye – which grows at 600 to 1700 m above sea level, and is native to certain regions in central and southern Italy. Thus, the increase in rye pollen around the site of Canòlo Nuovo may be a signal from the expansion of succession plants that followed in the wake of intensive olive cultivation.

4.2. Comparison with other palaeoclimate proxies from the Mediterranean region

In Fig. 3 selected curves of different palaeoenvironmental proxies from the Mediterranean region are aligned. The last curve was reconstructed using historical archives (Camuffo and Enzi, 1995). For the chronological scales of the environmental proxies we have always to keep in mind that there could be a bias due to the construction of chronologies (often based on radiocarbon dates that provide an interval in place of a precise year). As a result, differences of 50–100 years could be due to errors in single chronologies.

The rectangles indicate periods of increased or reduced humidity as detected by the isotopic data from Lago di Pergusa. The first wet period is found roughly between 450 and 720 AD. As we have already observed, it corresponds to a period of intense land-use, with open forests and relatively high values for weed and ruderal plants. This wet phase may also be found in all the other curves, even if it seems to start a century later in central and northern Italy, where the levels of Accesa and Mezzano lakes increase, an alluvial phase in northern Appenines is found, the Calderone glacier advances, and Tiber floods occur. The phase also begins later in the Balkans, where we noticed an increase in plant biomass together with a decrease of $\delta^{18}O$ at Shkodra Lake. These differences, however, could be due to minor errors in chronology.

The alluvial phases in Basilicata (southern Italy) and Tunisia, are similar to those observed at Lago di Pergusa. In the speleothem from the Sofular cave in Turkey, low values for $\delta^{13}C$ indicate that wet conditions occurred from around 500 until 650 AD. By around 750 AD, the Pergusa sediments start to record a decrease in human impact, as reflected by a low value for weeds and ruderals and an increase in woody taxa. Shortly after this time, the Arabs began their conquest of Sicily (827 AD).

The increase in AP recorded between 950 and 1100 AD may also be due to a slight increase of *Olea* (Fig. 2). It is worth noting that the cultivation of olive would have been made easier by an increase in temperature, such as that reconstructed for Pergusa (see Sadori et al., 2013, Fig. 7). During this relatively brief window of time, the level of Lago di Mezzano decreased and no Tiber floods were recorded.

At Pergusa, there follows a drier period lasting from around 1100 to 1350 AD. It corresponds with the lowering of both Accesa and Mezzano lakes that occurs a century later (the delay may be due to errors in chronologies). There are no alluvial events during this period.

A prolonged period of relatively low evaporation and increased AP% between 1400 and 1800 AD would have increased the level of Lago di Pergusa; during this time, flooding of the Tiber would have been more frequent, and it has also been possible to observe a glacial advance in central Italy and alluvial phases in the northern Apennines. This may be an expression of the Little Ice Age (LIA). A recent synthesis on Mediterranean floods and climate change (fig. 4 in Benito et al., 2014) provide evidence for a Little Ice Age in the central and western Mediterranean. It is worth mentioning, however, that no trace of it is found either at Shkodra lake or Sofular cave. This may be the result of contrasting patterns across the whole of the Mediterranean as proposed by Magny et al. (2012).

5. Socio-economic and environmental history of South Italy during the last two millennia

5.1. The Byzantine period

At the beginning of the Roman Imperial Period (31 BC) there is already evidence for the extensive impact of human activity around Lago di Pergusa. This should come as little surprise: since the conquest of Sicily in the late third century BC, the island had acted as the granary of Rome, supplying grain for the ever-growing city (Soraci, 2011). However, it was during the final centuries of the Roman period (fourth to sixth centuries) that the scale of the agrarian economy in Sicily reached its climax. This is clearly visible in an anomaly found in the pollen data from Pergusa, which we have marked with a grey rectangle in fig. 2 (dated to ca. 450–720 AD). During this period, the curve of isotopes does not mirror the curve of the total arboreal pollen (AP), which is the case at all other times during the last two millennia, and also prior to the beginning of our period of study. This phenomenon is a strong indication that the AP percentage was affected by a level of human activity much higher than it was before or would be again. During this period there was an expansion of cereal farming, with increased values of cerealia-type, rye (*Secale*), and of the secondary anthropogenic indicators (especially *Plantago* and *Rumex*). It is worth noting that rye had not been present around Pergusa prior to this period, but it may have been favoured on account of its resilience, even in poor quality soils. Although the values of cerealia-type remain relatively stable, the increase in cultivation during the later Roman period would have required types of cereal that could be grown on less fertile lands which, in all probability, had not been used for cereal farming before around 400 AD.

Lago di Pergusa is not the only pollen site in Sicily where we can observe an expansion of agriculture during the fourth and fifth centuries. At the coastal site of Biviere di Gela one notices a brief increase in human activity around 300–400 AD; here the secondary anthropogenic indicators, Chenopodiaceae and Brassicaceae, are indicative of intensification (Noti et al., 2009). At Gorgo Basso, for the period after 500 AD we observe a decrease in the amount of shrub vegetation and an increase in cerealia-type, *Rumex acetosella*, Poaceae, and initially also *Olea* (Tinner et al., 2009). At Urio Quattrocchi, a pronounced increase in *Cerealia*-type and *Plantago lanceolata*-type occurred around 400–500 AD. Interestingly, this new vegetation structure seems to continue beyond that date, as there are no clear signs of decrease in these anthropogenic indicators (Bisculum et al., 2012).

This pattern of agricultural growth is also attested in the archaeological evidence from various sites in Sicily, which suggests that the highest settlement density was achieved during the Late Roman period, and when more precisely dated, during the 5th c. This expansion took place not only on the coast, in those areas with easy access to maritime exchange networks, but also inland, suggesting that the entire island was part of a single economic system characterised by an unprecedented intensification of agricultural activity (Vaccaro, 2013). The pollen data from both the inland site of Pergusa and the coastal sites mentioned above, shows a similar vegetation pattern in the years 300–500 AD. If we turn to the peninsula, there is further evidence for settlement expansion during the fourth and fifth centuries AD. Recent archaeological evidence has confirmed that, in both Calabria and Apulia, settlement density in the countryside increased considerably during the course of the fifth century (see especially the contributions by Favia et al., Volpe et al., in Volpe and Turchiano, 2005).

The economic prosperity of southern Italy during the fourth and fifth centuries is clearly part of a wider phenomenon visible throughout the Eastern Mediterranean: in Anatolia and the Levant, new areas are cultivated and rural settlement expands on an impressive scale (Decker, 2009; Izdebski, 2013a; Izdebski et al. in this issue). In the case of Sicily and southern Italy, however, there may be an additional factor that encouraged economic growth: after Constantinople became the capital of the empire in AD 330, the grain transports from Egypt no longer came to the city of Rome, and the former capital would have had to get its grain supplies from different areas. This development would almost certainly have led to the intensification of agricultural activities in the south of Italy, as the demand for grain and other foodstuffs promised considerable profits for estate owners (Vaccaro, 2013; Vera, 1997). We should also bear in mind that – according to the isotopic data – the climate of Sicily became wetter after 400 AD, and this increased humidity would have made it easier to turn previously marginal lands into cereal fields or orchards. In other words, the economic opportunities of supplying Rome with food, combined with nearly 300 years of unusually advantageous climatic conditions, made it possible to expand cultivation beyond the limits dictated by the natural conditions that existed during the Imperial period. The combination of anthropogenic and natural factors may explain why the island experienced extreme exploitation during this period. However, as we shall soon see, the reliance of late Roman agriculture on more humid climatic conditions may have had damaging consequences for Sicilian agriculture when the climate became drier starting around 750 AD.

The period of prosperity did not last as long in the peninsula, effectively ending with the atrocities of the Byzantine-Gothic war in the 540s (Martin, 1993; Martin and Noyé, 2005, pp. 133–146). In Sicily, however, prosperity continued. During the Gothic wars Sicily supplied food to the besieged city of Rome as well as the Byzantine armies active on the mainland. Some fifty years later, when Rome was largely cut off from its hinterlands during the 590s and 600s, it once again received substantial amounts of grain from Sicily; this exchange is well illustrated in the letters of Gregory the Great (Izdebski, 2012). Twenty years later, Sicily came to the rescue of Constantinople. During the 620s, the Byzantine government introduced large quantities of new bronze coinage in order to conduct emergency acquisitions of grain for the imperial capital, after the loss of Egypt to the Persians in 619 AD. Egypt, known as the granary of the empire, remained in Persian hands for the next 10 years; it was eventually recaptured by the Byzantine forces in 629 at the end of the Persian war, but was decisively lost to the invading Arab army in 642 AD. The special arrangements put in place during the troublesome decade of AD 619–629 were gradually replaced by a new tax system that the Byzantine authorities may have developed on Sicily. Rather than collecting taxes as a monetary contribution, there was a move toward taxation in kind; in practical terms, this translated into a new supply of grain for the capital and the army (Prigent, 2006a).

The close links between the Sicily and the capital continued into the later seventh century. Lead seals of Byzantine officials found on the island suggest that it continued to supply grain for the imperial capital until at least the early eighth century, when the situation in the vicinity of Constantinople had grown more stable and it became possible to rely on a local supply system. However, Sicily was so important to the survival of the capital that the emperor Constans II moved there with his army in 662 in order to defend the island against the Arab attacks that threatened one of the last remaining 'bread baskets' of the empire (Prigent, 2010). Interestingly, grain was not the only agricultural product that Sicily exported during this period. There is considerable archaeological evidence that large amounts of wine were sent from the east coast of the Island to Rome and the Adriatic coasts during the seventh century (Arcifa, 2010; Castrizio, 2010). Given its economic importance, it is not surprising that Syracuse was the only city in the Byzantine Empire, apart from the capital, that had a mint. In fact, the number of seventh and eighth century coins found in eastern Sicily suggest an intensive monetary circulation which differentiates this province from most other regions of the empire (see fig. 4) (Morrisson and Prigent, 2010). The notable correspondence between the numismatic evidence and the pollen data during the Byzantine period would certainly suggest that Sicily managed to sustain its economic vitality during the seventh and eighth centuries; the slight temporal disparity between the agricultural evidence from Pergusa and monetary evidence from eastern Sicily may be attributed to the approximate character of the chronologies which, in the case of the pollen evidence, is based on radiocarbon dating with a possible error of up to 50 years.

In addition to coins and pollen, there is further archaeological evidence to suggest settlement continuity on Sicily. The remains of Byzantine amphorae suggest that, contrary to many other regions within the post-Roman Mediterranean, Sicily remained at the centre of a lively economic exchange (Ardizzone, 2010). For this reason, however, the island is something of an anomaly in the

Byzantine Mediterranean (cf. Izdebski et al., 2015): not only Italy, but also the Balkans (Curta, 2013) and Anatolia (Izdebski, 2013b) experienced extensive transformations leading to the creation of impoverished societies which displayed only a very limited continuation of late Roman environmental-economic patterns. The humid climatic conditions on Sicily, along with its economic and political significance, allowed the late Roman model of society to continue into the early Middle Ages without major interruptions.

Sicily's early-Medieval era of prosperity seems to have come to an end around 750 AD. After this date, the Byzantine government became less interested in Sicilian affairs: the governors were recruited from among the officials of lesser ranks, and the local elites were no longer granted prestigious court titles. Once Byzantium had become involved more seriously in Greece, the island began to lose its political significance (Nef and Prigent, 2006). However, there are also signs of an economic crisis which could at least partially explain the changing role of Sicily within the empire. The monetary exchange on Sicily also began to weaken during the second half of the eighth century: the gold coin of Byzantium, the solidus, experienced a continual debasement during this period, with its precious content gradually replaced with other, less costly metals (Morrisson and Prigent, 2010). Furthermore, the pottery remains from the eighth century layers in eastern Sicily exhibit clear signs of impoverishment (Arcifa, 2010) and, in some areas, archaeologists have observed a reduction in the overall number of sites after around 700–750 AD (e.g., in the territory of Segesta: Neri and Molinari, 2004; see also the contributions on other rural areas, by Filippi, Fiorilla, Panvini and Rizzo, published in Bonacasa and Maria, 2002; the hinterlands of Sofiana offer a different, less pessimistic scenario: Vaccaro, 2013).

The isotopic data from Pergusa suggests that 750 AD also saw the beginning of a shift towards more arid conditions. Unsurprisingly, the agriculture around the lake seems to have experienced intensive transformations around 750–800 AD. We may first observe a short-lived increase in olive pollen combined with very low levels of cereal pollen, followed by an increase in Cerealia-type and rye, and a decrease in olive. After this, we notice a longer period of abandonment, lasting some 100–150 years. At Biviere di Gela the pattern of change is clearer: after a period of intensification during late antiquity, there was little human impact during the early Middle Ages, which may be due to the coastal location of the site (the Arab raids started in the seventh century) (Noti et al., 2009). At Gorgo Basso the values of olive pollen had also started to decline after AD 600 (Tinner et al., 2009).

To conclude, the history of late Roman and Byzantine Sicily is exceptional for the combination of climatic and anthropogenic factors that encouraged heavy exploitation of the land. All the available evidence, be it textual, archaeological or palynological, suggests that cereal production on the island continued into the later centuries of the Byzantine presence on Sicily. Although there is no direct evidence that increased humidity played a role in the development of cereal agriculture on Sicily during this period, the temporal correlation is striking; the fact that agriculture developed beyond the limits achieved in the early Roman period would certainly suggest that new lands had become suitable for farming. The economic crisis experienced by Byzantine Sicily during the later part of the eighth century and the onset of much drier climatic conditions represent another significant temporal correlation. It suggests that once the climatic (and hydrological) conditions had changed, the old economic model was no longer fully viable, and that the necessary transformations brought about social and economic decline. As a result, Byzantine Sicily would already have been impoverished and weakened when the Arabs began their conquest in 827 AD.

5.2. From the Islamic invasion of Sicily until the Norman conquest

The first Arab incursions in Sicily occurred soon after 650 AD, however the real struggle for the Island did not begin until some 50 years later, after the Islamic forces had managed to conquer the whole of Byzantine North Africa (Carthage, the last Byzantine outpost fell in 695 AD) (Aḥmad, 1975). The final push to conquer the island began more than a century later, in 827 AD. The Byzantine general Euphemios, after an unsuccessful attempt at seizing the imperial throne in

Constantinople, turned to the Islamic rulers of Tunisia for military assistance. Although the leaders of the North African Muslims were under the rule of the caliphate, they attacked the island on their own initiative. In other words, the beginning of the conquest was a regional affair, in which the elites of a neighbouring region, who had remained in close contact with Sicily throughout the previous century, saw an opportunity to expand their dominion. The invasion of Sicily does not seem to have been an element of the power struggle between the caliphate and Byzantium which continued in Anatolia into the ninth century (Nef, 2011; Prigent, 2006b).

However it would take several decades for the conquest to be completed. Warfare between the Byzantine and Muslim armies continued for more than a century, pushing the frontier gradually eastwards (Nef and Prigent, 2013), and causing a political and economic fragmentation of the island. In Western Sicily, Byzantine coins ceased to circulate soon after the conquest and were quickly replaced by Islamic coinage (Castrizio, 2010; De Luca, 2010). However, the available ceramic evidence from excavations in eastern Sicily suggests that even after the conquest, during the ninth and tenth centuries AD, this part of the island maintained a substantial trade with Byzantium. This is not surprising, as the material culture of Eastern Sicily had become more closely related with the Eastern Mediterranean by as early at the eighth century, while the west of the island seems to have been influenced more strongly by the Tyrrhenian exchange networks (Arcifa, 2010). Soon after the conquest, Western Sicily would develop a thriving trade with Islamic North Africa (Ardizzone, 2010). However the prolonged warfare of the conquest period caused a further decline in Sicilian agriculture. Around Pergusa, we see signs of land abandonment dated exactly to this period (800–900 AD). The archaeological data, on the other hand, suggests that rural settlements experienced a certain degree of continuity between the Byzantine and Islamic periods. Several Byzantine sites in south-central Sicily continued into the Islamic period, even if there was a substantial restructuring of the pattern of the rural settlement (Salvina, 2004) A similar scenario may be observed in the area around Sofiana, where the number of sites dating from the tenth to the twelfth centuries (ten) is only 37.5% less than the number of sites dating from the eighth and ninth centuries (sixteen) (Vaccaro, 2013).

It is not immediately obvious why it took the Muslim forces so long to conquer Sicily; with the exception of Anatolia, the heartland of the Byzantine Empire, the Muslim forces had little difficulty taking control of the Byzantine provinces. However, the economic-environmental history of the island may help to explain this anomaly. Throughout the seventh and eighth centuries, the economic prosperity of Sicily attracted enough attention from the capital, and provided sufficient local resources to counter any attempts on the part of the Muslim forces to seize control. This situation may have changed after AD 750. The economic crisis that occurred on Sicily may have coincided with a change in the local hydrological conditions that were crucial to agriculture. It is therefore possible that the period of increased aridity that preceded and accompanied the Islamic conquest – the beginning of the dry period is dated to 750–850 AD while the decisive phase of the conquest occurred between 827 and 878 AD – contributed to the success of the invaders. Byzantine society on Sicily may have been weakened by the agricultural transformations required to deal with a changed climate (visible at Pergusa) as well as a general economic decline (attested by various types of evidence). By the early ninth century, the island may no longer have been capable of defending itself as successfully as it had previously, although the Byzantines still offered substantial resistance to the invaders, especially in the Eastern part of the island.

Once the turmoil of the conquest had largely subsided, the Sicilian economy started to show signs of recovery. Around Pergusa, we may observe a rise in chenopods around 900–1000 AD, followed by a new period of olive cultivation which culminated during the Norman period (1100–1200 AD). This sequence of vegetation changes, in which human disturbance is followed by a rise in olive pollen (on the possible interpretations of chenopods peaks, see section 3.2 above), may signal a larger-scale cultivation of olive around Pergusa; it is also strikingly similar to the sequence of vegetation changes recorded in the pollen record for 1–200 AD, when intensive olive cultivation was introduced during the early centuries of the Roman empire. Arabic textual sources inform us that new cultivars, including sugar cane or mulberry tree, were introduced to Sicily during the period of Islamic rule (although the latter is associated with silk production, and may have been introduced during the Byzantine period). A revival of rural sites in several areas also seems to have occurred under the Muslim rulers in the tenth and eleventh centuries (Molinari, 2004; Nef and Prigent, 2006).

While the recovery does not become fully visible in Sicily until the eleventh century, the southern part of the Italian peninsula had, by that time, already experienced a prolonged period of economic growth. Pollen data from certain sites in Calabria and Apulia reflect an expansion of agriculture staring as early as 800 AD. At Laghi Alimini in southern Apulia, the increase in anthropogenic taxa coincides with a settlement expansion clearly visible from the archaeological evidence (Arthur et al., 2012). At Canolo Nuovo in Calabria, agricultural expansion may not have started until after 1000 AD (Schneider, 1985). Additionally, the textual sources provide us with ample evidence that the southern part of Italy was a flourishing Byzantine province during the early eleventh century. For this period, we possess considerable archival evidence for the large-scale accumulation of wealth by the urban and ecclesiastical elites (Guillou, 1974; cf. Martin, 1993, pp. 329–400, on agriculture in Apulia during the tenth century).

5.3. The Norman and Late Medieval South Italy

Economic growth in the countryside of southern Italy reached its climax in the twelfth century, when the entire region was united under the Norman rule. The process of agricultural intensification is attested in the written sources, most prominently in the records from medieval archives in Apulia. Olive plantations and vineyards begin to appear as a result of increased trade during the eleventh and twelfth centuries; and from the twelfth century onward new cultivars are introduced, including new types of cereals along with specialised fellow vegetation, such as legumes. This intensification was almost certainly the result of an increased demographic and economic pressure (Martin, 1987). This picture of economic growth is confirmed by the pollen data.

At Pergusa, a rise in *Olea* and cereals occurred around 1000–1200 AD; after 1150 AD, however, there must have been an emphasis on cereals, as the values for olive pollen decrease while cereal values continue to grow. At Trifoglietti in Calabria, the impact of human activity begins sometime after 1000 AD (Joannin et al., 2012, Brugiapaglia et al., 2013). Interestingly, the agricultural activity of the twelfth century does not seem to have suffered from the drier climatic conditions visible in the isotopic data from Pergusa at around 1050–1150 AD. Only the appearance of the rye in the pollen record – a cereal that is more resistant to arid conditions than wheat – suggests the possible impact of this drier period.

From the thirteenth century onwards, southern Italy became a major supplier of wheat for the growing urban centres in northern Italy. However, one should not infer that the south was underdeveloped compared with the industrial and commercial north; rather, both parts of the peninsula were equally important elements within a larger synergic structure (Abulafia, 1977). Sicily, however, experienced a period of severe crisis starting from the end of the thirteenth century. Although the crisis may have started as a result of the military conflicts that followed the rebellion of the Sicilian Vespers, the situation grew considerably worse with the arrival of the Black Death in 1347 AD (Benedictow, 2004, pp. 68–73). At the end of the fourteenth century, the population of Sicily was half of what it had been at the beginning. In Fig. 5a one can see the most recent estimates for Sicily's population at various points during the later Middle Ages. The estimates for the year 1277 AD proposed by Epstein (1992) and Bresc (1986) differ considerably (850,000 versus 400,000). If we accept Epstein's estimates, the impact of plague must be judged as very severe (a population decrease of 60%) although Bresc's figures (a decrease of 18%) suggest a more moderate impact. While Epstein's results may better reflect the demographic reality of late medieval Sicily, his estimate for 1277 AD is perhaps too high (Marino, 1995; Percy, 1993). It is interesting to note that the impact of the plague is not clearly visible in the available pollen records from southern Italy. At Pergusa, there is only a short-term decrease in olive and cereal pollen (lasting some 50 years) which may date to the fourteenth century. At Lago Alimini Piccolo, the impact seems even smaller: the only possible sign of crisis around is a slight decrease in olive pollen around AD 1350–1400 accompanied by an increase in arboreal pollen concentration, which nonetheless does not interrupt the millennium-long expansion of olives around the site (Di Rita and Magri, 2009).

The fact that the plague did not result in an agricultural collapse around Pergusa should not surprise us. In fact, the effects of the Black Death on agriculture and rural settlement differed in the various parts of Sicily. Several of the larger estates attracted the rural population, and continued to expand throughout the fourteenth century despite the demographic problems elsewhere on the island (Backman, 1995, pp. 169–170). Moreover, the interior experienced less depopulation than the coast, and there is textual evidence to suggest that coastal populations migrated inland. However it is worth noting that depopulation in the countryside had already started in the 1280s and had become more intensive in the 1320s – that is, prior to the Black Death – during which time a high number of villages were deserted (Epstein, 1992, pp. 25–74). Due to the complex demographic geography of Sicily in the later Middle Ages, most of the general population trends on the island were expressed differently in the different regions, as is visible in fig. 5b.

The $\delta^{18}O$ data indicates that a new wet period began at Pergusa during the fifteenth century, and the Sicilian economy started to recover, with grain farming maintaining a high level of productivity until the seventeenth century. An additional consequence of the late medieval crisis was the expansion of animal husbandry and pasture at the expense of cereal farming; this occurred especially in Eastern Sicily and led to the creation of a more diversified agricultural system on the island (Epstein, 1992, pp. 163–176). As in the Byzantine period, the climatic and anthropogenic factors coincided during this late medieval economic revival. On the one hand, there was greater precipitation, which facilitated agricultural expansion; on the other, the low population levels of the 1370s-1400s provided a starting point for the demographic growth of the fifteenth century. In other words, there was enough well-watered land to sustain the growth of the island's population that, even by the end of the century, had not yet returned to its late-thirteenth century levels.

5.4. The Little Ice Age and the recent period

The reduced evaporation at Pergusa which started early in the fifteenth century lasted until the end of the eighteenth century, and may represents the effects of a Europe-wide climate change known as the Little Ice Age (LIA) (Fischer et al., 1998). At the present time, however, we still do not know the exact temporal and spatial patterns of climatic variability in southern Italy during this period.

In climate and history studies, the Little Ice Age is most often associated with the global crisis of the seventeenth century (for the most recent account, see Parker, 2013). Although the isotopic record from Pergusa does not document the dramatic fluctuations in climate attested elsewhere, they may be connected directly to short-term socio-political instability in Sicily (again, see Parker, 2013). After a century of demographic growth, during which the population far exceeded its medieval levels, signs of crisis began to appear in the seventeenth century. A documented political crisis may have led to social fragmentation (Davies, 1983), while a decline in the foreign demand for Sicilian wheat would have had a negative effect on the economy of the island (Benigno, 1989). More importantly, Italy suffered once again from an outbreak of plague during the seventeenth century, which would have slowed down the Italian economy, and contributed to a decrease in Sicilian grain exports (Alfani, 2013). As we can see in Fig. 5, Sicily's population did not grow as rapidly during the seventeenth century as it had a century earlier (Beloch, 1937; Aymard, 1978, gives a slightly more positive account). However, the island's population recovered quickly from the plague, and none of the outbreaks had consequences comparable to the scale of the Black Death (Aymard, 1973). Thus, we should not consider the seventeenth century to have been a period of substantial demographic crisis on the island, and the population continued to grow throughout the eighteenth century (Aymard, 1968, 1978). Nevertheless, the pollen record from Pergusa shows a decrease in different anthropogenic indicators – both cultivated plants, such as olive or cerealia-type, and secondary anthropogenic indicators, such as *Plantago* – between 1600 and 1700 AD. This may have been related to the end of the large-scale livestock rearing in the area of Castrogiovanni (Enna) after 1600 AD (Aymard, 1971).

Agriculture around Pergusa recovered during the course of the following century. The main changes we found at the top of the Pergusa pollen record relate to the renewal of *Juglans* (nut) cultivation and to the cultivation of *Olea* (olive); following a a sudden switch to dryer conditions at the end of the eighteenth century, olive cultivation became more intensive than ever (fig. 2 and 3). As *Olea* is outside its natural distribution area at Pergusa, its cultivation must have been favoured by dryer and warmer weather conditions than before. The increase in *Rumex* pollen may be evidence for more pasture, but it may also indicate a more open landscape.

6. Conclusions

Our conclusions must begin with an important observation regarding the availability of data. While the archaeological and historical evidence for this region exists in relative abundance and allows us to construct a nuanced interpretation of its socio-environmental history, reliable climate proxies and pollen records for southern Italy during the last 2,000 years are rather scarce. However, our data from the selected case-study area of Pergusa demonstrates a continuous interaction between environmental change and human history. Our multi-proxy approach – that is the combined use of isotope and pollen analyses on the same core – has allowed us to avoid potentially misleading interpretations, such as attributing all landscape changes solely to climatic fluctuations or to the impact of human activity. Instead we have managed to distinguish the various ways in which the societies of Sicily and southern Italy responded to changes in their regional climatic conditions, and identify the different land use patterns that were dominant in each historical period. This result could have not been achieved without close interdisciplinary collaboration. Only through the interaction and the exchange of opinions between different specialists can we arrive at a satisfying interpretation of the environmental changes visible in the pollen diagrams.

Lago di Pergusa was a key reference site for southern Italy, due to its central position in Sicily and its proximity to the site of Enna, an town which has been inhabited continuously throughout the last two millennia. Because of its uninterrupted settlement history, the area around Lago di Pergusa was affected by the various socio-economic trends visible throughout the island of Sicily from the Roman era until the early modern period; it thus offers a record of vegetation history that may be easily linked with societal developments known from other types of evidence.

With the use of isotopic data, we were able to identify two periods of enhanced humidity: the first coincided with the late Roman and early Byzantine periods (ca. 450–750 AD), while the second occurred during the late medieval and early modern periods (ca. 1400–1800 AD). The first humid period (Fig. 3) has correspondences in other Mediterranean records, and the second is also well attested in records from Italian peninsula, and may be seen as part of the Little Ice Age which affected much of Europe. We also identified a period of decreased humidity between around 1100 and 1350 AD, which seems to be related to the lowering of the central Italian lakes.

An unprecedented period of human activity occurred during the late Roman and early Byzantine period; the increased humidity during this time would have made it possible for agriculture to develop within the Sicilian landscape on an unprecedented scale. Our reconstruction, based on the pollen record suggests an open landscape in a period of increased water availability. A sudden and strong period of dryness starting sometime around 750–800 AD may help to explain the collapse of the Byzantine society in Sicily and the final success of the Arab conquest. After this decline – which may have been initiated by a combination of climate change and prolonged Byzantine-Arab warfare during the ninth century – the pollen record suggests that a long time passed before agriculture started to recover.

This decline, however, is the only case we were able to identify in which climatic fluctuations contributed to a major socio-economic change. During the Middle Ages, the drier conditions did not impede the agricultural recovery of the Norman period, and the late medieval crisis that started in the 1280s and culminated in the late fourteenth century were associated with other causes, specifically warfare and plague. Although the Black Death caused considerable population losses on Sicily, its effects are not clearly visible in the pollen record, apart from a short-term drop in some of the anthropogenic indicators. The plague did not bring about a decrease in agriculture around Pergusa comparable to the effects of the dry period that started in 750 AD. Certainly the wetter conditions between 1400 and 1800 AD would have been beneficial to agriculture, and would have helped the population of Sicily to reach high levels; however, the drying trend in the eighteenth century, unlike that of 750 AD, did not result in a socio-economic collapse.

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Table caption

Table 1. Key dates in the history of South Italy, AD 1-2000.

Figure caption

Figure 1. Lago di Pergusa (Sicily): a) Location and b) satellite view of the lake. c) lacustrine vegetation in A, high medium-high level stand and B, low level stand. Main taxa of the lacustrine vegetation concentric belts: a – *Phragmites australis*, b – *Juncus maritimus*, c – *Atriplex latifolia*, d – *Suaeda maritima*, e – *Salicornia patula* with many Asteroideae and Cichorioideae, f – *Chara*; g - microbial mat (from Calvo et al., 1995, modified). d) Map of sites cited in the text. 1 Northern

Apennines (Giraudi, 2014); 2 Lago dell'Accesa (Magny et al., 2012); 3 Lago di Mezzano (Giraudi 2004; Sadori et al., 2004); 4 Central Apennines (Giraudi, 2014); 5 Tiber river basin (Camuffo and Enzi, 1995); 6 Lago Battaglia (Caroli and Caldara, 2007); 7 Lago Grande di Monticchio (Allen et al., 2002); 8 Basilicata (Picarreta et al., 2011); 9 Lago Alimini Piccolo (Di Rita and Magri, 2009); 10 Lago di Trifoglietti (Joannin et al., 2012); 11 Canòlo Nuovo (Grüger, 1977; Schneider, 1985); 12 Urio Quattrocchi (Bisculm et al., 2012); 13 Grotta Carburangeli (Frisia et al., 2006); 14 Gorgo Basso (Tinner et al., 2009) and Lago di Preola (Calò et al., 2013; Magny et al., 2011); 15 Tunisia (Zielhofer and Faust, 2008); 16 Lago di Venere (Calò et al., 2013); 17 Biviere di Gela (Noti et al., 2009); 18 Santa Marija Bay (Carroll et al., 2012); 19 Liqeni i Shkodrës – Shkodra lake (Sadori et al., 2015a; Zanchetta et al., 2012b); 20 Sofular Cave (Fleitmann et al., 2009; Göktürk, 2011 in Luterbacher et al. 2012).

Figure 1. Lago di Pergusa: isotopic and pollen data. Periods of increased humidity are marked in light grey.

Figure 3. Comparison of different terrestrial environmental proxies of central-eastern Mediterranean. a, b, c, d Lago di Pergusa (this paper and Sadori et al., 2013); e, f Liqeni i Shkodrës – Shkodra lake (Sadori et al., 2015a; Zanchetta et al., 2012b); g Sofular Cave (Fleitmann et al., 2009; Göktürk, 2011 in Luterbacher et al. 2012); h Lago dell'Accesa (Magny et al., 2012; Zanchetta et al., 2012a); i Lago di Mezzano (Giraudi et al., 2011); j, k northern and central Apennines (Giraudi, 2014); l Basilicata (Piccarreta et al., 2011); m Tunisia (Zielhofer and Faust, 2008); n Tiber floods (Camuffo and Enzi, 1995).

Figure 4. Monetary finds from Sicily, Athens, Ephesos and a church site in Constantinople (normalised) (based on fig. 6.5, 6.6, 6.8 and 6.10 in Morrisson, 2002) plotted against *Secale* and cereal pollen taxa from the Pergusa record.

Figure 5. (a) population estimates for Sicily in the later Middle Ages (based on: tables 2.1 and 2.3 in Epstein, 1992; Bresc, 1986, 59-77; Beloch, 1937, vol. I, 152); (b) differences in demographic

history between the three parts of Sicily (table 2.1 in Epstein, 1992), plotted against selected pollen taxa and the stable isotope record (more humid conditions towards the top of the Y axis).

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Table 1

Year AD	Key events and reigns
440	After six centuries of peace, South Italy becomes target of the Vandal attacks
476	The dissolution of the Western Roman Empire; South Italy becomes part of the Italian state of Odoacer and Theodoric the Great
535	South Italy is conquered by the Eastern Roman Empire (Byzantium); for the next two decades, the peninsula suffers devastating warfare, Sicily remains largely intact
568	The Lombards invade Italy and subsequently create one of their states in inland South Italy; Sicily remains intact and continues to be a Byzantine province
827	Start of the Islamic conquest of Sicily
878	Syracuse conquered by the Arabs; the end of the Byzantine province of Sicily
1091	The Normans complete the conquest of Sicily; in subsequent decades they unite South Italy in one Christian kingdom
1282	The rebellion of the Sicilian Vespers: as a result Sicily becomes a separate political entity as opposed to the Kingdom of Naples
1347	Black Death comes to Sicily for the first time
1494	Kingdoms of Sicily and Naples united by the king of Aragon (Spain)

Figure 1
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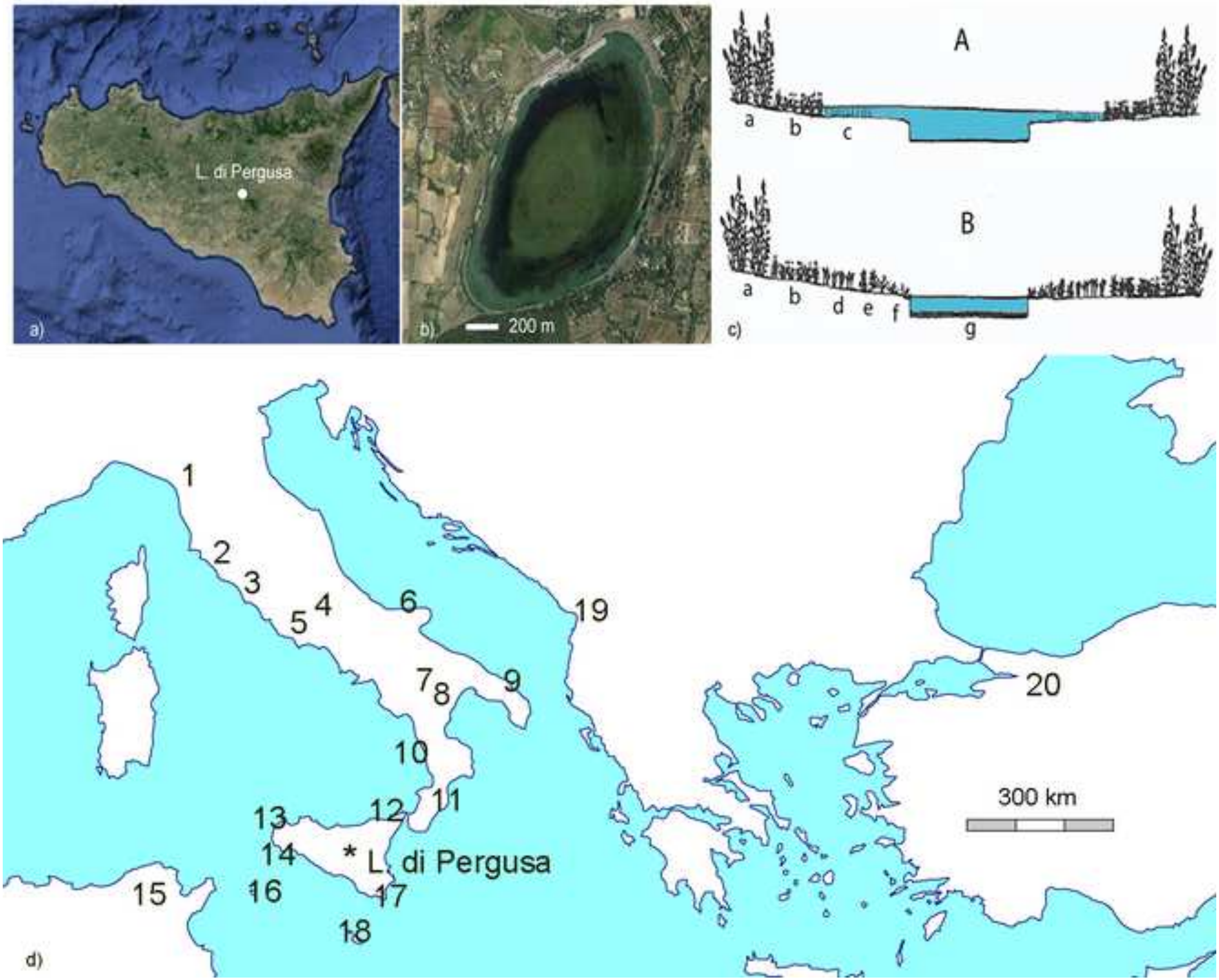
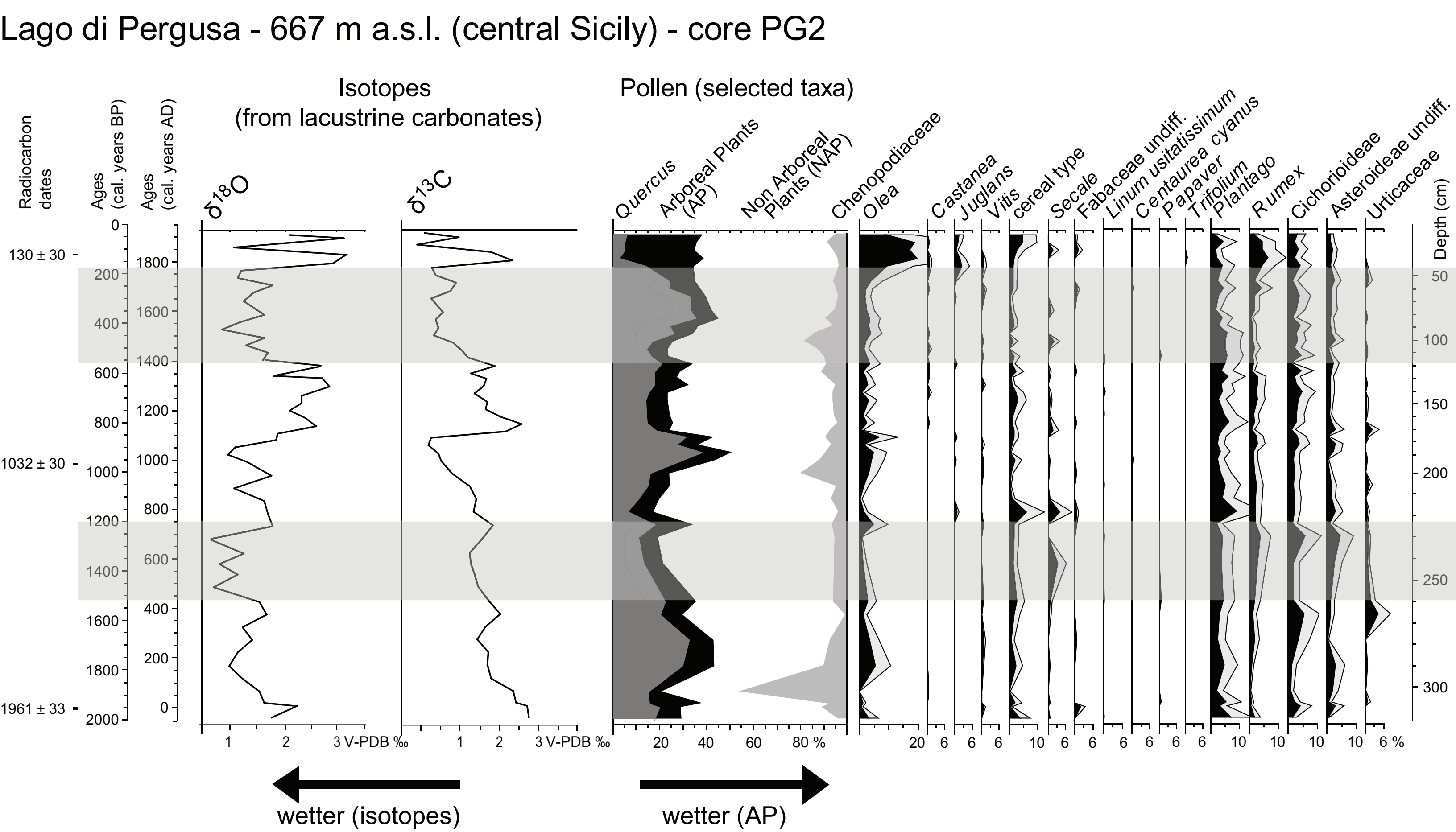
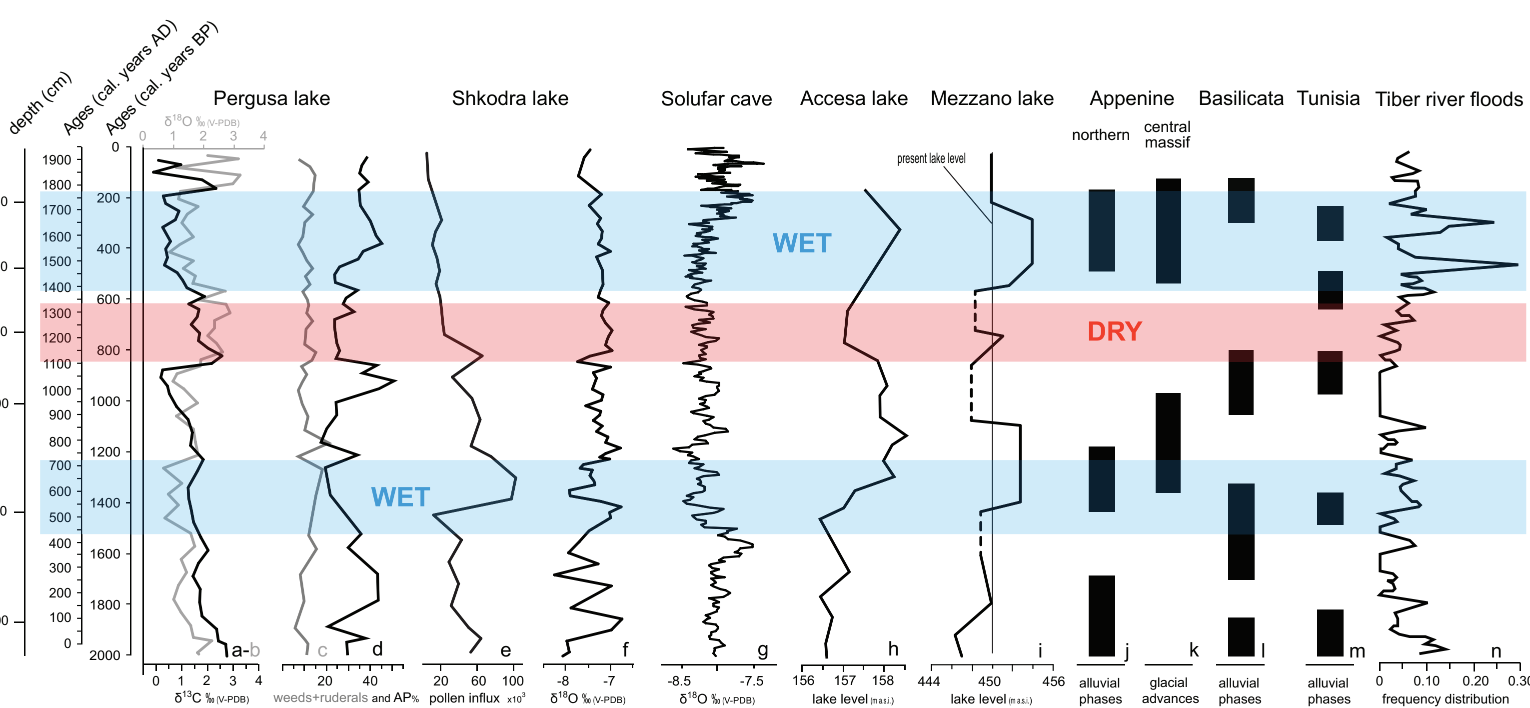


Figure 2



Lago di Pergusa - 667 m a.s.l. (central Sicily) - core PG2
Radiocarbon dates
Ages (cal. years BP)
Ages (cal. years AD)
Isotopes (from lacustrine carbonates)
δ18O
δ13C
Pollen (selected taxa)
Quercus
Arboreal Plants (AP)
Non Arboreal Plants (NAP)
Chenopodiaceae
Olea
Castanea
Juglans
Vitis
cereal type
Secale
Fabaceae undiff.
Linum usitatissimum
Centaurea cyanus
Papaver
Trifolium
Plantago
Rumex
Cichorioideae
Asteroideae undiff.
Urticaceae
Depth (cm)
130 ± 30
1032 ± 30
1961 ± 33
V-PDB ‰
wetter (isotopes)
wetter (AP)

Figure 3



depth (cm)
Ages (cal. years AD)
Ages (cal. years BP)
Pergusa lake
Shkodra lake
Solufar cave
Accesa lake
Mezzano lake
Appenine
northern
central massif
Basilicata
Tunisia
Tiber river floods
present lake level
WET
DRY
WET
δ¹⁸O ‰ (V-PDB)
δ¹³C ‰ (V-PDB)
weeds+ruderals and AP%
pollen influx x10³
δ¹⁸O ‰ (V-PDB)
δ¹⁸O ‰ (V-PDB)
lake level (m a.s.l.)
lake level (m a.s.l.)
alluvial phases
glacial advances
alluvial phases
alluvial phases
frequency distribution

Figure 4

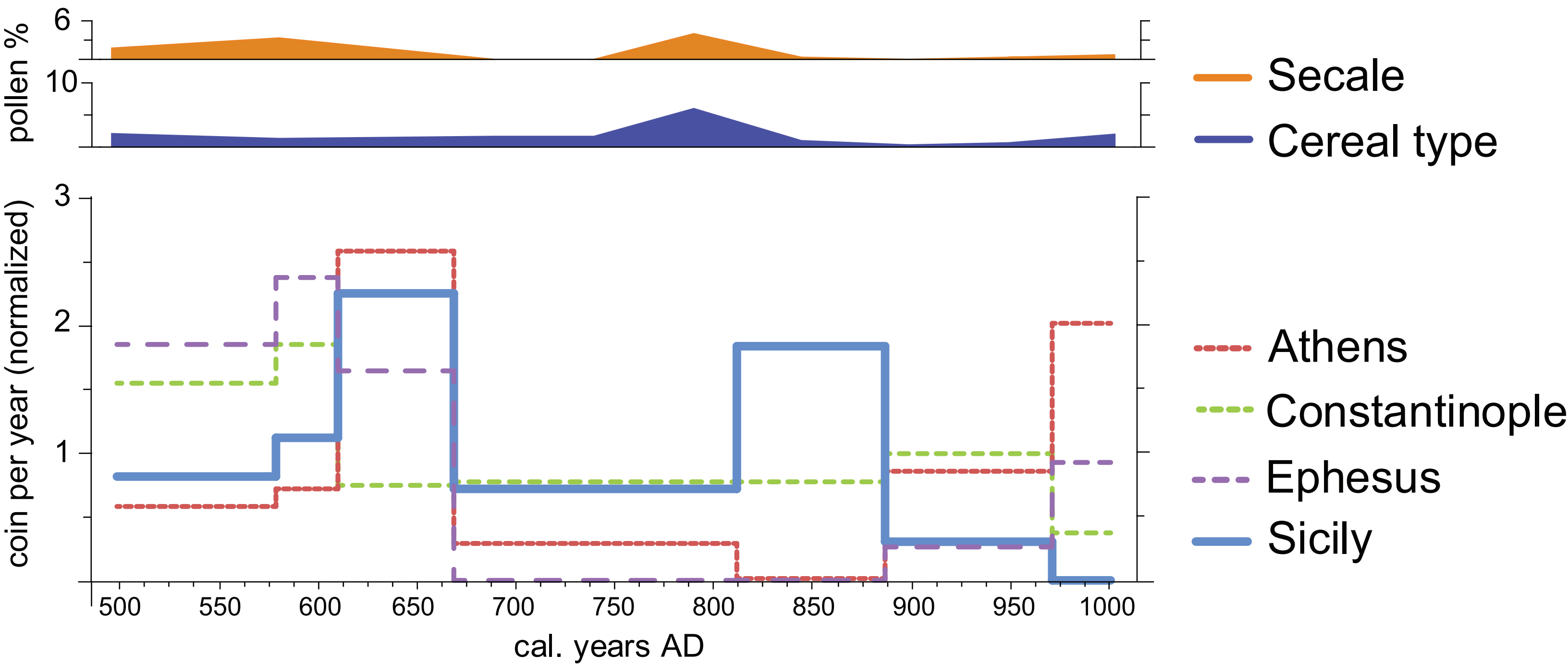
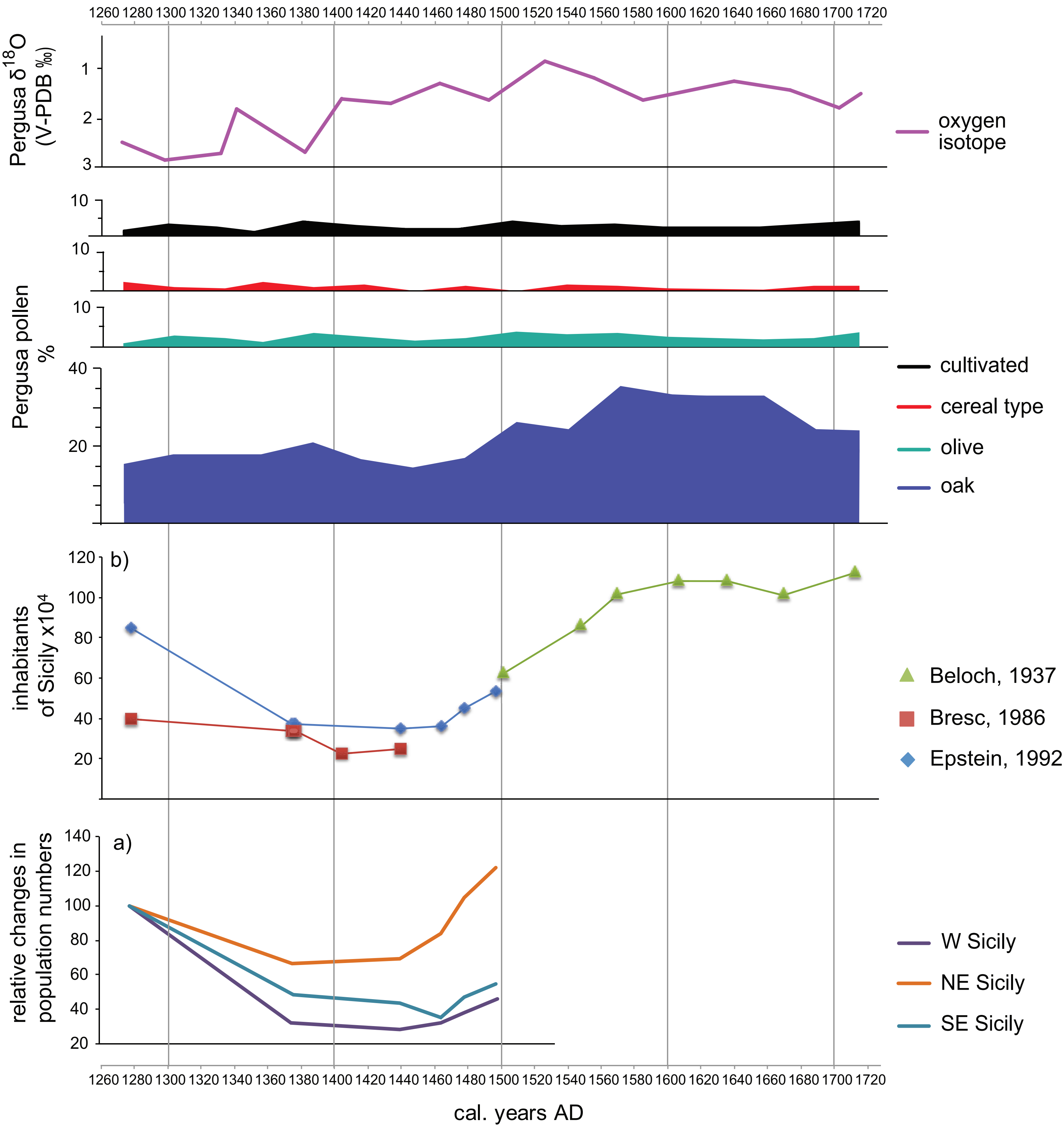

6
10
pollen %
Secale
Cereal type
3
2
1
coin per year (normalized)
500
550
600
650
700
750
800
850
900
950
1000
cal. years AD
Athens
Constantinople
Ephesus
Sicily

Figure 5



1260 1280 1300 1320 1340 1360 1380 1400 1420 1440 1460 1480 1500 1520 1540 1560 1580 1600 1620 1640 1660 1680 1700 1720
Pergusa δ18O (V-PDB ‰)
1
2
3
oxygen isotope
10
10
10
Pergusa pollen %
40
20
cultivated
cereal type
olive
oak
120
100
80
60
40
20
b)
inhabitants of Sicily x10⁴
Beloch, 1937
Bresc, 1986
Epstein, 1992
140
120
100
80
60
40
20
a)
relative changes in population numbers
W Sicily
NE Sicily
SE Sicily
1260 1280 1300 1320 1340 1360 1380 1400 1420 1440 1460 1480 1500 1520 1540 1560 1580 1600 1620 1640 1660 1680 1700 1720
cal. years AD