7300 years of vegetation history and climate for NW Malta: a Holocene perspective

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Abstract

This paper investigates the Holocene vegetation dynamics for Burmarrad in north-west Malta and provides a pollen-based quantitative palaeoclimatic reconstruction for this centrally located Mediterranean archipelago. The pollen record from this site provides new insight into the vegetation changes from 7280 to 1730 cal BP which correspond well with other regional records. The climate reconstruction for the area also provides strong correlation with southern (below 40°N) Mediterranean sites. Our interpretation suggests an initially open landscape during the early Neolithic, surrounding a large palaeobay, developing into a dense *Pistacia* scrubland ca. 6700 cal BP. From about 4450 cal BP the landscape once again becomes open, coinciding with the start of the Bronze Age on the archipelago. This period is concurrent with increased climatic instability (between 4500 and 3700 cal BP) which is followed by a gradual decrease in summer moisture availability in the late Holocene. During the early Roman occupation period (1972 to 1730 cal BP) the landscape remains generally open with a moderate increase in *Olea*. This increase corresponds to archaeological evidence for olive oil production in the area, along with increases in cultivated crop taxa and associated ruderal species, as well as a rise in fire events. The Maltese archipelago provides important insight into vegetation, human impacts and climatic changes in an island context during the Holocene.

1 Introduction

Interpreting the complex relationship between vegetation dynamics, climate change and anthropogenic activities during the Holocene is important for understanding past societies and their environment (Weiner, 2010; Walsh, 2013). Palynology, the study of pollen and spores (e.g. Erdtman, 1943; Faegri and Iversen, 2000; Moore et al., 1991; Traverse, 2008), has been an important element in this interpretation and has been central to environmental reconstruction since the early twentieth century (MacDonald and Edwards, 1991). The analysis of pollen grains extracted from sediment cores from terrestrial and marine environments, as part of an interdisciplinary approach, provides quantitative data on the past changes in vegetation compositions (e.g. Behre, 1981; Giesecke et al., 2011; Sadori et al., 2013a), revealing valuable palaeoecological information that can assist with climate reconstructions (e.g. Bartlein et al., 2011; Mauri et al., 2015). Over the past twenty five years there has been a growing body of knowledge relating to Holocene vegetation changes particularly within the Mediterranean. This region is considered a hotspot of biodiversity (Médail and Quézel, 1999) as well as a climate change 'hotspot' (Giorgi and Lionello, 2008). Recent research has highlighted possible anthropogenic influences along with the, often hard to separate, climatic signal through palaeoenvironmental reconstruction, such as to the west (Carrión et al., 2007; Estiarte et al., 2008; López Sáez et al., 2002; Pantaléon-Cano et al., 2003), centrally (Bellini et al., 2009; Calò et al., 2012; Combourieu-Nebout et al., 2013; Di Rita and Magri, 2012; Noti et al., 2009; Peyron et al., 2011; Sadori et al., 2013b; Tinner et al., 2009), as well as eastern areas (Bottema and Sarpaki, 2003; Finkelstein and Langgut, 2014; Hajar et al., 2010; Jahns, 2005; Kaniewski et al, 2014; van Zeist et al., 2009).

Numerous studies have highlighted the climatic contrast between the western versus eastern and northern versus southern sides of the Mediterranean basin during the Holocene (Brayshaw et al., 2011; Jalut et al., 2009; Magny et al., 2012; Roberts et al., 2011, Peyron et al., 2013). It is generally considered that environmental change was primarily nature-dominated in the wetter early Holocene and human-dominated in the warmer, drier late Holocene (Berger and Guilaine, 2009), the mid-Holocene (6-3 ka BP) remaining a 'melange' (Roberts et al., 2011); therefore focus is often placed on this mid-Holocene climatic transition (Collins et al., 2012; Fletcher et al., 2012; Mercuri et al., 2011; Pérez-Obiol et al., 2011; Vannière et al., 2011).

Within the Mediterranean, the centrally located Maltese archipelago (Fig. 1a) provides a key site to study these dynamics in an island context during the Holocene. However, with no peat bogs or lake deposits, suitable sites for palaeo-vegetation data collection are very limited; notwithstanding this situation some recent research has been carried out on coastal areas (Carroll et al., 2012; Djamali et al., 2012; Fenech, 2007; Marriner et al., 2012).

The purpose of this study is to expand on the current knowledge of the Holocene vegetation dynamics on this strategically located archipelago, positioned almost midway between the western and eastern edges of the Mediterranean, through the study of a terrestrial core taken from Burmarrad, the second largest flood plain, on the Maltese Islands (Fig. 1d).

This will allow for:

a) completing the previous results from Burmarrad obtained by Djamali et al. (2012), that covered a shorter period during the early to mid Holocene (7350-5600 cal BP);

b) a new palaeovegetation reconstruction from 7280 cal BP to 1730 cal BP for NW Malta;

c) the first quantitative palaeoclimatic reconstruction for the Maltese islands.

It is hoped that the more interdisciplinary research conducted both within this archipelago and other Mediterranean locations will provide more data to enable concise reconstructions of the fluctuating vegetation assemblages and climatic variations present over the Holocene. This information, in turn, might provide a better understanding of the various processes and factors affecting not only past but also present and future landscapes.

2 Setting

2.1 Location

The Maltese archipelago (latitude: 35°48'28" – 36°05'00" North, longitude: 14°11'04" – 14°34'37" East) is approximately 96 km from Sicily and 290 km from the coast of Libya. The land area is nearly 316 km^2, comprising of a number of small low-lying islands, three of which are inhabited

(Fig. 1b); Malta (245.7 km^2), Gozo (67.1 km^2) and Comino (2.8 km^2) with a few uninhabited islets being less than 0.1 km^2 in size (Cassar et al., 2008). The geology of the islands consists of five main types of sedimentary rocks: Upper Coralline Limestone, Greensand, Blue Clay, Globigerina Limestone and Lower Coralline Limestone, deposited during the Oligocene and Miocene (Pedley et al., 2002). One of the most characteristic geomorphological features of the islands is the "wieden" (Checuti et al., 1992), a hybrid landform with a physical appearance of a river valley but in process more like an arid region's wadi (Anderson, 1997).

The archipelago's vegetation, similar to other Mediterranean islands and coastal areas, is strongly effected by intense summer heat and low precipitation, as well as increasing anthropogenic activity in recent millennia (Grove and Rackham, 2001; Roberts, 2014). Presently, the three main semi-natural vegetation types are garrigue, steppe and maquis (Table 1), while there are a few much smaller communities developed as woodlands, in freshwater and on rocky habitats, on sand dunes and in coastal wetlands; these smaller communities are significant due to the rare endemic species found within them (Schembri, 1997).

Current evidence for the archipelago establishes human occupation on the islands at about 7200 years ago, with the initial settlers originating from Sicily (Blouet, 2007). During the period covered by the BM2 core the islands have undergone a succession of occupiers; during the Neolithic, Temple and Bronze periods (Trump, 2002) as well as the Historical period with Phoenician, Punic and Roman settlements (Bonanno, 2005).

2.2 Climate

The climate of the archipelago (Fig. 1c) is considered to be typically Mediterranean (Chetcuti et al., 1992), with mild, wet winters and hot, dry summers; while the spring and autumn seasons are short (Blondel et al., 2010). The annual precipitation is 530 mm, with 70% of this rainfall occurring between October and March, though much is lost to evapotranspiration (Anderson, 1997). The Northwesterly wind (*majjistral*) is the most common wind direction for the islands, averaging about 20.7% of the days annually (Galdies, 2011).

2.3 Burmarrad region

The Burmarrad area where the BM2 core was taken (Fig. 1d) is currently an agricultural plain with a number of settlements, along with patches of maquis, garrigue and steppe along its edges, as well as one small remnant stand of indigenous olive trees. Though hard to date, the latter are considered to be up to twelve hundred years old (Grech, 2001). Terracing with rubble walls for agricultural purposes can also be found on the rocky slopes of the catchment area. The present agricultural plain is subject to seasonal flooding; however, before silting in, there is strong archaeological evidence to suggest that it was used as a natural anchorage up until at least Roman times (Gambin, 2005; Trump, 1972). The earliest evidence for occupation in this area is in the form of a prehistoric tomb at San Pawl Milqi dating to 6050-5750 BP (Locatelli, 2001). The fluctuating cultural changes since this time have influenced the widespread landscape transformation during the Holocene not only in this area, but also throughout the archipelago.

3 Methods

Through the Franco-Maltese ANR project PaleoMed (C. Morhange, leader), a number of cores have been taken from locations on the Maltese archipelago with the aim of probing the islands' environmental history. A multi-disciplinary team has been investigating a number of bodies of evidence including sediments, charcoal, pollen and shells. A mid-Holocene section of the BM1 sediment core has been examined (Djamali et al., 2012); while geoarchaeological analysis of the Burmarrad area has been undertaken by Marriner et al. (2012).

3.1 Coring and Sampling

A percussion corer (diameter 10 cm) was used to extract the BM2 core. The 10 m long core was sampled at regular 5 to 10 cm intervals, while the top 2 m was not considered due to proximity to the surface. The methodology used to define the sedimentary environments is based on high resolution sedimentological and palaeoecological data (ostracods and marine molluscs), the initial facies descriptions (such as colour and lithofacies) were conducted under standardized laboratory conditions (see Marriner et al., 2012).

3.2 Laboratory Analysis

Pollen extraction was undertaken following the classic method described by Moore et al. (1991). Each of the 1 cm^3 samples were chemically treated with 10% HCl to remove the carbonate fraction, 48% HF to remove the siliciclastic fraction, and concentrated (37%) HCl was used to remove the silicofluorides produced during HF treatment. Following these treatments, acetolysis was used to remove any organic material and to outline the pollen wall structure to aid identification. To calculate the pollen concentrations, a known amount of *Lycopodium* spore tablets were added to the samples prior to treatment. The pollen percentages are calculated using the pollen sum of all terrestrial pollen counted; it excludes Cyperaceae and other aquatic/hygrophilous species, NPPs (Non Pollen Palynomorphs) and undetermined/indeterminable grains.

A mean total count of at least 300 terrestrial pollen grains was used for each sample, this amount is considered sufficient to provide a fossil assemblage census (Benton and Harper, 2009). Pollen identification was undertaken using the IMBE's pollen reference collection and the pollen atlases of Europe and North Africa (Reille, 1992, 1995, 1998) along with the pollen atlas of central Europe (Beug, 2004). Cereal-type pollen was described as Poaceae >45 µm with a minimum annulus diameter of 8-10 µm (following López-Merino et al., 2010).

Non-Pollen Palymorphs (NPPs) were identified using a number of references: Cugny (2011), Mudie et al. (2011), Haas (1996), van Geel (1978) and Macphail and Stevenson (2004). Pollen percentages were calculated in TILIA, while C2 software (Juggins, 2007) enabled the construction of the pollen diagrams. The pollen diagram taxa have been grouped according to ecology and life form: trees and shrubs, herbs, aquatic and hygrophilous species, coprophilous associated species, and NPPs. Microcharcoals (woody not herbaceous particles) smaller than 10 µm were excluded from the count. The *Lycopodium* spore tablets and sample weight were also used to estimate microcharcoal concentrations (Stockmarr, 1971).

This paper presents the results of pollen analysis carried out on 48 samples collected from the BM2 core between the depths 210 cm and 1000 cm. Some parts of the core did not provide any palynological material to be represented in the diagram (in particular the section between 450 cm and 240 cm).

3.3 Pollen-based quantitative climate reconstruction

Use of only one method for pollen-based palaeoclimate reconstructions could reduce the robustness of the results obtained (Birks, 2011; Brewer et al., 2008), therefore a multi-method approach was utilised for the climatic reconstruction based on the BM2 data set. The chosen approach has been successfully used in studies throughout the Mediterranean area (Peyron et al., 2013; Sadori et al., 2013a). Three methods were chosen: the modern analogue technique 'MAT' which compares past assemblages with modern assemblages (Guiot, 1990); the weighted averaging 'WA' method (Ter Braak and Van Dam, 1989); and the weighted average-partial least square technique 'WAPLS' (Ter Braak and Juggins, 1993). The MAT is the only one based on a comparison of past pollen assemblages to modern pollen assemblages, while the WA and WAPLS are transfer functions that require a statistical calibration between environmental variables and modern pollen assemblages;

Peyron et al. (2013) provide a comprehensive outline of these three approaches. The climate parameters estimated from the Burmarrad core are the temperature of the coldest month (MTCO) and the seasonal precipitation. Calculations for the winter and summer precipitations are based on the sum of the months: December, January, February and June, July, August respectively.

3.4 Age model

Four radiocarbon dates, calibrated using IntCal09 and Marine09 (Reimer et al., 2009) have been used for the BM2 core (Table 2). The samples used for the dating consisted of two charcoal pieces, one grain and one wood fragment. An age model based on these four dates was constructed using the R-code Clam (Blaauw, 2010); this is obtained by repeated random sampling of the dates' calibrated distributions to produce a robust age-depth model through the sampled ages, displayed in the linear interpolation diagram (Fig. 2).

4 Results

4.1 Sediment and chronology

The BM2 core has been subdivided into five lithostratigraphic zones (Fig. 2), recording a general transition from upper estuarine, through marine to a marsh/fluvial environment. The visual core description is as follows: the lower part of the sequence is predominately composed of grey silts (Unit 1a: 1000-800 cm) followed by slightly darker grey silts (Unit 1b: 800–710 cm) both deposited in an estuarine environment, grey shelly sands (Unit 2: 710-460 cm) deposited under marine conditions, marshy muds (Unit 3: 460–300 cm) and marshy muds with oxide mottling (Unit 4: 300-210 cm) and finally, at the upper part, brown sandy clays (Unit 5: 210-0 cm). The two latter sedimentary units display different degrees of pedogenesis. No pollen samples were taken from the top 200 cm surface section due to the considerable biologic and anthropogenic activity that this layer is regarded to have undergone.

Results of the Accelerator Mass Spectrometry (AMS) dating are provided in Fig. 2. The lowest part of the core is radiocarbon dated to approximately 7280 cal BP while the top corresponds to approximately 1730 cal BP. The interpolated curve is quite steep in the midsection of this diagram. This may be an indication of anthropogenic activity in this area causing accelerated runoff and rapid infill of the plain during this period (Gambin, 2005; Marriner et al., 2012). Although all chronology should be treated with caution, it is noted that there is good correlation between the BM1 (Djamali et al., 2012) and BM2 cores. Reworking processes in low-energy ria environments such as these tends to be low; furthermore to overcome reservoir issues we have dated charcoal and short-lived plant material. Our interpretations are based on a chronological timescale established according to four radiocarbon dates, we assume that sedimentation rate in the intervals between the dating points remain relatively constant, however we do not exclude the possibility that in some depths, some changes in sedimentation rate may have occurred leading to slightly different ages for the observed environmental variations.

4.2 Pollen diagram

From the BM2 core only 48 of the 57 spectra are recorded in the diagram; either because they were poor in pollen (between depth 450-240 cm) or due to gaps occurring in the sediment extraction process (940-890 cm and 680-600 cm). The pollen concentration in the core generally was poor however the preservation of the grains was, on the whole, satisfactory. There was sufficient diversity of taxa to reflect pollen contributions from a number of habitats, including wetland as well as a variety of dry ground environments.

The pollen diagram provides percentages for all the terrestrial and aquatic pollen counted, as well as that of spores, microcharcoal, microforaminifera and dinoflagellates, the pollen sum was calculated using terrestrial pollen totals only. No taxa were omitted from the pollen diagram, however pollen productivity and dispersal levels (Hevly, 1981) and possible preservation variability (Havinga, 1971) have been considered (Fig. 3-6).

A total of 98 pollen and spore types were identified, including 17 arboreal pollen (AP) taxa and 56 non-arboreal pollen (NAP) taxa, the latter comprising herbs and weed species. With regard to NPP type, 17 different taxa were identified (Fig. 6). Following Cushing (1967) the diagram has been divided into Local Pollen Assemblage Zones (LPAZ), these five zones are based on principle terrestrial taxa changes.

4.2.1 LPAZ1 (1000–960 cm) Early Holocene: ca. 7280-6700 cal BP

The lower part of this zone (980 cm) is radiocarbon dated to 6055±35 BP. AP taxa are very low (6% and 8%) consisting of *Quercus* (deciduous and evergreen), *Pistacia* and *Erica arborea*-type. NAP taxa are dominant, between 92% and 94% mostly composed of Cichorioideae, Poaceae and Asteroideae, along with Chenopodiaceae, *Convolvulus*, *Plantago*, Cerealia-type. Microcharcoal was recorded at concentration levels start at 3.7, then fluctuate between 6.6 to 8.1. Microforaminifera range from 9.8% to 18.9%, dinoflagellates, 50% to 14% and pollen of aquatic plants, at 3% to 6%, the latter being at its highest percentage recorded throughout the five LPAZs. This zone dates to the early Neolithic, Għar Dalam cultural phase.

4.2.2 LPAZ2 (960-850 cm) Early to mid Holocene: ca. 6700-5000 cal BP

This zone is characterised by a very significant rise in AP taxa, increasing to a maximum of 65% (880 cm). The majority of this AP is comprised of *Pistacia* pollen (almost 60%). NAP taxa are much lower than the previous zone, generally between 35% and 60%. Cichorioideae, though beginning the zone at 21%, dip to 7% before rising to 18%. Poaceae significantly decrease to around 1%. With regard to NPPs, though present in very low percentages in LPAZ1 there is also some presence of *Glomus, Sporormiella* and *Delitschia*, while *Coniochaeta* appears for the first time, peaking at 5% (860 cm). Aquatics in this zone are slightly lower than in LPAZ1. Microcharcoal concentration decreases significantly after the transition to this zone ranging between 1.3 and 2.2 (the lowest level reached in the whole core sequence), then rising towards the end to 8.3, before decreasing slightly to 7.6. Dinoflagellates peak at the beginning of this zone at 40% diminishing to only <1%, while microforaminifera peak in the middle of this zone at 28% tapering off to 6%. This zone covers both the Neolithic (end of Għar Dalam, as well as Grey and Red Skorba) and Temple (Zebbug, Mgarr, Ġgantija and Salfieni) periods (Fig. 7).

4.2.3 LPAZ3 (850-800 cm) Mid Holocene: ca. 5000-4438 cal BP

This zone is radiocarbon dated to 4010±35BP at 820 cm. AP vary between 13% and 45%; while NAP taxa fluctuate between 55% and 87%. The transition to this zone is marked by the significant rise in *Olea*, peaking at 19% (830 cm) *Pistacia*, though relatively high at the beginning at 21%, reaches a low of 6% (810 cm). New AP taxa entering the record include *Betula* and *Phillyrea*, while deciduous *Quercus* records a highest peak of the whole core sequence in this zone at 4. Brassicaceae peak at 11% (its highest in the whole sequence) then decreases to 7%. *Pseudoschizaea* has continued to increase from the previous zone, reaching 9% by the end of LPAZ3, while *Glomus* rises almost in unison to 7%. Aquatics are at their lowest for the whole sequence. The microcharcoal concentration level is fairly high ranging between 3.5 and 8.3. The comparable cultural phase (Fig. 7) is the end of the Temple period (Tarxien phase).

4.2.4 LPAZ4a (800-685 cm) Mid to late Holocene: ca. 4438-4140 cal BP

The mid part of this sequence (720 cm) is radiocarbon dated to 3810±35 BP. AP are in decline, ranging between 12% and 29%, while NAP are high, fluctuating between 71% and 88%. Aquatic taxa remain fairly similar in percentage to LPAZ3. The beginning of this zone is marked by the highest microcharcoal concentration recorded, 14.9. *Olea*, though still present, has diminished drastically to values of 1% to 5% and *Pistacia* to between <1% and 10%. Of the NAP, Apiaceae have increased up to 5%, as have Asteroideae with a peak of 32% (the highest recorded in the core) and *Plantago*-type pollen, with *P. lanceolata*-type reaching its highest level in the core, 10%. *Sporormiella* peak in this zone at 32%; as do *Pseudoschizaea* at 14% and *Glomus* spp. at 15%, the later again mirroring the *Pseudoschizaea* increase. The cal BP dates correspond to the end of the Temple period (Tarxien) and beginning of the Bronze Age (Tarxien Cemetery).

4.2.5 LPAZ4b (685–455 cm) Mid to late Holocene: ca. 4140-3682 cal BP

The mid part of this sequence (500 cm) is radiocarbon dated to 3655±35 BP. AP are still relatively low, only ranging between 6% and 25%, while NAP remain high; 75% to 95% (highest recorded). Microcharcoal concentrations are generally much lower, ranging between 2.2 and 5.1 (except for two peaks 12.7 & 11.6 towards the end). *Olea*, occurs between <1% and 4% and *Pistacia* only 3% to 19%. Of the NAP taxa, Euphorbiaceae dramatically peaks at 41% and Apiaceae reach their peak with 7%, while Asteroideae remain high with between 9% and 23%, as does Cichorioideae, 32%. Chenopodiaceae peaks at 48% (the highest in the whole sequence). Aquatic taxa are still low. *Pseudoschizaea* and *Glomus* spp. both remain relatively high. The zone corresponds to the beginning of Bronze Age (Tarxien Cemetery phase).

4.2.6 LPAZ5 (455–210 cm) the late Holocene: ca. 3682-1731 cal BP

This last analysed section of the core has two notable AP species peaks, though as a whole sequence LPAZ5 records the lowest AP record of 10% dropping from 18%, while NAP taxa remain high at 82% to 90%. Firstly, the start of LPAZ5 has a significant *Pinus* increase, the pollen from this species has been present throughout all the zones at low levels, 0% to 4%, but now records a peak of 10%. *Pistacia* on the other hand is present in its lowest percentages, between <1% and 4%. Towards the end of this zone a second but smaller *Olea* peak occurs, reaching 10%, while NAP taxa Cerealia-type pollen (*Triticum*, 2%), 7%, Cichorioideae, 63%, Brassicaceae, 11%, and, *Scabiosa*, 7%, all record peaks. Aquatic taxa are recorded at their lowest levels. This last zone also has another two microcharcoal concentration peaks reaching 9.2 and 10.4. This final LPAZ starts within the Bronze Age (Tarxien Cemetery) phase, followed by a break in the palynological record (3600-2000 cal BP), and ends within the early Roman phase.

4.3 Climate reconstruction for the Burmarrad area, Malta

A quantitative climate reconstruction has been performed for Malta on the BM2 pollen sequence. The results (Fig. 8) include: temperature, MTCO-mean temperature coldest month; and winter and summer precipitation. The findings are compared and contrasted with other Mediterranean climate reconstructions (see in section 5.2).

4.3.1 Temperature reconstruction - MTCO

Between ca. 7000 and 4800 cal BP the temperature (MTCO) is fairly stable at around 11^{o}C, close to present-day values. After 4800 the temperature becomes more unstable with a minimum at 7^{o}C (~4100 cal BP) and maximum at 14°C (3700 cal BP). Just after this period there is a sharp decline, however more data would be necessary to confirm this trend. After 3600 cal BP the dashed line is due to an absence of palynological data for this period. The period between 2000 and 1800 cal BP is marked by a brief increase in temperature to 12^{o}C close to the present-day coldest month mean minimum temperature for Malta.

4.3.2 Precipitation reconstruction

Winter precipitation displays much more variability than summer. Although reconstructed values differ following different methods (MAT, WAPLS and WA) they illustrate the same trends. From 7000 cal BP to 4600 cal BP winter and summer precipitation are generally high and tend to decrease especially after 6000 cal BP. The period between 4500 and 3800 cal BP is characterized by low winter precipitation indicating a dry period. Again there is no fluctuation displayed between 3700 and 2000 cal BP due to a break in the sequence. Between 2000 cal and 1800 cal BP precipitation values are under the present-day ones.

5 Discussion

5.1 Vegetation dynamics and climate fluctuations

A number of studies have highlighted the problem of disentangling the human and climate induced changes in the Mediterranean region (e.g. Behre, 1990; Pons and Quezel, 1985; Sadori et al, 2004; Roberts et al., 2011; Zanchetta et al, 2013). More often than not it may be a fluctuating combination of these two forces driving the changes rather than a single factor, with one amplifying or even moderating the vegetation signals provided in the palynological record. While it is acknowledged that vegetation patterns can vary even within small island settings such as Malta (Hunt, 2015), the BM2 core provides insight into both changing vegetation dynamics and hydroclimatic fluctuations in the Burmarrad valley system from 7280 to 1730 cal BP.

5.1.1 Early Neolithic

Trump (2002) states that evidence of the first settlers in Malta, around 7200-7000 BP, is found at the Skorba and Għar Dalam prehistoric sites. These original occupiers coming from Sicily (Blouet, 2007), brought with them knowledge in tool making (stone, wood and bone) and agricultural practices (Pace, 2004), as well as crop (barley, lentils, emmer and club wheat) and domesticated animals such as sheep, goats, cattle and pigs (Trump, 1972). However, the exact date when humans arrived in Malta remains a key question. Broodbank (2013) postulates that permanent Mediterranean island settlements were probably preceded by early visitations, however these remain 'archaeologically invisible' (Colledge and Conolly, 2007). The Mediterranean Sea, as well as other areas such as the Persian Gulf (Wells, 1922), were being sailed as early as 9950 cal BP. Even before the Holocene epoch, during the Upper Palaeolithic and Younger Dryas, coastal and island crossings were taking place (Broodbank, 2006, 2013); given the inter-island visibility and this early movement of seafarers, it is plausible that the Maltese islands may have been visited, and possibly temporarily occupied, before being permanently settled during the Neolithic.

Much of southern mainland Europe saw decreasing deciduous woodland areas (from the early Neolithic onwards (Delhon et al., 2009). This vegetation does not appear abundant on the Maltese Islands during this period (Carroll et al., 2012; Djamali et al., 2012), though it has been postulated that deciduous forest was the dominant vegetation at this time (Grech, 2001). Evidence for the environment during this early Neolithic period in Burmarrad suggests an initially open landscape at ca. 7280-6700 cal BP surrounding a large palaeobay during the maximum marine transgression period (Marriner et al., 2012) with mainly non-arboreal pollen and aquatic/wetland taxa. Recorded species indicating this environment are *Botryococcus*, a common green algae and *Phaeroceros laevis*, a bryophyte, which is associated with continually moist or slightly wet, often acidic, soils (Boros et al., 1993), generally located in flood plains, ditches, streams and freshwater marsh areas. It is also considered one of the initial species post fire events (Bates, 2009). However, *P. laevis*, similar to most bryophytes, is not associated with halophytic conditions (Warny et al., 2012). This species might also be considered an indicator of human activity (Djamali et al., 2012). These results are consistent with pollen records from the BM1 core, dated to a similar period from the same flood plain (Djamali et al., 2012); as well as the coastal areas of the neighbouring island of Sicily (Noti et al., 2009) and SE Spain just prior to 7000 cal BP (Pantaléon-Cano et al., 2003). However, not all Mediterranean coastal sites had an open environment at this time, with some areas experiencing it earlier, such as other coastal and inland regions in Sicily (Calò et al., 2012; Tinner et al., 2009) and western Greece (Avramidis et al., 2012).

Although the evidence from the BM2 core and the BM1 core (Djamali et al., 2012) points to this area having an open landscape, it is necessary to highlight that there are Maltese archaeological records from the Neolithic period from other locations. Such evidence might point to a different more 'woody' environment, such as the discovery of *Cercis siliquastrum, Crataegus* sp. and *Fraxinus* sp. charcoal remains (Metcalfe, 1966). Both *C. siliquestrum* (Fabaceae) and *Crataegus* (Rosaceae) are extremely under-represented in pollen diagrams, due to the low pollen production and their dispersal methods. These are deciduous arboreal taxa that either did not appear in the pollen record of the BM2 core or only in minimal and infrequent quantities. Therefore these species may have originated in isolated patches in other regions on the archipelago or were brought as timber to the island by the early farmers or trading seafarers along with other goods.

Many of the key anthropogenic pollen indicators (API) used in different parts of the Mediterranean region, such as primary crop species (*Vitis, Olea*, cereals and pulses) and secondary 'weed' species (*Artemisia*, Chenopodiaceae, *P. lanceolata, Rumex, Urtica*) are native to the Mediterranean area (Brun et al., 2007; Grove and Rackham, 2001; Mercuri et al., 2013; Sadori et al., 2013a) making it difficult to state with any certainty that an individual species is evidence of anthropogenic activity. Although it may be possible to take a combination of key cultivated and ruderal species to provide a stronger indication of human presence (such as Carrión et al., 2010a; Behre, 1990); even if this activity only has a weak influence on the natural vegetation or perhaps acts as an amplifier to the stronger climatic stimulus. Using the works of Andrieu-Ponel et al. (1999), Behre (1990), Brun et al. (2007); Carrion et al. (2010a), Li et al. (2008), and Mercuri et al. (2013), selected taxa from the BM2 core have been identified with consideration of their biogeography to highlight potential evidence of human activity throughout the sequence: cultivated (which includes cereals and associated secondary indicator taxa) and nitrophilous species (taxa often inferring livestock, pasture and settlement) (Fig. 3). Based on different groups of API, we suggest that traces of human activity are present from the base of the BM2 core (7280 cal BP), similar to Noti et al.'s (2009) southern Sicily results, crop taxa (Cerealia-type) and associated ruderal species (such as *P. lanceolata*, Chenopodiaceae, Cichorioideae, Brassicaceae and *Sporormiella*) are noted from the start of the early Neolithic onwards.

These initial traces of palynological evidence, mainly based on NAP taxa which are, due to their phenology, considered more sensitive and responsive to environmental change (Markgraf and Kenny, 2013), coincide with archeological evidence for nearby permanent dwelling structures on the island (Pace, 2004; Trump, 2002), as well as abundant microcharcoals, the latter might be indicative of landscape modification through the use of fire, which has been recorded during the same time period in neighbouring Sicily (Noti et al., 2009) as well as throughout other Mediterranean areas (Vannière et al., 2011); although climate driven fire events can not be discounted (Sadori, Masi & Ricotta, 2015). Nonetheless, the extent to which these first recorded settlers actually impacted the landscape from its 'original state' is hard to decipher without pre-occupation data. What is clear is that arboreal pollen was extremely low in this catchment area during the early Neolithic, and those tree species actually recorded in the pollen sequence such as *Pinus*, may well have been present due to long distance transportation (Calò et al., 2012; Court-Picon et al., 2006; Hjelle, 1999).

5.1.2 Mid Neolithic to early Temple Period

The three cultural phases of the Maltese Neolithic period are delineated mainly by changes in pottery styles. The initial style being almost identical to pottery found in Stentinello, Sicily (Trump, 2004). These remains have been recovered from both the Għar Dalam cave and the Skorba huts, the latter located very close to the Burmarrad catchment area (Fig. 1b), as well as fragments for other locations in the archipelago including Gozo. It is highly probable that during this first Għar Dalam phase (Fig. 7) many more geographically important sites around the island were being settled (Pace, 2004), while farming customs and practices were possibly undergoing adaptation. The first temples were built later ca. 5450 cal BP during the Ġgantija phase (Fig. 7).

The major recorded change in the landscape is from a predominantly open herbaceous and wetland environment, to a much more closed evergreen arboreal cover. At ca. 6700 cal BP there is a rapid expansion of *Pistacia*, reaching a peak of 60% at 5500 cal BP, this peak coincides with the boundary between the Zebbug and Mgarr phases of the Temple Period (Fig. 7). Evidence from these phases can be found within the catchment area, such as the tomb dating to the Zebbug phase at San Pawl Milqi. These unusually high percentages for *Pistacia*, generally considered underrepresented in records (Collins et al., 2012) produce low to moderate pollen quantities that are poorly dispersed (Beer et al., 2007), is suggestive of very dense areas of *Pistacia* scrubland within the Burmarrad catchment area. This high percentage was also recorded by Djamali et al. (2012) in the same plain (BM1 core). However, it was not part of the pollen records from Carroll et al. (2012) taken from Salina Bay, situated within the same catchment area as the BM1 and BM2 cores. This may be due to a number of reasons: *Pistacia* pollen not dispersing to the Salina core site (for example, geomorphic, hydrologic and/or vegetative features in the landscape affecting pollen movement), different preservation or deposition conditions within the core sediments and/or different methods utilised for the pollen extraction process.

Similar rapid and large expansion of *Pistacia* during this period appears in records from Sicily at Biviere de Gela (Noti et al., 2009), Lago Preola (Calò et al., 2012) and Gorgo Basso, where an earlier even larger expansion is recorded between 10,000 and 7500 yr cal BP (Tinner et al., 2009). This earlier *Pistacia* peak and subsequent decline were also noted in Crete (Bottema and Sarpaki, 2003) and western Greece (Jahns, 2003). Djamali et al (2012) provide a concise account of the life cycle, distribution and possible expansion timeframe difference of this genus in relation to the Malta record. The trigger for this *Pistacia* increase has been proposed as being climatic in origin. Noti et al. (2007) suggest the expansion of forests and scrublands between 7000-5000 cal BP recorded in southern Sicily is due to increased moisture availability at this time, which is also noted in southern Spain (Carrion, 2002).

With regard to NAP taxa, the level recorded is the lowest within the whole sequence, with particularly low percentages of nitrophilous taxa, supporting the theory of dense scrubland, that would restrict the growth of other plant species. Chenopodiaceae taxa use, as a possible indictor of a nitrophilous environment, is treated with caution. Many in this taxon are known halophytes (Grigore et al., 2008) and possess a close association with aridity (Pyankov et al., 2000); therefore their use, especially given this coastal zone context, is always in conjunction with other key taxa. Additionally, there is the lowest level of Poaceae, including Cerealia-type (*Triticum*-type), further confirming the dense scrubland scenario. Microcharcoal quantities are also at their lowest levels, a decrease that is noted in other sites in southern European localities, such as Lago Pergusa (Sadori and Giardini, 2007) and Trifoglietti (Joannin et al., 2012) in Italy. Sadori and Giardini (2007) state that this decline in fire events corresponds to forest closing; in the case of Burmarrad this could be considered as scrubland closing.

Burmarrad's palaeo-lagoon is still present during this period, with key indicator species such as dinoflagellates reaching their highest level; these are primarily marine organisms (Traverse, 2008). Their presence confirms the lower estuarine environment at the site recorded in both BM1 (Djamali et al., 2012; Marriner et al., 2012) and BM2 (this study).

5.1.3 Late Temple Period

The temple period in Malta lasted between 6050 and 4450 cal BP; this period is quite unique to the archipelago (Pace, 2004). To date, nowhere else in the world are there freestanding stone buildings (such as Ħaġar Qim, Mnajdra and Ġgantija (Fig. 1b)) dating to this period. The first temple structure is dated to ca. 5450 cal BP, built during the Ġgantija phase (Fig. 7). The purpose of these buildings is thought to be for ritual purposes, for the estimated 10000 people settled on the islands at this time (Trump, 2002).

During this temple building phase there is a notable increase of *Olea* from 4938 cal BP peaking at 4635 cal BP (20%). This increase in *Olea* is similar to that observed in Sicily and Minorca around 5000 cal BP (Pérez-Obiol and Sadori, 2007). However this increase is later than that noted by Tinner et al. (2009) at Gorgo Basso (6500 cal BP), but earlier than the one recorded by Sadori et al. (2013) at Pergusa (3200 cal BP), an increase that they propose is less likely to be 'natural' in origin. Pérez-Obiol and Sadori (2007) argue that it is difficult to state whether these early increases in *Olea* are climatic or anthropogenic in origin; though likely driven by climate, the possibility that Neolithic people were cultivating it cannot be excluded (Beaulieu et al., 2005). Carrion et al. (2010b) through wood-charcoal and wood analysis from prehistoric sites have shown that *Olea europaea* L. var. *sylvestris*, the oleaster (shrubby form), was abundant in the western Mediterranean during the early to mid Holocene (8800-5600 cal BP), they suggest it may have been the dominant species in thermophilous plant formations during this time, with wild varieties thriving in the warmest regions and generally near coastal areas. The oleaster usually takes a shrubby form while the *Olea europaea* L. var. *europaea* is more tree-like. Davis (1994) suggests that *Olea* levels around 20% might be indicative of local cultivation (within 5 km) while values >5% may indicate olive cultivation on a wider regional scale.

With this increase in *Olea* there is also a steady increase in herbaceous taxa, particularly nitrophilous and anthropogenic pollen indicator species (Fig. 3). Another significant increase is seen in Brassicaceae, though previously at minimal levels, it now reaches around 15%. Noti et al. (2009) also observed an increase in herbaceous taxa at Biviere di Gela in southern Sicily (namely Chenopodiaceae-type, Cichorioideae, Brassicaceae, *Mercurialis annua* and *Rumex acetosella*-type) at around the same time. The issue with Brassicaceae (along with Asteraceae, Chenopodiaceae, Poaceae and Rubiaceae) is the fact that it has undifferentiated families composing arable weeds, as well as disturbed habitats and sometimes marsh-plant species such as *Nasturtium officinale* (Zeist et al., 2009) and the pollen produced only shows slight morphological variation, so taxonomic level determination generally only reaches genus or family level (Brun et al., 2007). Therefore an increase in Brassicaceae by itself might not be a clear indicator of human activity, however when combined with the increase in other taxa such as *Plantago*-type, Poaceae, Cerealia-type and/or *Rumex* (Costantini et al., 2009; Djamali et al., 2012) or Sordariaceae (Carrión et al., 2007) this can strengthen its signal of anthropogenic presence, in the latter case suggesting possible pastoral activity. In this regard, in the BM2 core, there is a synchronous increase in API taxa (e.g. Chenopodiaceae, *Plantago*-type, Poaceae and *Rumex*) with Brassicaceae, as well as an increase in coprophilous-associated NPPs such as *Sordaria, Delitschia*, Coniochaetaceae and *Sporormiella* (Cugny et al., 2010; Gelorini et al., 2012), suggestive of human activity, particularly the possible grazing of livestock in the area.

5.1.4 Bronze Age

The Bronze Age in Malta occurred between 4450 cal BP and 2650 cal BP (Fig. 7), and is divided into three phases representing different colonisations of these islands: Tarxien Cemetery, Borg-In-Nadur and Baħrija, the latter settlers co-inhabiting the island with the Borg-In-Nadur people for about 200 years (Pace, 2004). Trump (2004) suggests that the difference in cultures between the Temple and Bronze Age is so apparent it is possible that the islands past through a phase of abandonment, though this remains the subject of an ongoing debate. During the Bronze Age, fortified settlements were built on strategically located hilltops complete with underground food storage facilities known as 'silo-piths' (Buhagiar, 2007), while dolmen structures (possibly used for the burial of cremated remains) were also constructed. Even though there is evidence that these Bronze Age people built dwellings and undertook agricultural activity, including livestock management and possible crop rotation (Fenech, 2007), the previous Temple Period, with its megalithic temple civilization, is considered culturally and economically superior (Buhagiar, 2014). The population of the islands during the Bronze Age is suggested to have been smaller than that of the Temple Period (Blouet, 2007) though their impact on the landscape can still be traced. One such impact found around the islands is the ancient cart rut tracks. These parallel channels are incised into the limestone rock (Hughes, 1999), 22 such networks have been recorded in the Burmarrad catchment area alone (Trump, 2004). There has been speculation on the origin, use and date of these cart ruts since they were first referenced in 1647 by Gian Francesco Abela, one of Malta's earliest historians (Hughes, 1999; Mottershead et al., 2008). Although it is not this paper's purpose to delve into their much-debated chronology and use, it is pertinent to point out that at least some are suggested to be Bronze Age in origin (Trump, 2004)..

Throughout the early and mid Bronze Age, arboreal species in the Burmarrad catchment area are decreasing in abundance, while herbaceous taxa are increasing, suggesting the opening up of the landscape. Furthermore, the increased microcharcoal concentration at the start of this sequence might indicate the use of slash-and-burn to this end. This increase in fire activity around 4500 cal

BP is also noted in southern Sicily at Gela di Biviere (Noti et al., 2009) and slightly earlier (5000 cal BP) at Lago Pergusa (Sadori and Giardini, 2007). It is also observed as a general trend in the Mediterranean from around 4000 to 3000 cal. BP (Vannière et al., 2011). The cause of this increased fire activity is suggested to be partly due to human activity and associated disturbances.

Pastoral activity plant indicators (such as *Rumex* and *Plantago lanceolata*-type) reach their highest levels in this sequence. *P. lanceolata* is known to grow in both hay meadows and grazed areas (Briggs, 2009) though there are distinct ecotypic variants for co-adaptive traits depending on the habitat (Van Groenendael, 1986 and Steans, 1976, cited in Briggs 2009). However, further evidence including a very significant increase in *Sporomiella*, a coprophilious fungi associated with pastoral activities (Pavlopoulos et al., 2010), along with increases in nitrophilous taxa (Li et al., 2008) such as *Urtica* and an exceptionally large peak in Chenopodiaceae, at ca. 4000 cal BP, strengthens the interpretation that land use in the Burmarrad area included grazing from around 4200 cal BP onwards. This increase in the use of livestock supports the argument put forward by Blouet (2007) whereby he proposes that, during the Bronze Age, 'war-like' conditions led to a shift towards livestock use rather than crop cultivation, due to the ability to be able to move animals quickly into the fortified settlements.

The early part of the Bronze Age in this area is also marked by a rise in *Pseudoschizaea* (a Zygnematacean algae spore) and *Glomus* (Glomaceae). Carrión et al. (2010) state that an increase in both these taxa may indicate increased soil erosion. Supporting this idea, increasing *Glomus* spp were noted by Ejarque et al. (2011) in areas of greater soil perturbance and erosion. Furthermore Estiatre et al. (2008) describe *Pseudoschizaea* as indicative of soil erosive activity especially when associated with certain taxa, such as Asteraceae, that are known markers of edaphic processes. In the case of the early Bronze Age in Burmarrad, there is an increase in Asteraceae coinciding with the increase of *Glomus* spp and *Pseudoschizaea*, further supporting the suggestion that during this time there is increased erosional activity, which is synchronous with a reduction in pollen concentration rate as well as reduced arboreal taxa. This increased erosion can also be seen within the changing dynamics of the ria. At around 7000 cal BP the area formed a marine lagoon (area ca. 1.8 km^2) followed by a sharp decrease in marine mollusc taxa from ca. 4000 cal BP, with the area infilling with fluvial sediment and gradually becoming landlocked (Marriner et al., 2012).

This increasing human pressure on the landscape during the Bronze Age is not isolated to the Maltese archipelago or the central Mediterranean area (Mercuri, 2014), it has also been recorded throughout the whole region, between 5000 and 3000 cal BP, as societies and their associated ecological disturbances become more apparent (Sadori and Giardini, 2007; Mercuri et al., 2015). Sadori et al. (2011) note two signals within the Mediterranean; the first corresponds to a climate event of 4300 to 3800 BP (Magny et al., 2009), that of a sudden and brief episode between 4400 and 4100 cal BP which initially affects the arboreal pollen concentration followed by the percentages (generally being accompanied by human presence indicators), then a second between 3900 and 3400 BP, which they suggest is slightly longer and involved intensive land exploitation.

Towards the latter part of this period in Burmarrad (ca. 3600 cal BP) the remaining Mediterranean arboreal taxa decline again. However, there is a distinct increase in *Pinus*, reaching over 10% from its previous levels of 1 to 4% throughout the whole sequence. MacDonald and Cwynar (1985) suggest that when *Pinus* reaches 20% it becomes significant in the environment, lower percentages being more likely due to background noise from long distant transport. Furthermore, Calo et al. (2012) state that *Pinus* levels of 10% might still be representative of long distant transport because the species is a known producer of large quantities of well-dispersed pollen, therefore its pollen can be found even if the plant is not locally abundant. The origin of this *Pinus* pollen might not be Sicily or mainland Europe because *Pinus* (along with *Corylus*, *Alnus* and *Ostrya*) has been documented to be on the island prior to the Holocene, in Pleistocene deposits (Hunt, 1997). Therefore this 10% increase at Burmarrad might be indicative of *Pinus* either now growing in small communities within the catchment area or perhaps in larger communities elsewhere on the archipelago. In neighbouring Sicily, *Pinus* levels increase at a similar time at Lago Preola (Calò et al., 2012) and Gorgo Basso (Tinner et al., 2009). However, Carroll et al. (2012) recorded considerably more *Pinus* around this time (3900 cal BP onwards) within the same catchment area (reaching levels close to 80%) although they suggest this may be due to infilling of a former dredged channel (mid 19th century) rather than indicative of local vegetation at this time.

In addition, towards the middle of the Bronze Age period, there is a gradual decline in nitrophilous and pastoral taxa (Fig. 3) perhaps indicating a reduction in the amount of livestock within the catchment area. On the other hand, there is an increase in Poaceae as well as a considerable rise in *Euphorbia*. This latter taxon (along with *Kickxia*, *Papaver rhoeas-group, Sinapis, Scleranthus,* and *Valerianella*) is considered one of the classic indicators of cultivated areas in southern Europe (Brun et al., 2007). Therefore the Burmarrad area, while remaining a generally open landscape, may well have transformed from a predominately grazed area to a more cultivated one from the middle of the Bronze Age period onwards. Marriner et al. (2012) suggest that by around 3000 cal BP the Burmarrad ria had reduced to 0.9 km^2 (50% smaller than its 7000 cal BP maximum marine transgression) providing a fertile deltaic floodplain for food production. Further supporting the suggestion of agricultural activity at this time are the silo-piths found within the hilltop settlements (Buhagiar, 2007). These provide indirect evidence that the amount of agricultural production was great enough to enable food storage to take place during this time. In Sicily, the evergreen vegetation decreased between 4500 to 3700 cal BP (such as at Biviere di Gela, Gorgo Basso and Lago Preola (Fig. 1a)), a similar reduction can be observed within the Burmarrad catchment area. These sites in Sicily then record a recovery of evergreen taxa between 3700 to 2600 cal BP. Almost synchronously an increase is noted at around 3680 cal BP in NW Malta. Unfortunately the Burmarrad core has a break in the record just after this date, though it may be reasonable to suggest that a similar recovery period to Sicily occurred on the archipelago.

5.1.5 Historical period

BM2 core sequence (Fig. 7) covers the first three phases of the Historical period: Phoenician 2750-2430 BP, Punic 2430-2168 BP and Roman 2168-1404 BP (Pace, 2004), although palynological data is currently only available for the period 1972-173 cal BP. At the beginning of the second Punic War the islands changed from Carthaginian to Roman rule, forming part of the Sicilian province (Bonanno, 2005). However, for about the first three hundred years the Punic culture, detectable in pottery styles and inscriptions, persisted (Blouet, 2007). Seventeen Roman period sites have been linked to the production and exportation of olive oil on the islands (Gambin, 2005), along with extensive port remains, such as quays and various buildings including warehouses, around the Marsa area (Gambin, 2004/5), being in close proximity to the Grand Harbour, a naturally sheltered ria. Following Roman occupation in 2168 BP, archaeological remains and textual evidence both suggest that Malta was producing refined textiles and that some islanders were living in sophisticated dwellings such as a typical domus located in Rabat (Bonanno, 2005). The Burmarrad area also has archaeological evidence of Roman occupation. Evidence includes large oil-producing Roman villas (San Pawl Milqi and Bidnija), burial complexes (Bonanno, 2005), along with ceramic deposits datable to the Punico-Roman period from the silted ancient harbour (Gambin, 2005).

The last part of the core sequence for the Burmarrad plain dates to the mid-Roman phase (1972-1730 cal BP). The landscape in the catchment area at this time appears relatively open, *Pinus* levels have reduced and NAP taxa are high, with a marked peak in Cichorioideae, Brassicaceae and Cerealia-type, as well as smaller increases in *Triticum*-type and *Plantago*-type. An increase in agricultural activity within this area is supported by the presence of these cultivated crop and associated ruderal taxa. Marriner et al. (2012) conclude that around this time a large part of the area had become a well-developed fertile deltaic plain, therefore it is very likely that it was used for cultivation purposes. These crop taxa are generally considered to have poor dispersal, being under-represented (though present), even when near cultivated land (Brun et al., 2007; Behre, 1981).

When interpreting pollen data, possible long distance transport, including that of cereals should be considered (Birks and Birks, 1980; Court-Picon et al., 2005). Another consideration regarding Poaceae, including cereals and other crop species, is that pollen dispersal and its potential deposition is dependent on harvesting methods (Hall et al., 2013). Furthermore, it has been suggested by López-Merino et al. (2010) that crop cultivation may decrease the herbaceous plant community abundance, while abandonment can have the opposite effect. This increase in cultivated species and corresponding decrease in herbaceous taxa can be noted in the pollen record of Burmarrad during this time. Although attention must be placed on the over- or under-representation situation caused by a plant's life cycle. Under-represented taxa, such as cereals, are considered to produce low quantities of pollen that are poorly dispersed (Court-Picon et al., 2006). This can cause over-representation of extra-local and regional pollen that is anemophilous in nature. Furthermore, pollen production of local Poaceae taxa in intensive livestock areas has been suggested to be low due to overgrazing (Hjelle, 1998; Mazier et al., 2006), which possibly would also allow for over-representation of extra-local and regional pollen, although Ejarque et al. (2011) observed contrasting results in their modern pollen-rain study.

Another notable increase is that of *Olea*, peaking at ca. 1800 cal BP. Although not as large as the one recorded in the Temple Period it reaches nearly 10%. This level appears consistent with Di Rita and Magri's (2009) research from an early period (3500-2700 cal BP) that finds *Olea* percentages never exceeding 10% in sites within the evergreen vegetation belt in Italy and the Balkans (such as Lago Battaglia (Caroli & Caldara, 2007), Lago dell'Accesa, Lake Voulkaria and Malo Jezero). *Olea* is considered an emblematic plant of the Mediterranean (Kaniewski et al., 2012; Di Rita and Melis, 2013) acting as a bio-indicator to define the limits of this region's vegetation (Grove and Rackham, 2001; Carrión et al., 2010; Roberts et al., 2011) being both drought-tolerant and cold-intolerant (Collins et al., 2012), though its adequacy as a true bio-indicator has been questioned due, in part, to its cultivation (Blondel et al, 2010). *Olea* is a good producer and disperser of pollen (van Zeist et al., 2009). Its pollen can be found in the surface samples even when the plant is not present in the region (Canellas-Bolta et al., 2009; Joannin et al., 2012), though other researchers (Davis, 1994; Stevenson, 1981) note that it may only be a good producer but a poor disperser. It has been observed that *Olea* pollen can vary greatly in modern surface samples within olive stands, such as between 3-40% (van Zeist and Bottema, 1991) and 7.6-56.4% (Florenzano, 2013). In fact Florenanzo (2013) notes this level decreased to just 2.1-7.6% at 500 m from the stand. Djamali et al. (2015) suggest that their SW Iran *Olea* levels, reaching 8.2%, indicate small-scale olive groves distributed over the catchment area. With this is mind, the origin of BM2's *Olea* increase, if not from Burmarrad, is most likely still from within the islands. However, Carroll et al. (2012) did not record *Olea* in their Salina Bay sequence in any great quantities and it was not noted as present during this particular phase (possible explanations for the latter site provided in 5.1.2).

The interpretation that *Olea* was present on the island, possibly within the Burmarrad area, is based both on the palynological evidence provided in BM2 as well as from archaeological and geoarchaeological evidence as stated by Gambin (2004, 2005, 2012) and Bruno (2007) that suggests Burmarrad was an area of olive production during the Roman period. The Roman villa of San Pawl Milqi, situated within the catchment area, has substantial structures for olive pressing and oil production (Cefai et al., 2005). Also supporting this idea, is the nearby presence of an ancient grove that is situated next to a surveyed but unexcavated Roman villa (Docter et al., 2012). Furthermore, the scale and quantity of these archeological remains suggest that the oil production exceeded the needs of the local population (Gambin, 2005; Marriner et al., 2012). This rise in *Olea* cultivation in the Roman period corresponds well with that observed in Tripolitania, Libya (Barker, Gilbertson, Jones & Mattingly, 1996), as well as other areas such as Spain (Pantaléon-Cano et al., 2003) and the Levant (Kaniewski et al., 2014; Litt et al., 2012). Di Rita and Magri (2009:304) note the 'Roman occupation coincided with a modest diffusion of *Olea'*; they suggest that between 2500 and 1500 cal BP the climate conditions in southern Italy were not so advantageous for olive cultivation (whereas the Bronze Age people benefited from plentiful wild olive productions), though more generally Jalut et al. (2009) propose that from 3600 BP the increase in *Olea* is due to drier conditions making its cultivation favourable. The interpretation in the case of Burmarrad is that the *Olea* increase was human influenced with favourable local growing conditions.

With regard to *Olea* expansion at this time in other localities, this increase is not recorded in the southern Sicilian sites, while in Greece Van Overloop (1986, as cited in Reale and Dirmeyer, 2000) observes the Roman period having a general decrease in AP taxa (including *Olea*) with increasing steppe vegetation. On the other hand, increases in *Olea* were recorded in western Mediterranean sites such as southern Spain (Pantaléon-Cano et al., 2003) and on the eastern edges of the region, such as the Levant (Kaniewski et al., 2014; Litt et al., 2012).

Other notable changes include higher levels of microcharcoal, compared to the Bronze Age, which can also be observed at Lago Preola, Sicily (Calò et al., 2012). Additionally, there is the highest peak of both *Glomus* and Cichoriaceae taxa in the whole sequence. Cichorioideae is used with caution, it is known to be over-represented in pollen diagrams, especially when found in badly preserved material (Mercuri et al., 2006), due to selective preservation of pollen grains; the same is true for Chenopodiaceae (Di Rita and Magri, 2009). However, recent research by Florenzano et al. (2015) suggests that Cichorieae can be used as an indicator of some types of primary open habitats as well as secondary pastures sites. In BM2, the other pollen and spores encountered in these samples were of good preservation so this particular issue can be discounted. Furthermore, Mercuri et al. (2006) suggest that the presence of cereal and (abundant) Cichorioideae pollen together can provide evidence for human settlements and their associated crop fields and pastures. These two taxa are at their most abundant at this time in Burmarrad and therefore very likely indicate an anthropogenic signal. With regard to *Glomus*, a known indicator of soil disturbance, this high level might suggest an increase in human influenced erosional activity. This is concurrent with continued infilling of the ria (Marriner et al., 2012). Wilson (2013) notes that Roman scholars (such as Pausanias, AD160) were aware of ‘the effects of agriculture on increasing erosion and the concomitant downstream deposit of alluvial fans’.

5.2 An interpretation of climatic change

The Holocene climate has fluctuated both spatially and temporally on a global scale (Mayewski et al., 2004) as well as within the Mediterranean basin (e.g. Brayshaw et al., 2011; Jalut et al., 2009; Magny et al., 2002, 2011; Roberts et al., 2011; Mauri et al., 2015). Human impacts have affected the natural vegetation of the Mediterranean since the mid Holocene, but disentangling climatic and anthropogenic causes of vegetation change is complex. Our climatic reconstruction seems consistent with independent records from the Mediterranean such as lake-levels from Sicily (Fig 8) or speleothems from Israel (Magny et al., 2012, Bar-Matthews and Ayalon, 2011), and large scales paleoclimate reconstruction (Mauri et al., 2015). This reconstruction provides valuable insight into the palaeo-climate of this centrally situated archipelago between 7280 and 1730 cal BP, allowing for comparisons to be made with other reconstructions undertaken within the Mediterranean region (Figs. 8 and 9).

5.2.1 Temperature

The trends observed within the Burmarrad sequence are comparable to other southern Mediterranean climate reconstructions, particularly Sicilian and southern Italian mainland sites

(Peyron et al., 2013). The temperature for Malta is slightly warmer than that recorded at Lago Pergusa, Sicily (Sadori et al., 2013b), this lake is situated at a higher altitude (667m asl), however the overall pattern of fluctuation is similar (Fig. 8). This difference may be due in part to the more southerly latitude of the Maltese islands. Orography is another factor that may create both regional and local variances in Mediterranean heat wave, wind and cyclonic activity (Gladich et al., 2008; Lionello et al., 2006; Sotillo et al., 2003). The Maltese archipelago's relatively small area and low-lying terrain differ greatly from Sicily's larger and much more mountainous area.

The reconstructed MTCO temperature for Burmarrad can be summarised as warm in the early Holocene, followed by instability after 4800 cal BP, particularly between 4100 and 3700 cal BP with a minimum at 7°C. This period of fluctuation between 4400 and 3700 cal BP coincides with rapid climate change (RCC) events on a global scale noted between 4200-3800 BP (Mayewski et al., 2004), as well as regionally within the Mediterranean (Combourieu-Nebout et al., 2013; Jalut et al., 2009; Magny and Combourieu Nebout, 2013). During the Holocene, the development of complex societies within the Mediterranean region have been noted to be 'coincident with and partly stimulated by these climatic changes' (Roberts et al., 2011). With respect to Malta, this period saw the onset of the Bronze Age and its notable differences from the previous temple building period not only culturally but also in vegetation and increased soil erosion (section 5.1.4). We also cannot exclude for this period a possible bias in our climate reconstructions due the increasing human impact.

5.2.2 Precipitation

Peyron et al. (2013) propose a north-south divide for Italy, similar to that seen in the eastern Mediterranean (Dormoy et al., 2009; Kotthoff et al., 2008, 2011), which supports the mid-Holocene opposing summer precipitation hypothesis for the Mediterranean; that of a reduced summer precipitation for northern sites (above 40^{o}N) and a maximum for southern sites (below 40^{o}N) for the early to mid-Holocene period. The early Holocene reconstruction from Malta suggests a gradual increase in summer precipitation from ca. 7000 cal BP, peaking at around 5300 cal BP. Within Sicily, Frisia et al. (2006) suggest that between 7500 and 6500 BP multi-decadal dry spells created hydrologically unstable conditions that probably favoured the development of Neolithic agriculturalism. In Malta, the first evidence of settlement is dated to around 7200-7000 cal BP (Trump, 2002), which includes archaeological as well as palynological indications of agricultural activity (section 5.1.1). In the late Holocene, the summer precipitation in the Burmarrad catchment area decreases to below previous levels, but can be potentially biased by human impact. The only anomaly is the 1700 cal BP increase in summer precipitation at the very end of the sequence; further investigation is required to explain the cause of this event. This rise at 1700 cal BP does however appear to exhibit a similarity with Jalut et al.'s (2009) observation that within the western Mediterranean an arid phase occurred between 2850 and 1730 cal BP, which they point out correlates to an eastern Mediterranean dry episode 3000-1700 cal BP. More data from Malta is required either side of this 1700 cal BP date to verify this similarity.

Burmarrad's winter precipitation pattern and quantity is, on the whole, comparable with Lago Pergusa (Fig. 8). Both areas are subject to an increase in winter precipitation between 7000 and 5500 cal BP, followed by a slight decrease until just before 5000 cal BP. Djamali et al. (2012) suggest that the early Holocene (7350-6960 cal BP) was relatively dry, favouring steppe vegetation in the Maltese islands (as well as some other Mediterranean sites). This was most probably due to the indirect effect of the subtropical monsoon intensifications, with the maximum moisture availability occurring during the time of *Pistacia* expansion. At 5000 cal BP, another increase occurs, though to a greater extent in Lago Pergusa. From 5000 until 4500 cal BP, both sites experience a decrease followed by a period of instability between 4500 and 3700 cal BP. In the Pergusa site this instability continues to about 3000 cal BP, however it does not feature in the Burmarrad core due to a gap in the sequence. This phase coincides with the 4400-3500 cal BP drier phase noted at Lago Trifoglietti (Joannin et al., 2012). Both sites then experience a decrease in precipitation between 2000 and 1700 cal BP, again coinciding with drier phases noted at Lago Trifoglietti and within the Mediterranean as a whole (Jalut et al., 2009).

Based on results from Sicily's Lago Pergusa (pollen-based) and Lago Preola (lake-level), Magny et al. (2011) describe the pattern of Holocene precipitation as having a maximum winter and summer wetness between 9800-4500 cal BP, followed by declining winter and summer wetness. This is largely consistent with findings from Burmarrad. These changing moisture levels during the Holocene have been linked to significant societal changes. Sadori et al. (2015) propose that periods of increased humidity, over the last 2000 years, coincided with both agricultural and demographic expansions. While Weiss and Bradley (2001) suggest that, around 4250 BP, a number of cultures were at their economic peak, such as Mesopotamia's Akkadian empire, Egypt's Old Kingdom civilization and Palestine, Greece and Crete's Early Bronze societies; however these once flourishing areas declined rapidly after 4150 BP possibly due to severe drought and cooling. The event has been recorded elsewhere in the world and seems to have acted at a global scale (Booth et al., 2005). The impact of drought events on the human socio-economy, and the consequent impacts on the landscape, should thus not be underestimated as has been recently suggested by Sharifi et al. (2015) for the continental Middle East. These increases in aridity not only affect the vegetation communities directly but also indirectly by altering the anthropogenic pressure on the local landscape, both directly in those regions, as well as wherever the displaced people migrate. This combined effect is not confined to the eastern Mediterranean at this time. Closer to the Maltese archipelago, Noti et al. (2009) suggest that at Gela di Biviere, Sicily, between 5000 and 4000 cal BP, the anthropogenic impact occurring on the landscape is probably influenced by the climatic changes.

As well as the north-south divide, there are also east-west differences in moisture that have been recorded in the Mediterranean during the early Holocene (Roberts et al., 2011; Vannière et al., 2011). Whereby during the early Holocene the north-eastern region underwent a period of increased winter precipitation up until 6000 BP followed by a decline; whereas south of the Dead Sea Hunt, Gilbertson & El-Rishi (2007) suggest a general decrease in precipitation through the early to mid Holocene. While in the western region, though less pronounced, the maximum increases occurred between 6000 and 3000 BP before declining to current levels (Roberts et al., 2011); see Zielhofer and Faust (2008) for mid-late Holocene fluctuations recorded in Tunisia. Therefore, given Malta's central location, finding its 'climatic' position poses an interesting task. The first part is fairly simple, lying below 40°N (Fig. 9) its climatic reconstruction is quite synchronous with other southern localities (Peyron et al., 2013); however its east-west position is more debatable and beyond the purpose of this paper, though with changing climatic drivers, such as the North Atlantic Oscillation (NAO) and subtropical monsoon system and their associated moisture levels (Morley et al., 2014), the archipelago's 'position' might possibly vary throughout the Holocene as the system fluctuates.

6 Conclusion

This paper presents vegetation dynamics from ca. 7280 to 1730 cal BP for Burmarrad in northwest Malta, along with a pollen-based climate reconstruction for this archipelago. The vegetation changes recorded within the catchment area correspond well with those observed in the shorter early to mid-Holocene sequence of BM1 core, as well as those from neighbouring southern sites in coastal Sicily. If vegetation changes in Burmarrad are similar to those in coastal Sicily then it may be possible to infer similarities to other areas within Malta itself, or at least it can be 'reasonably assumed' though such assumptions would have to be tested.

This inference might also be supported by the fact that Malta has a relatively low topographic variability and is almost completely located within the same bioclimatic and vegetation belt (Thermo-Mediterranean) similar to that of coastal Sicily. In such a context, the slightly varying responses of biomes/vegetations to hydroclimatic trends as observed in highland vs. lowland Sicily (e.g. in Pergusa versus Gorgo Basso) would not be observed in Malta.

The climatic reconstruction is based on the pollen record from this northwestern region, however the island is relatively small in size therefore our interpretations can probably be taken for the area as a whole. The reconstruction also provides strong correlation to climatic reconstructions conducted for southern Mediterranean sites. The main findings are:

1) Between ca. 7280 to 6700 cal BP (early Neolithic period) the results record an initially open landscape at the site, surrounding a large palaeobay, with arboreal pollen taxa at their lowest levels.

2) From ca. 6700 cal BP dense *Pistacia* scrubland developed, similar to that observed in the BM1 core, as well as at southern Sicilian sites at around this time. This predominantly *Pistacia* scrubland lasted into the Temple period (4900 cal BP), whereafter it decreased and became more mixed with increasing levels of *Olea*. The climate reconstruction points to a more moist period during the *Pistacia* expansion.

3) From ca. 4450 cal BP the landscape became more open again, coinciding with the start of the Bronze Age on the archipelago. Notably, fire events also increase during this period as do indications of increased soil erosion (*Pseudoschizaea* and *Glomus* taxa); while the palaeobay undergoes infilling, becoming about half its original size by 3000 cal BP. Towards the middle of the Bronze age, there is an increase in both nitrophilous plant taxa and coprophilous fungi (such as *Sporormiella*) indicative of grazing activity. This period coincides with increased climatic instability (between 4600 and 3700 cal BP) which is followed by a gradual decrease in summer moisture availability.

4) During the early Roman occupation period the landscape is still fairly open with an increase in *Olea* corresponding to archaeological evidence of a Roman port and agricultural activity in the area, such as rural Roman villas with artefacts relating to olive production. There is also an increase in cultivated crop taxa and associated ruderal species, along with a rise in fire events. There is reduced precipiation at this time, similar to that noted in sites in southern Italy as well as a generally drier trend recorded within the Mediterranean region.

Through continued interdisciplinary research both on this archipelago and other Mediterranean locations more precise reconstructions of vegetation assemblages and climatic variations can be provided for the Holocene. These robust and comprehensive datasets can provide information on the various processes and drivers influencing not only past but also present and future landscapes. The question of Holocene climate or human-driven environmental change remains a tricky one. An alternative approach might be to consider these two factors, which Sadori et al. (2013) emphasise have a 'synergy', as interactive or dual-action for at least the mid-Holocene onwards; in this way it might bring us closer to a better understanding and appreciation of the continually evolving Mediterranean 'living mosaic' landscape.

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References

Anderson, E. W.: The wied: a representative Mediterranean landform, GeoJournal, 41, 111-114, 1997.

Andrieu, V., Brugiapaglia, E., Cheddadi, R., Reille, M., Beaulieu, J.-L., and Barbero, M.: A computerized data base for the palynological recording of human activity in the Mediterranean basin, in: Environmental Reconstruction in: Mediterranean Landscape Archaeology, edited by: Leveau, P., Walsh, K., Trement, F., and Barker, G., Oxbow Books, Oxford, 17-24, 1999.

Avramidis, P., Geraga, M., Lazarova, M., and Kontopoulos, N.: Holocene record of environmental changes and palaeoclimatic implications in Alykes Lagoon, Zakynthos Island, western Greece, Mediterranean Sea, Quatern. Int., 293, 184-195, 2013.

Barker, G., Gilbertson, D., Jones, B. & Mattingly, D.: Farming the Desert, The UNESCO Libyan Valleys Archaeological Survey, Paris: UNESCO Publishing; Tripoli: Department of Antiquities; London: Society for Libyan Studies, Vol. 1, Synthesis (Ed. Barker, G.). pp 404, 1996.

Bar-Matthews, M., and Ayalon, A.: Mid-Holocene climate vari- ations revealed by high-resolution speleothem records from Soreq Cave, Israel and their correlations with cultural changes, Holocene, 21, 163–172, 2011.

Bar-Matthews, M., Ayalon, A., and Kaufman, A.: Middle to Late Holocene (6500 yr period) paleoclimate in the eastern Mediter- ranean region from stable isotopic composition of speleothems from Soreq Cave, Isra¨ el, in: Environment and society in times of climate change, edited by: Issar, A. and Brown, N., Kluwer Academic, Dordrecht, 203–214, 1998.

Bartlein, P. J., Harrison, S. P., Brewer, S., Connor, S., Davis, B. A. S., Gajewski, K., Guiot, J., Harrison-Prentice, T. I., Henderson, A., Peyron, O., Prentice, I. C., Scholze, M., Seppä, H., Shuman, B., Sugita, S., Thompson, R. S., Viau, A. E., Williams, J., and Wu, H.: Pollen-based continental climate reconstructions at 6 and 21 ka: a global synthesis, Clim. Dyn., 37, 775–802, doi:10.1007/s00382-010-0904-1, 2011.

Bates, J. W.: Mineral nutrition and substratum ecology, in: Bryophyte Biology, edited by: Goffinet, B., and Shaw, A. J., Cambridge University Press, Cambridge, 299–356, 2009.

Beaulieu, J.-L., Miras, Y., Andrieu-Ponel, V., and Guiter, F.: Vegetation dynamics in north-western Mediterranean regions: Instability of the Mediterranean bioclimate, Plant Biosyst., 139, 114–126, doi:10.1080/11263500500197858, 2005.

Beer, R., Tinner, W., Carraro, G., and Grisa, E.: Pollen representation in surface samples of the *Juniperus*, *Picea* and *Juglans* forest belts of Kyrgyzstan, central Asia, Holocene, 17, 599–611, doi:10.1177/0959683607078984, 2007.

Behre, K.-E.: The interpretation of anthropogenic indicators in pollen diagrams, Pollen et Spores, 23, 225–245, 1981.

Behre, K.-E.: Some reflections on anthropogenic indicators in the record of prehistoric occupation phases in pollen diagrams from the Near East, in Man's role in the shaping of the eastern Mediterranean landscape, edited by: Bottema, S., Entjes-Nieborg, G., and van Zeist, W., Balkema, Rotterdam, 219–237, 1990.

Bellini, C., Mariotti-Lippi, M., and Montanari, C.: The Holocene landscape history of the NW Italian coasts, Holocene, 8, 1161–1172, 2009.

Benton, M. and Harper, D. A. T.: Introduction to Paleobiology and the Fossil Record, Wiley-Blackwell, Oxon, 608 pp., 2009.

Berger, J. F. and Guilaine, J.: The 8200 calBP abrupt environmental change and the Neolithic transition: A Mediterranean perspective, Quat. Int., 200, 31–49, doi:10.1016/j.quaint.2008.05.013, 2009.

Beug, H.-J.: Leitfaden der Pollenbestimmung fur Mitteleuropa und angrenzende Gebiete, Pfeil, München, 2004.

Birks, H. J. B.: Strengths and weaknesses of quantitative climate reconstructions based on late-Quaternary biological proxies, Open Ecol. J., 3(1), 68–110, doi:10.2174/1874213001003020068, 2011.

Blaauw, M.: Methods and code for “classical“ age-modelling of radiocarbon sequences, Quaternary Geochronol., 5, 512–518, 2010.

Blondel, J., Aronson, J., Bodiou, J.-Y., and Boeuf, G.: The Mediterranean Region - Biological Diversity in Space and Time 2nd edn., Oxford University Press, Oxford, 2010.

Blouet, B.: The Story of Malta, revised edn., Allied Publications, Malta, 2007.

Bonanno, A.: Malta: Phoenician, Punic and Roman, Midsea Books, Malta, 2005.

Booth, R. K., Jackson, S. T., Forman, S. L., Kutzbach, J. E., Bettis, E. A., Kreig, J., and Wright, D. K.: A severe centennial-scale drought in midcontinental North America 4200 years ago and apparent global linkages, Holocene, 15, 321-328, 2005.

Boros, A., Járai-Komlódi, M., Toth, Z., and Nilsson, S.: An Atlas of Recent European Bryophyte Spores, Scientia Publishing, Budapest, 321 pp., 1993.

Bottema, S. and Sarpaki, A.: Environmental change in Crete: A 9000-year record of Holocene vegetation history and the effect of the Santorini eruption, Holocene, 13, 733–749, doi:10.1191/0959683603hl659rp, 2003.

Bowen-Jones, H., Dewdney, J.C., and Fisher, W.B.: Malta: Background for Development, Dept. of Geography, University of Durham, Durham, 1961.

Brayshaw, D. J., Rambeau, C. M. C., and Smith, S. J.: Changes in Mediterranean climate during the Holocene: Insights from global and regional climate modelling, Holocene, 21, 15–31, doi:10.1177/0959683610377528, 2011.

Brewer, S., Guiot, J., Sánchez-Goñi, M. F., and Klotz, S.: The climate in Europe during the Eemian: a multi-method approach using pollen data, Quat. Sci. Rev., 27, 2303–2315, doi:10.1016/j.quascirev.2008.08.029, 2008.

Briggs, D.: Plant microevolution and conservation in Human-influenced ecosystems, Cambridge University Press, Cambridge, 598 pp., 2009.

Broodbank, C.: The origins and early development of Mediterranean maritime activity, J. Mediterr. Archaeol., 19, 199–230, doi:10.1558//jmea.2006.v19i2.199, 2006.

Broodbank, C.: The Making of the Middle Sea: A history of the Mediterranean from the beginning to the Emergence oft he Classical World, Thames and Hudson, London, 672 pp., 2013.

Brun, C., Dessaint, F., Richard, H., and Bretagnolle, F.: Arable-weed flora and its pollen representation: A case study from the eastern part of France, Rev. Palaeobot. Palynol., 146, 29–50, doi:10.1016/j.revpalbo.2007.02.001, 2007.

Bruno, B.: Roman and Byzantine Malta - trade and economy, Midsea Books, Malta, 2009.

Buhagiar, K.: Bahrija: its archaeological significance, Melita Historia, XIV(4), 357-374, 2007.

Buhagiar, M.: Essays on the Archaeology and Ancient History of the Maltese Islands: Bronze Age to Byzantine, Midsea Books, Malta, 2014.

Calò, C., Henne, P. D., Curry, B., Magny, M., Vescovi, E., La Mantia, T., Pasta, S., Vannière, B., and Tinner, W.: Spatio-temporal patterns of Holocene environmental change in southern Sicily, Palaeogeogr. Palaeoclimatol. Palaeoecol., 323-325, 110–122, doi:10.1016/j.palaeo.2012.01.038, 2012.

Canellas-Bolta, N., Rull, V., Vigo, J., and Mercade, A.: Modern pollen-vegetation relationships along an altitudinal transect in the central Pyrenees (southwestern Europe), Holocene, 19, 1185–1200, doi:10.1177/0959683609345082, 2009.

Caroli, I., & Caldara, M.: Vegetation history of Lago Battaglia (Eastern Gargano coast, Apulia Italy) during the middle-late Holocene, Veg. Hist. Archaeobot 16, 317-327, 2007.

Carrión, J. S.: Patterns and processes of late Quaternary environmental change in a montane region of southwestern Europe, Quat. Sci. Rev., 21, 2047–2066, 2002.

Carrión, J. S., Fuentes, N., González-Sampériz, P., Sánchez Quirante, L., Finlayson, J. C., Fernández, S., and Andrade, A.: Holocene environmental change in a montane region of southern Europe with a long history of human settlement, Quat. Sci. Rev., 26, 11-12, 1455–1475, doi:10.1016/j.quascirev.2007.03.013, 2007.

Carrión, J. S., Fernández, S., González-Sampériz, P., Gil-Romera, G., Badal, E., Carrión-Marco, Y., López-Merino, L., López-Sáez, J. A., Fierro, E., and Burjachs, F.: Expected trends and surprises in the Lateglacial and Holocene vegetation history of the Iberian Peninsula and Balearic Islands, Rev. Palaeobot. Palynol., 162(3), 458–475, doi:10.1016/j.revpalbo.2009.12.007, 2010a.

Carrión, Y., Ntinou, M., and Badal, E.: *Olea europaea* L. in the North Mediterranean Basin during the Pleniglacial and the Early-Middle Holocene, Quat. Sci. Rev., 29, 7-8, 952–968, doi:10.1016/j.quascirev.2009.12.015, 2010b.

Carroll, F. A., Hunt, C. O., Schembri, P. J., and Bonanno, A.: Holocene climate change, vegetation history and human impact in the Central Mediterranean: evidence from the Maltese Islands, Quat. Sci. Rev., 52, 24–40, doi:10.1016/j.quascirev.2012.07.010, 2012.

Cassar, L. F., Conrad, E., and Schembri, P. J.: The Maltese Archipelago, in: Mediterranean Island Landscapes, edited by: Vogiatzakis, I. N., Pungetti G. and Mannion A. M., Natural and Cultural Approaches, Springer, Dordrecht, 297–322, 2008.

Cefai, S., Cassar, J., and Locatelli, D.: San Pawl Milqi, Burmarrad, Malta – presentation of a multi-cultural site in a changing landscape, in: Proceedings of the ICOMOS Scientific Sym- posium: Monuments and Sites in their Setting – Conserving Cultural Heritage in Changing Townscapes and Landscapes, Section III: Evolving Townscapes and Landscapes within their Settings: Managing Dynamic Change, 17–24 October 2005, Xi'an, China, Section III no. 46, 2005

Chetcuti, D., Buhagiar, A., Schembri, P.J., and Ventura, F.: The climate of the Maltese Islands: a review, Malta University Press, Msida, Malta, 1992.

Colledge, S. and Conolly, J. (Eds.): The Origins and Spread of Domestic Plants in Southwest Asia and Europe, Left Coast Press, Walnut Creek (CA), 2007.

Collins, P. M., Davis, B. A. S., and Kaplan, J. O.: The mid-Holocene vegetation of the Mediterranean region and southern Europe, and comparison with the present day, J. Biogeogr., 39, 1848–1861, doi:10.1111/j.1365-2699.2012.02738.x, 2012.

Combourieu-Nebout, N., Peyron, O., Bout-Roumazeilles, V., Goring, S., Dormoy, I., Joannin, S., Sadori, L., Siani, G., and Magny, M.: Holocene vegetation and climate changes in the central Mediterranean inferred from a high-resolution marine pollen record (Adriatic Sea), Clim. Past, 9, 2023–2042, doi:10.5194/cp-9-2023-2013, 2013.

Costantini, E. A. C., Priori, S., Urban, B., Hilgers, A., Sauer, D., Protano, G., Trombino, L., Hülle, D., and Nannoni, F.: Multidisciplinary characterization of the middle Holocene eolian deposits of the Elsa River basin (central Italy), Quat. Int., 209, 107–130, doi:10.1016/j.quaint.2009.02.025, 2009.

Court-Picon, M., Buttler, A. and Beaulieu, J.-L.: Modern pollen–vegetation relationships in the Champsaur valley (French Alps) and their potential in the interpretation of fossil pollen records of past cultural landscapes, Review of Palaeobotany and Palynology, 135, 13–39, 2005.

Court-Picon, M., Buttler, A., and Beaulieu, J.-L.: Modern pollen/vegetation/land-use relationships in mountain environments: An example from the Champsaur valley (French Alps), Veg. Hist. Archaeobot., 15, 151–168, doi:10.1007/s00334-005-0008-8, 2006.

Cugny, C.: Apports des microfossiles non-polliniques a l'histoire du pastoralisme sur le versant nord Pyrene en entre referentiels actuels et reconstitution du passe, Unpublished PhD, Universite Toulouse 2, Le Mirail, 2011.

Cugny, C., Mazier, F., and Galop, D.: Modern and fossil non-pollen palynomorphs from the Basque mountains (western Pyrenees, France): the use of coprophilous fungi to reconstruct pastoral activity, Veg. Hist. Archaeobot., 19, 391–408, doi:10.1007/s00334-010-0242-6, 2010.

Cushing, E. J.: Evidence for differential pollen preservation in late Quaternary sediments in Minnesota. Review of Palaeobotany and Palynology, 4, 87-101, 1967.

Davis, B.: Palaeolimnology and Holocene Environmental change from endoreic NE Spain, Unpublished PhD, Newcastle University, Newcastle, 1994.

Davis, O. K.: Palynology: An important tool for discoveing historic ecosystems, in: The Historical Ecological Handbook: A restorationist's guide to reference ecosystems, edited by: Egan, D. and Howell, E.A., Island Press, The Science and Practice of Ecological Restoration series edition, London, 457 pp., 2005.

Delhon, C., Thiébault, S., and Berger, J. F.: Environment and landscape management during the Middle Neolithic in Southern France: Evidence for agro-sylvo-pastoral systems in the Middle Rhone Valley, Quat. Int., 200, 50–65, doi:10.1016/j.quaint.2008.05.008, 2009.

Di Rita, F. and Magri, D.: Holocene drought, deforestation and evergreen vegetation development in the central Mediterranean : a 5500 year record from Lago Alimini Piccolo, Apulia, southeast Italy, Holocene, 2, 295–306, 2009.

Di Rita, F. and Magri, D.: An overview of the Holocene vegetation history from the central Mediterranean coasts, J. Mediterr. Earth Stud., 4, 35–52, doi:10.3304/JMES.2012.003, 2012.

Di Rita, F. and Melis, R. T.: The cultural landscape near the ancient city of Tharros (central West Sardinia): vegetation changes and human impact, J. Archaeol. Sci., 40, 4271–4282, doi:10.1016/j.jas.2013.06.027, 2013.

Djamali, M., Gambin, B., Marriner, N., Andrieu-Ponel, V., Gambin, T., Gandouin, E., Lanfranco, S., Médail, F., Pavon, D., Ponel, P., and Morhange, C.: Vegetation dynamics during the early to mid-Holocene transition in NW Malta, human impact versus climatic forcing, Veg. Hist. Archaeobot., 22, 367–380, doi:10.1007/s00334-012-0380-0, 2012.

Djamali, M., Jones, M. D., Migliore, J., Balatti, S., Fader, M., Contreras, S., Hosseini, Z., Lahijani, H., Naderi, A. Shumilovskikh, L., Tengberg, M., and Weeks, L.: Olive cultivation in the heart of the Persain Achaemenid Empire: new insights into agricultural practices and environmental changes reflected in a late Holocene pollen record from Lake Parishan, SW Iran, Veget Hist Archaeobot, 1-15, doi: 10.1007/s00334-015-0545-8, 2015.

Docter, R. F., Vella, N. C., Cutajar, N., Bonanno, A., and Pace, A.: Rural Malta: First results of the joint Belgo-Maltese survey project, Babesch, 87, 107-149, 2012.

Dormoy, I., Peyron, O., Combourieu-Neboutb, N., Goring, S., Kotthoff, U., Magny, M., and Pross, J.: Terrestrial climate variability and seasonality changes in the Mediterranean region between 15000 and 4000 years BP deduced from marine pollen records, Clim. Past Discuss., 5, 735–770, doi:10.5194/cpd-5-735-2009, 2009.

Edrtman, G.: An Introduction to Pollen Analysis, Chronica Botanica Company, Waltham, Mass., 1943.

Ejarque, A., Miras, Y., and Riera, S.: Pollen and non-pollen palynomorph indicators of vegetation and highland grazing activities obtained from modern surface and dung datasets in the eastern Pyrenees, Rev. Palaeobot. Palynol., 167, 123–139, doi:10.1016/j.revpalbo.2011.08.001, 2011.

Estiarte, M., Peñuelas, J., López-Martínez, C., and Pérez-Obiol, R.: Holocene palaeoenvironment in a former coastal lagoon of the arid south eastern Iberian Peninsula: salinization effects on δ15N, Veg. Hist. Archaeobot., 17, 667–674, doi:10.1007/s00334-008-0153-y, 2008.

Faegri, K. and Iversen, J.: Textbook of Pollen Analysis, IV edn., Blackburn Press, New Jersey 2000.

Fenech K.: Human induced changes in the environment and landscape of the Maltese Islands from the Neolithic to the 15th century AD, BAR Internat Ser 1, 682, Oxford, 2007.

Finkelstein, I. and Langgut, D.: Dry climate in the Middle Bronze I and its impact on settlement patterns in the Levant and beyond : New Pollen Evidence, J. Near East. Stud., 73, 2, 219–234, 2014.

Fletcher, W. J., Debret, M., and Sanchez Goñi, M. F.: Mid-Holocene emergence of a low-frequency millennial oscillation in western Mediterranean climate : Implications for past dynamics of the North Atlantic atmospheric westerlies, The Holocene, 23, 153–166, doi:10.1177/0959683612460783, 2013.

Florenzano, A.: Evoluzione di un paesaggio mediterraneo nella ricostruzione archeoambientale di siti lucani: Evolution of a Mediterranean landscape as shown by the archaeo-environmental reconstruction of Lucanian sites, PhD Dissertation, Universita degli Studi di Modena e Reggio Emilia, Modena, 2013.

Florenzano, A., Marignani, M., Rosati, L. Fascetti, S. & Mercuri, A. M.: Are Cichorieae an indicator of open habitats and pastoralism in current and past vegetation studies? Plant Biosyst. 149, 154-165, 2015.

Frisia, S., Borsato, A., Mangini, A., Spötl, C., Madonia, G., and Sauro, U.: Holocene climate variability in Sicily from a discontinuous stalagmite record and the Mesolithic to Neolithic transition, Quat. Res., 66, 388–400, doi:10.1016/j.yqres.2006.05.003, 2006.

Galdies, C.: The Climate of Malta: Statistics, trends and analysis 1951-2010, National Statistics Office, Malta, 2011.

Gambin, T.: Islands of the Middle Sea: an archaeology of a coastline, in: Evolución paleoambiental de los puertos y fondeaderos antiguos en el Mediterráneo occidental, edited by: De Maria, L., Turchetti, R., Rubbettino Editore, Soveria Mannelli, 127–146, 2004.

Gambin, T.: Archaeological discoveries at Marsa over the centuries, Malta Archaeological Review, 7, 49-54, 2004/5.

Gambin, T.: The maritime landscapes of Malta from the Roman period to the Middle Ages, Unpublished PhD, University of Bristol, Bristol, 2005.

Gambin, T.: A drop in the ocean – Malta's trade in olive oil during the Roman periods, in: The Zejtun Roman Villa, edited by: Ruben Abela, Wirt Iz-Zejtun, Malta, 2012.

Gelorini, V., Ssemmanda, I., and Verschuren, D.: Validation of non-pollen palynomorphs as paleoenvironmental indicators in tropical Africa : Contrasting ~ 200-year paleolimnological records of climate change and human impact, Rev. Palaeobot. Palynol., 186, 90–101, doi:10.1016/j.revpalbo.2012.05.006, 2012.

Giesecke, T., Bennett, K. D., Birks, H. J. B., Bjune, A. E., Bozilova, E., Feurdean, A., Finsinger, W., Froyd, C., Pokorný, P., Rösch, M., Seppä, H., Tonkov, S., Valsecchi, V., and Wolters, S.: The pace of Holocene vegetation change – testing for synchronous developments, Quat. Sci. Rev., 30, 2805–2814, doi:10.1016/j.quascirev.2011.06.014, 2011.

Giorgi, F. and Lionello, P.: Climate change projections for the Mediterranean region, Glob. Planet. Change, 63(2-3), 90–104, doi:10.1016/j.gloplacha.2007.09.005, 2008.

Grech, C. F.: A Forest History of the Maltese Islands, Unpublished PhD, University of Aberdeen, Aberdeen, 2001.

Grigore, M. and Toma, C.: Ecological Anatomy of halophyte species from the Chenopodiaceae family, Ecology, 62–67, 2008.

Grove, A. T. and Rackham, O.: The Nature of Mediterranean Europe: An Ecological History, Yale University Press, London, 2001.

Guiot J.: Methodology of the last climatic cycle reconstruction in France from pollen data, Palaeogeogr. Palaeocl., 80, 49–69, 1990.

Haas, J.-N.: Palaeoecological indicators found in pollen preparations from Holocene freshwater lake sediments, Rev Palaeobot Palynol, 91, 371–382, 1996.

Hajar, L., Haïdar-Boustani, M., Khater, C., and Cheddadi, R.: Environmental changes in Lebanon during the Holocene: Man vs. climate impacts, J. Arid Environ., 74, 746–755, doi:10.1016/j.jaridenv.2008.11.002, 2010.

Hall, S. J., Trujillo, J., Nakase, D., Strawhacker, C., Kruse-Peeples, M., Schaafsma, H., and Briggs, J.: Legacies of prehistoric agricultural practices within plant and soil properties across an arid ecosystem, Ecosystems, 16, 1273–1293, doi:10.1007/s10021-013-9681-0, 2013.

Havinga, A.: An experimental investigation into the decay of pollen and spores in various soil types, in: Sporopollenin, edited by: Brooks, J., Grant, P. R., Muir, M. D., Van Gijzel, P., and Shaw, G., Academic Press, New York, 446-479, 1971.

Hevly, R. H.: Pollen production, transport and preservation: potentials and limitations in archeological palynology, J. Ethnobiol., 1, 39–54, 1981.

Hjelle, K. L.: Herb pollen representation in surface moss samples from mown meadows and pastures in western Norway, Veg. Hist. Archaeobot., 7, 79–96, doi:10.1007/BF01373926, 1998.

Hjelle, K. L.: Use of modern pollen samples and estimated pollen representation factors as aids in the interpretation of cultural activity in local pollen diagrams, Nor. Archaeol. Rev., 32, 19–39, doi:10.1080/002936599420885, 1999.

Hughes, K. J.: Persistent features from a palaeo-landscape: the ancient tracks of the Maltese Islands, Geogr. J., 165, 1, 62–78, doi:10.2307/3060511, 1999.

Hunt, C. O.: Quaternary deposits in the Maltese Islands: a microcosm of environmental change in Mediterranean lands, Geogr J., 41, 101–109, 1997.

Hunt, C. O.: Palynology of some archaeological deposits from Tas-Silq, in: Tas-Silg, Marsaxlokk (Malta) I: Archaeological Excavations Conducted by the University of Malta, 1996-2005, edited by: Bonanno, A. & Vella, N. C., Ancient Near Eastern Studies Supplement Series, 48, Peeters Publishing, Leuven, 2015.

Issar, A.: Climate Changes during the Holocene and their Impact on Hydrological Systems, Cambridge University Press, Cambridge, 2003.

Jahns, S.: A late Holocene pollen diagram from the Megaris, Greece, giving possible evidence for cultivation of Ceratonia siliqua L. during the last 2000 years, Veg. Hist. Archaeobot., 12, 127–130, doi:10.1007/s00334-003-0013-8, 2003.

Jahns, S.: The Holocene history of vegetation and settlement at the coastal site of Lake Voulkaria in Acarnania, western Greece, Veg. Hist. Archaeobot., 14, 55–66, doi:10.1007/s00334-004-0053-8, 2005.

Jalut, G., Dedoubat, J. J., Fontugne, M., and Otto, T.: Holocene circum-Mediterranean vegetation changes: climate forcing and human impact, Quatern. Int., 200, 4–18, doi:10.1016/j.quaint.2008.03.012, 2009.

Joannin, S., Brugiapaglia, E., Beaulieu, J. L., Bernardo, L., Magny, M., Peyron, O., Goring, S., and Vannière, B.: Pollen-based reconstruction of Holocene vegetation and climate in southern Italy: the case of Lago Trifoglietti, Clim. Past, 8, 1973–1996, doi:10.5194/cp-8-1973-2012, 2012.

Juggins, S.: C2 Software for ecological and palaeoecological data analysis and visualisation, User Guide Version 1.5., University of Newcastle, Newcastle-upon-Tyne, 2007.

Kaniewski, D., Van Campo, E., Boiv, T., Terral, J. F., Khadari, B., and Besnard, G.: Primary domestication and early uses of the emblematic olive tree: palaeobotantical, historical and molecular evidences from the Middle East, Biol. Rev. 87, 885-899, 2012.

Kaniewski, D., Van Campo, E., Morhange, C., Guiot, J., Zuiely, D., Le Burel, S., Otto, T., and Artzy, M.: Velnerability of Mediterranean ecosystems to long term changes along the coast of Israel, PLoS ONE, 9, e102090, doi:10.1371/journal.pone.0102090, 2014.

Kerschbaumer, A. and Lutz, M.: Origin and influence of PM10 in urban and in rural environments, Adv. Sci. Res., 2, 53–55, doi:10.5194/asr-2-53-2008, 2008.

Kotthoff, U., Pross, J., Müller, U. C., Peyron, O., Schmiedl, G., Schulz, H., and Bordon, A.: Climate dynamics in the borderlands of the Aegean Sea during formation of sapropel S1 deduced from a marine pollen record, Quat. Sci. Rev., 27, 832–845, doi:10.1016/j.quascirev.2007.12.001, 2008.

Kotthoff, U., Koutsodendris, A., Pross, J., Schmiedl, G., Bornemann, A., Kaul, C., Marino, G., Peyron, O., and Schiebel, R.: Impact of Lateglacial cold events on the northern Aegean region reconstructed from marine and terrestrial proxy data, J. Quat. Sci., 26, 86–96, doi:10.1002/jqs.1430, 2011.

Kouli, K., Gogou, A., Bouloubassi, I., Triantaphyllou, M. V., Ioakim, C., Katsouras, G., Roussakis, G., and Lykousis, V.: Late postglacial paleoenvironmental change in the northeastern Mediterranean region: Combined palynological and molecular biomarker evidence, Quaternary Int., 261, 118–127, 2012.

Li, Y., Zhou, L., and Cui, H.: Pollen indicators of human activity, Chinese Sci. Bull., 53, 1281–1293, doi:10.1007/s11434-008-0181-0, 2008.

Lionello, P., Malanotte-Rizzoli, P., and Boscolo, R.: Mediterranean Climate Variability, Elsevier B.V., Amsterdam, 2006.

Litt, T., Ohlwein, C., Neumann, F. H., Hense, A., and Stein, M.: Holocene climate variability in the Levant from the Dead Sea pollen record, Quatern. Sci. Rev., 49, 95–105, doi:10.1016/j.quascirev.2012.06.012, 2012.

Locatelli, D.: The Roman Villa at San Pawl Milqi: History and perspectives of an archaeological site, Treasures of Malta, 7, 73-79, 2001.

López Sáez, A. J., López Garcia, P., and Sánchez, M. M.: Palaeoecology and Holocene environmental change from a saline lake in south-west Spain: protohistorical and prehistorical vegetation in Cadiz Bay, Quatern. Int., 94, 197–206, 2002.

López-Merino, L., Cortizas, A. M., and López-Sáez, J. A.: Early agriculture and palaeoenvironmental history in the North of the Iberian Peninsula: a multi-proxy analysis of the Monte Areo mire (Asturias, Spain), J. Archaeol. Sci., 37, 1978–1988, doi:10.1016/j.jas.2010.03.003, 2010.

MacDonald, G. M. and Cwynar, L. C.: A fossil pollen based reconstruction oft he late Quaternary history of lodgepole pine (*Pinus contorta* spp. *latifolia*) in the western interior of Canada, Can J. Forest Res, 15, 1039-1044, 1985.

MacDonald, G. M. and Edwards, K. J.: Holocene palynology: 1. Principles, population and community ecology, palaeoclimatology, Prog. Phys. Geog., 15, 261–289, doi:10.1177/030913339101500303, 1991.

Macphail, M. and Stevenson, J.: Fungal spores in Archaeologocal Contexts: Part 1 Background Evidence, CAR, Canberra, 2004.

Magny, M. and Combourieu Nebout, N.: Holocene changes in environment and climate in the central Mediterranean as reflected by lake and marine records, Clim. Past, 9, 1447–1454, doi:10.5194/cp-9-1447-2013, 2013.

Magny, M., Miramont, C., and Sivan, O.: Assessment of the impact of climate and anthropogenic factors on Holocene Mediterranean vegetation in Europe on the basis of palaeohydrological records, Palaeogeogr. Palaeoclimatol. Palaeoecl., 186, 47–59, doi:10.1016/S0031-0182(02)00442-X, 2002.

Magny, M., de Beaulieu, J. L., Drescher-Schneider, R., Vannière, B., Walter-Simonnet, A. V., Miras, Y., Millet, L., Bossuet, G., Peyron, O., Brugiapaglia, E., and Leroux, A.: Holocene climate changes in the central Mediterranean as recorded by lake-level fluctuations at Lake Accesa (Tuscany, Italy), Quaternary Sci. Rev., 26, 1736–1758, 2007.

Magny, M., Vannière, B., Zanchetta, G., Fouache, E., Touchais, G., Petrika, L., Coussot, C., Walter-Simonnet, A-V., and Arnaud, F.: Possible complexity of the climatic event around 4300-3800 cal. BP in the central and western Mediterranean, Holocene, 19, 823–833, doi:10.1177/0959683609337360, 2009.

Magny, M., Vannière, B., Calo, C., Millet, L., Leroux, A., Peyron, O., Zanchetta, G., La Mantia, T., and Tinner, W.: Holocene hydrological changes in south-western Mediterranean as recorded by lake-level fluctuations at Lago Preola, a coastal lake in southern Sicily, Italy, Quaternary Science Reviews, 30(12-20), 2459-2475, 2011.

Magny, M., Peyron, O., Sadori, L., Ortu, E., Zanchetta, G., Vannière, B., and Tinner, W.: Contrasting patterns of precipitation seasonality during the Holocene in the south- and north-central Mediterranean, J. Quatern. Sci., , 27, 290-6, 2012.

Markgraf, V. and Kenny, R.: Character of rapid vegetation and cliamte change during the late-glacial in southernmost South America, in: Past and Future Rapid Environmental Changes: The Spatial and Evolutionary Responses of Terrestrial Biota, edited by: Huntley, B., Cramer, W., Morgan, A. V. , Prentice, H. C., and Allen, J. R. M., Springer Science & Business Media, 1997.

Marriner, N., Gambin, T., Djamali, M., Morhange, C., and Spiteri, M.: Geoarchaeology of the Burmarrad ria and early Holocene human impacts in western Malta, Palaeogeogr. Palaeoclimatol. Palaeoecol., 339-341, 52–65, doi:10.1016/j.palaeo.2012.04.022, 2012.

Mauri, A., Davis, B. A. S., Collins, P. M., and Kaplan, J. O.: The climate of Europe during the Holocene: a gridded pollen-based reconstruction and its multi-proxy evaluation, Quat. Sci. Rev., 112, 109–127, doi:10.1016/j.quascirev.2015.01.013, 2015.

Mayewski, P. A., Rohling, E. J., Curtstager, J., Karlen, W., Maasch, K., Davidmeeker, L., Meyerson, E., Gasse, F., Vankreveld, S., and Holmgren, K.: Holocene climate variability, Quat. Res., 62, 3, 243–255, doi:10.1016/j.yqres.2004.07.001, 2004.

Mazier, F., Galop, D., Brun, C., and Buttler, A.: Modern pollen assemblages from grazed vegetation in the western Pyrenees, France: a numerical tool for more precise reconstruction of past cultural landscapes, The Holocene, 16(1), 91–103, doi:10.1191/0959683606hl908rp, 2006.

Médail, F. and Quézel, P.: Biodiversity Hotspots in the Mediterranean Basin: Setting global conservation priorities, Conserv. Biol., 13(6), 1510–1513, doi:10.1046/j.1523-1739.1999.98467.x, 1999.

Mercuri, A. M., Accorsi, C. A., Mazzanti, M. B., Bosi, G., Cardarelli, A., Labate, D., Marchesini, M., and Grandi, G. T.: Economy and environment of Bronze Age settlements – Terramaras – on the Po Plain (Northern Italy): first results from the archaeobotanical research at the Terramara di Montale, Veget Hist Archaeobot, 16(1), 43–60, doi:10.1007/s00334-006-0034-1, 2006.

Mercuri, A. M., Bandini Mazzanti, M., Florenzano, A., Montecchi, M., Rattighieri, E., and Torri, P.: Anthropogenic Pollen Indicators (API) from archaeological sites as local evidence of human-induced environments in the Italian Peninsula, Ann. Bot., 3, 143–153, doi:10.4462/annbotrm-10316, 2013.

Mercuri, A. M., Bandini Mazzanti, M., Florenzano, A., Montecchi, M. C. & Rattighieri, E.: Olea, Juglans and Castanea: the OJC group as pollen evidence of the development of human-induced environments in the Italian peninsula. Quat. Int. 303, 24-42, 2013.

Mercuri, A.M.: Genesis and evolution of the cultural landscape in central Mediterranean: the ‘where, when and how’ through the palynological approach, Landsc. Ecol. 29, 1799-1810, 2014.

Mercuri, A. M., Allevato, E., Arobba, D., Bandini Mazzanti, M., Bosi, G., Caramiello, R., Castiglioni, E., ... Rinaldi, R.: Pollen and macroremains from Holocene archaeological sites: a dataset for the understanding of the biocultural diversity of the Italian landscape, Rev. Palaeobot. Palynol. 218, 250-326, 2015.

Metcalfe, C. R.: Report on the botanical determination of charcoal samples, in: Skorba: excavations carried out on behalf of the National Museum of Malta, 1961–1963. Reports of the Research Committee of the Society of Antiquaries of London, Appendix V, edited by Trump D.H., The Society of Antiquaries, London and the National Museum of Malta, 1966.

Moore P. D., Webb J. A., and Collinson M. E.: Pollen analysis, 2nd Edn. Blackwell, Oxford, 1991.

Morley, A., Rosenthal, Y., and DeMenocal, P.: Ocean-atmosphere climate shift during the mid-to-late Holocene transition, Earth Planet. Sci. Lett., 388, 18–26, doi:10.1016/j.epsl.2013.11.039, 2014.

Mottershead, D., Pearson, A., and Schaefer, M.: The cart ruts of Malta: an applied geomorphology approach, Antiquity, 82, December, 1065–1079, 2007.

Mudie, P. J., Leroy, S. A. G., Marret, F., Gerasimenko, N., Kholeif, S. E. A, Sapelko, T., and Filipova-Marinova, M.: Nonpollen palynomorphs: indicators of salinity and environmental change in the Caspian-Black Sea-Mediterranean corridor, The Geological Society of America Special Paper, 473, 1–27, 2011.

Noti, R., Leeuwen, J. F. N., Colombaroli, D., Vescovi, E., Pasta, S., Mantia, T., and Tinner, W.: Mid- and late-Holocene vegetation and fire history at Biviere di Gela, a coastal lake in southern Sicily, Italy, Veg. Hist. Archaeobot., 18(5), 371–387, doi:10.1007/s00334-009-0211-0, 2009.

Pace, A.: The building of megalithic Malta, in: Malta before History, edited by Cilia, D., Miranda Books, Malta, 2004.

Pantaléon-Cano, J., Yll, E.-I., Pérez-Obiol, R., and Roure, J. M.: Palynological evidence for vegetational history in semi-arid areas of the western Mediterranean (Almería, Spain), The Holocene, 13(1), 109–119, doi:10.1191/0959683603hl598rp, 2003.

Pavlopoulos, K., Triantaphyllou, M., Karkanas, P., Kouli, K., Syrides, G., Vouvalidis, K., Palyvos, N., and Tsourou, T.: Paleoenvironmental evolution and prehistoric human environment, in the embayment of Palamari (Skyros Island, Greece) during Middle-Late Holocene, Quat. Int., 216(1-2), 41–53, doi:10.1016/j.quaint.2009.08.015, 2010.

Pedley H. M., Hughes Clarke, M., and Galea, P.: Limestone Isles in a Crystal Sea, The geology of the Maltese Islands, Publishers Enterprises Group, Malta, 2002.

Pérez-Obiol, R. and Sadori, L.: Similarities and dissimilarities, synchronisms and diachronisms in the Holocene vegetation history of the Balearic Islands and Sicily, Veget Hist Archaeobot, 16, 259–265, doi:10.1007/s00334-006-0038-x, 2007.

Pérez-Obiol, R., Jalut, G., Julia, R., Pelachs, A., Iriarte, M. J., Otto, T., and Hernandez-Beloqui, B.: Mid-Holocene vegetation and climatic history of the Iberian Peninsula, The Holocene, 21(1), 75–93, doi:10.1177/0959683610384161, 2011.

Peyron, O., Goring, S., Dormoy, I., Kotthoff, U., Pross, J., De Beaulieu, J.-L., Drescher-Schneider, R., Vannière, B., and Magny, M.: Holocene seasonality changes in the central Mediterranean region reconstructed from the pollen sequences of Lake Accesa (Italy) and Tenaghi Philippon (Greece), The Holocene, 21(1), 131–146, doi:10.1177/0959683610384162, 2011.

Peyron, O., Magny, M., Goring, S., Joannin, S., De Beaulieu, J.-L., Brugiapaglia, E., Sadori, L., Garfi, G., Kouli, K., Ioakim, C., and Combourieu-Nebout, N.: Contrasting patterns of climatic changes during the Holocene across the Italian Peninsula reconstructed from pollen data, Clim. Past, 9(3), 1233–1252, doi:10.5194/cp-9-1233-2013, 2013.

Pons, A. and Quezel, P.: The history of the flora and vegetation and past and present human disturbance in the Mediterranean region, in: Plant conservation in the Mediterranean area, edited by Gomez-Campo C., Dr. W. Junk Publisher, Dordrecht, 25–43 pp., 1985.

Pross, J., Kotthoff, U., M¨ uller, U. C., Peyron, O., Dormoy, I., Schmiedl, G., Kalaitzidis, S., and Smith, A. M.: Massive per- turbation in terrestrial ecosystems of the Eastern Mediterranean region associated with the 8.2 kyr climatic event, Geology, 37, 887–890, 2009.

Pyankov, V. I., Gunin, P. D., Tsoog, S., and Black, C. C.: C4 plants in the vegetation of Mongolia: their natural occurrence and geographical distribution in relation to climate, Oecologia, 123(1), 15–31, doi:10.1007/s004420050985, 2000.

Reale, O. and Dirmeyer, P.: Modeling the effects of vegetation on Mediterranean climate during the Roman Classical Period, Part I: Climate history and model sensitivity, Glob. Planet. Change, 25, 3-4, 163–184, doi:10.1016/S0921-8181(00)00002-3, 2000.

Reille, M.: Pollen et spores d'Europe et d'Afrique du Nord, Laboratoire de botanique historique et de palynologie, Marseille, 1992.

Reille, M.: Pollen et spores d'Europe et d'Afrique du Nord, Laboratoire de botanique historique et de palynologie-Suppl 1, Marseille, 1995.

Reille, M.: Pollen et spores d'Europe et d'Afrique du Nord, Laboratoire de botanique historique et de palynologie-Suppl 2, Marseille, 1998.

Reimer, P. J., Baillie, M. G. L., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Bronk Ramsey, C., Buck, C. E., Burr, G., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Hajdas, I., Heaton, T. J., Hogg, A. G., Hughen, K. A., Kaiser, K. F., Kromer, B., McCormac, F. G., Manning, S. W., Reimer, R. W., Richards, D. A., Southon, J., Turney, C. S. M., van der Plicht, J., and Weyhenmeyer, C.: IntCal09 and Marine09 radiocarbon age calibration curves, 0–50,000 years cal BP. Radiocarbon 51, 1111–1150, 2009.

Roberts, N.; The Holocene: An Environmental History, 3rd Edition, Wiley-Blackwell, 2014.

Roberts, N., Brayshaw, D., Kuzucuoglu, C., Pérez-Obiol, R., and Sadori, L.: The mid-Holocene climatic transition in the Mediterranean: Causes and consequences, The Holocene, 21(1), 3–13, doi:10.1177/0959683610388058, 2011.

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

Sadori, L. and Giardini, M.: Charcoal analysis, a method to study vegetation and climate of the Holocene: The case of Lago di Pergusa (Sicily, Italy), Geobios, 40(2), 173–180, doi:10.1016/j.geobios.2006.04.002, 2007.

Sadori, L., Jahns, S., and Peyron, O.: Mid-Holocene vegetation history of the central Mediterranean, The Holocene, 21(1), 117–129, doi:10.1177/0959683610377530, 2011.

Sadori, L., Bertini, A., Combourieu-Nebout, N., Kouli, K., Mariotti Lippi, M., Roberts, N., and Mercuri, A. M.: Palynology and Mediterranean vegetation history, Flora Mediterr., 23, 141–156, doi:10.7320/FlMedit23.141, 2013a.

Sadori, L., Ortu, E., Peyron, O., Zanchetta, G., Vannière, B., Desmet, M., and Magny, M.: The last 7 millennia of vegetation and climate changes at Lago di Pergusa (central Sicily, Italy), Clim. Past, 9(4), 1969–1984, doi:10.5194/cp-9-1969-2013, 2013b.

Sadori, L., Masi, A., & Ricotta, C.: Climate driven past fires in central Sicily, Plant Biosyst., 149, 166-173, 2015.

Sadori, L., Giraudi, C., Masi, A., Magny, M., Ortu, E., Zanchetta, G., & Izdebski, A.: Climate, environment and society in southern Italy during the last 2000 years. A review of the environmental, historical and archaeological evidence. Quaternary Science Reviews, doi:10.1016/j.quascirev.2015.09.020, 2015.

Schembri, P. J.: The Maltese Islands: climate, vegetation and landscape, GeoJournal, 41, 2, 115–125, 1997.

Sharifi, A., Pourmand, A., Canuel, E. A., Ferer-Tyler, E., Peterson, L. C., Aichner, B., Feakins, S. J., Daryaee, T., Djamali, M., Naderi, A., Lahijani, H. A. K., and Swart, P. K.: Abrupt climate variability since the last deglaciation based on a high-resolution, multi-proxy peat record from NW Iran: The hand that rocked the Cradle of Civilization? Quaternary Science Reviews, 123, 215-230, 2015.

Sotillo, M. G., Ramis, C., Romero, R., Alonso, S., and Homar, V.: Role of orography in the spatial distribution of precipitation over the Spanish Mediterranean zone, Clim. Res., 23(3), 247–261, doi:10.3354/cr023247, 2003.

Stevens, D. T., Lanfranco, E., Mallia, A., and Schembri, P. J.: Biodiversity conservation and utilisation in the Maltese Islands, in Monitoring Biodiversity, Developing Island States, Malta, 1995.

Stevenson, A, D.: Pollen studies in semi-arid areas: North east Iran and south west Spain, Unpublished PhD, King's College University, London, 1981.

Stockmarr, J.: Tablets with spores used in absolute pollen analysis, Pollen et Spores, 13, 615-621, 1971.

Ter Braak, C. J. F. and Juggins, S.: Weighted averaging partial least squares regression (WA-PLS): An improved method for reconstructing environmental variables from species assemblages, Hydrobiologia, 269/270, 485–502, 1993.

Ter Braak, C. J. F. and van Dam, H.: Inferring pH from diatoms: A comparison of old and new calibration methods, Hydrobiologia, 178, 209–223, 1989.

Tinner, W., van Leeuwen, J. F. N., Colombaroli, D., Vescovi, E., van der Knaap, W. O., Henne, P. D., Pasta, S., D'Angelo, S., and La Mantia, T.: Holocene environmental and climatic changes at Gorgo Basso, a coastal lake in southern Sicily, Italy, Quat. Sci. Rev., 28(15-16), 1498–1510, doi:10.1016/j.quascirev.2009.02.001, 2009.

Traverse, A.: Paleopalynology, 2nd Edn, Springer, 2008.

Trump, D. H.: Malta: An Archaeological Guide, Faber and Faber, London, 1972.

Trump, D. H.: Malta: Prehistory and Temples, Midsea Books, Malta, 2002.

Trump, D. H.: Dating Malta's prehistory, in: Malta before History, edited by Cilia, D., Miranda Books, Malta, 2004.

Tweddle, J. C. and Edwards, K. J.: Pollen preservation zones as an interpretative tool in Holocene palynology, Rev. Palaeobot. Palynol., 161(1-2), 59–76, doi:10.1016/j.revpalbo.2010.03.004, 2010.

Van Geel, B.: A palaeoecological study of Holocene peat bog sections in Germany and the Netherlands, based on the analysis of pollen, spores and macro- and microscopic remains of fungi, algae, cormophytes and animals, Review of Palaeobotany and Palynology, 25, 1-120, 1978.

Vannière, B., Power, M. J., Roberts, N., Tinner, W., Carrion, J., Magny, M., Bartlein, P., Colombaroli, D., Daniau, A. L., Finsinger, W., Gil-Romera, G., Kaltenrieder, P., Pini, R., Sadori, L., Turner, R., Valsecchi, V., and Vescovi, E.: Circum-Mediterranean fire activity and climate changes during the mid-Holocene environmental transition (8500-2500 cal. BP), The Holocene, 21(1), 53–73, doi:10.1177/0959683610384164, 2011.

van Zeist, W. and Bottema, S.: Late Quaternary vegetation of the Near East, Beihefte zum Tubinger Atlas des Vorderen Orients: Reihe A, Naturwissenscaften 18, Reichet, Weisbaden, 1991.

van Zeist, W., Baruch, U., and Bottema, S.: Holocene palaeoecology of the Hula area, northeastern Israel, in: A Timeless Vale. Archaeological and Related Essays on the Jordan Valley in Honour of

Gerrit Van Der Kooij on the Occasion of his Sixty-Fifth Birthday, edited by Kaptijn K and Petit L. P., Leiden University Press, Leiden:. 29-64 pp., 2009.

Walsh, K.: The Archaeology of Mediterranean Landscapes: Human-Environment Interaction from the Neolithic to the Roman Period, Cambridge University Press, Cambridge, 387 pp., 2013.

Warny, S., Jarzen, D. M., Evans, A., Hesp, P., and Bart, P.: Environmental significance of abundant and diverse hornwort spores in a potential submerged Paleoindian site in the Gulf of Mexico, Palynology, December, 1–20, doi:10.1080/01916122.2012.666507, 2012.

Weiner, S.: Microarchaeology. Beyond the Visible Archaeological Record, Cambridge University Press, Cambridge, 2010.

Weiss, H. and Bradley, R. S.: What Drives Societal Collapse?, Science, 80, 291, 5504, 609–610, doi:DOI: 10.1126/science.1058775, 2001.

Wells, H. G.: A Short History of the World, Cassell & Co, Ltd, UK, 1922.

Wilson, A.: The Mediterranean Environment in Ancient History: Perspectives and Prospects, in: The Ancient Mediterranean Environment between Science and History, edited by Harris W. V., Brill, Lieder Boston, 2013.

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

CAPTIONS

Table 1. Selection of plant taxa characteristic of the main Maltese vegetation communities (adapted from Schembri, 1997; Stevens et al., 1995)

Table 2. Radiocarbon dates obtained from the Burmarrad BM2 core

Fig 1. Study Area. a) Mediterranean region highlighting the Maltese Islands (Selected regional sites mentioned in text: 1: Lago Preola, 2: Gorgo Basso, 3: Biviere di Gela, 4: Lago Pergusa, 5: Lago Trifoglietti, 6: Lago Accesa, 7: Lago Ledro, 8: Tenaghi P., 9: SL152, 10: MNB-3, 11: NS14, 12: HCM2-22, 13: Soreq Cave. base map source: Arizona Geographic Alliance); b) Maltese Islands: key sites mentioned in text; c) average annual temperature and rainfall (based on Galdies (2011) data for the 30-year climatic period 1961-1990); d) the topography and catchment area (blue) of Burmarrad.

Fig 2. BM2 sedimentary profile and age-depth model interpolated curve

Fig 3. Burmarrad simplified pollen diagram: selected percentage curves and pollen concentration. Mediterranean arboreal taxa: *Ephedra, Erica, Juniperus, Olea, Phillyrea, Pinus* and *Pistacia.* Nitrophilous taxa: *Rumex, Urtica* and *P. lanceolata-type.* Cultivation indicator taxa: including crops (Cerealia-type, *Triticum*-type) and some associated secondary indicator species (Brassicaceae, *Convolvulus)*

Fig 4. Burmarrad pollen percentage diagram: trees and shrubs

Fig 5. Burmarrad pollen percentage diagram: herbaceous taxa

Fig 6. Burmarrad pollen percentage diagram: aquatic/wetland taxa and NPPs

Fig 7. Synthesis of cultural phases, LPAZs, sediment, vegetation dynamics and climatic reconstruction: BM2 core, Malta

Fig 8: Comparison between pollen-inferred climate for Malta (35.9°N, Burmarrad, Malta) and Lago Pergusa (37.5°N, Sicily) using MAT, WAPLS and WA and lake levels for Lago Preola (37.4°N, Sicily). a) mean temperature of coldest month (MTCO), b) winter precipitation, c) summer precipitation. (Malta's present-day values are indicated with an arrow on the scale bar).

Fig 9. Synthesis of general trends and key events indicating Malta's reconstructed climatic position (all data, except Burmarrad, from Peyron et al., 2013)