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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

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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). The 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; Lopez Saez 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 vs. eastern and northern vs. 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 lakes deposits, suitable sites for palaeo-vegetation data collection are very limited; notwithstanding this situation some recent research has

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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 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″ N, longitude: 14°11′04″–14°34′37″ E) is approximately 96 km from Sicily and 290 km from the north coast of

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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 10 ha in size (Cassar et al., 2008). The geology of the islands consists of five main types of sedimentary rocks deposited during 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 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

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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, 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 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 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 initial facies descriptions (such as colour and lithofacies) were conducted under standardized laboratory conditions (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 mm with a minimum annulus diameter of 8–10 mm (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,

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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.

This paper presents the results of pollen analysis carried out on 48 samples collected from the BM2 core between the depths 210 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 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 in 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 pollen 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.

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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

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in this area causing accelerated runoff and rapid infill of the plain during this period (Gambin, 2005; Marriner et al., 2012).

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 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, charcoal, 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 (Figs. 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. Charcoal was recorded at 93 to 256 %, along with mi-

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croforaminifera, 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. Charcoal decreases dramatically at the transition to this zone with only 9 % (the lowest level reached in the whole core sequence), then rises in the middle to 80 %, before decreasing again to 39 %. 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 ± 35 BP 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 *Quercus* records the 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 charcoal level is fairly high ranging between 52 and 132 %. 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 charcoal percentage recorded, 324 %. *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 Temple).

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). Charcoal percentages are much lower, ranging between 25 and 67 %. *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 Temple phase).

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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 charcoal peaks reaching around 259 %. This final LPAZ starts within the Bronze Age (Tarxien Temple) 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 Sect. 5.2).

4.3.1 Temperature reconstruction – MTCO

Between ca. 7000 and 4800 cal BP the temperature (MTCO) is fairly stable at around 11 °C, close to present-day values. After 4800 the temperature becomes more unstable with a minimum at 7 °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 in-

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crease in temperature to 12 °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 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 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 Quézel, 1985; Sadori et al., 2004; Roberts et al., 2011). 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. The BM2 core provides insight into both changing vegetation dynamics and hydroclimatic fluctuations in the Burmarrad valley system from 7280 to 1730 cal BP.

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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 people arrived in Malta remains a key question. Broadbank (2013) postulates that permanent Mediterranean island settlements were probably preceded by early visitations, however these remain "archaeologically invisible" (Colledge and Conolly, 2007). The Mediterranean 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 that south-eastern Sicily is visible from the higher vantage points of Malta, this early movement of seafarers might add weight to Mifsud and Mifsud's (1997) theory that humans may have been present on the archipelago even during Palaeolithic times. Therefore, it is very plausible that the Maltese islands may have been visited, and even temporarily occupied, numerous times 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, from palynological records, 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

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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 underwent this 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).

Though the evidence from BM2 core, and the BM1 core (Djamali et al., 2012), points to this region having an open landscape, it is necessary to highlight that there are Maltese archaeological records from the Neolithic period from other locations that might provide evidence of 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 perhaps originated in isolated patches in other regions on the archipelago or were brought as timber to the island by the first 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; Sadori et al., 2013a) making it difficult to state with any certainty that an in-

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dividual species is evidence of anthropogenic activity. Though 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); Carrión et al. (2010a); Li et al. (2008), and Mercuri et al. (2013), selected taxa from the BM2 Malta 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). 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).

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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 from other locations on the island 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 customs and farming practices were possibly undergoing adaptation, similar to the pottery styles (Trump, 2004). 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 period at San Pawl Milqi. These unusually high percentages for *Pistacia*, which is generally considered underrepresented in records (Collins et al., 2012) producing 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. This high percentage was also recorded by Djamali et al. (2012) in the same plain (BM1 core) from around this time. 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 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 processing.

This rapid and large expansion of *Pistacia* at around this time appears in records from Sicily at Biviere de Gela (Noti et al., 2009), Lago Preola (Calò et al., 2012) and Gorgo Basso, where an initial even larger expansion is recorded earlier between 10 000 and 7500 yr cal BP (Tinner et al., 2009); this earlier *Pistacia* peak and then decline was 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 (Carrión, 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 at their lowest levels as well, a decrease that is also noted in other localities in southern European sites, such as Lake 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 being 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).

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5.1.3 Late Temple Period

The temple period in Malta lasted between 6050 and 4450 cal BP; this period is quite unique to this archipelago (Pace, 2004), nowhere else in the world are there freestanding stone buildings dating to this period (such as Haġar Qim, Mnajdra and Ġgantija (Fig. 1b)). 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 religious purposes, for the estimated 10 000 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). This *Olea* increase is later than the increase noted by Tinner et al. (2009) at Gorgo Basso (6500 cal BP), but earlier than that recorded by Sadori et al. (2013b) 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

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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 *Sporomiella* (Cugny et al., 2010; Gelorini et al., 2012), therefore 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 and 2650 cal BP (Fig. 7), and is divided into three phases representing different colonisations of these islands: Tarxien Temple, Borg-In-Nadur and Bahjira, 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 were abandoned between them, though this remains to be confirmed. During the Bronze Age, fortified settlements were strategically built on hilltops along with underground food storage facilities known as “silo-piths” (Buhagiar, 2007), while dolmen structures (possibly used for the burial of cremated remains)

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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 more culturally and economically superior (Buhagiar, 2014). The population of the islands during the Bronze Age is suggested to have been smaller than during 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 alone (Trump, 2004). The formation and date of these cart ruts have been speculated since they were first referenced in 1647 by one of Malta's earliest historians Gian Francesco Abela (Hughes, 1999; Mottershead et al., 2008). However it is not this paper's purpose to delve into their much-debated chronology and use. At least some are suggested to be Bronze Age in origin (Trump, 2004) and are probably indicative of wheeled transportation taking place. Mottershead et al. (2008) suggest their formation is due to the movement of people and carts eroding the soil away, eventually exposing the local bedrock to further erosional activity.

Throughout the early and mid Bronze Age, in the Burmarrad catchment area, arboreal species are decreasing in abundance while herbaceous taxa are increasing, suggestive of the opening up of the landscape; the very sharp increase in microcharcoal 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), as well as 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

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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 this catchment area, 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) then from ca. 4000 cal BP there is a sharp decrease in marine mollusc taxa, 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, it has 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). 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 the amount of *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. This long distance transport might not have come from 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 island. In fact 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 %), however they suggest this may be due to infilling of a former dredged channel rather than indicative of local vegetation at this time. In neighbouring Sicily *Pinus* levels also increase at a similar time at Lago Preola (Calò et al., 2012) and Gorgo Basso (Tinner et al., 2009).

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

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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 enabled 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. These Sicilian sites then record a recovery of evergreen taxa between 3700 to 2600 cal BP. Almost synchronously an increase is noted to start 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), though palynological data is currently only available for the period 1972–1730 cal BP. Around 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, found in pottery styles and inscriptions, still persisted (Blouet, 2007). Seventeen Roman period sites have been linked to the production and exportation of olive oil on the islands (Gambin,

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2005), along with extensive port remains, such as quays and various buildings including warehouses, around the Marsa area (Blouet, 2007), 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 (Bonnano, 2005). The Burmarrad area also has archaeological evidence of Roman occupation. Evidence includes a large oil-producing Roman villa (San Pawl Milqi), burial complexes (Bonnano, 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 early-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. These increases suggest agricultural activity within the area, due to the presence of these cultivated crop and associated ruderal taxa. Marriner et al. (2012) conclude that around this time 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. Though attention must be placed on the over- or under-

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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, though 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, though 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, 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). 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 within the islands. How-

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ever, Carroll et al. (2012) did not record *Olea* pollen in their Marsa core, neither was it recorded in their Salina Bay sequence in any great quantities and 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 archaeological and geoarchaeological evidence from Gambin (2004, 2005) and Bruno (2007) that suggests Burmarrad was an area of olive production during the Roman period. The Roman villa within the catchment area having structures for olive pressing (Cefai et al., 2005), as well as Grech's (2001) suggestion that the currently protected ancient olive grove at Bidnija, again within the catchment area, might have its origins from Roman times. This is due to their planting pattern and a Roman oil press was found buried close to the trees. Also supporting this idea, the ancient grove 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). 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

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(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 are 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 overrepresented 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). 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). 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).

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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 Lake Pergusa, Sicily (Sadori et al., 2013b), this lake is situated at a higher altitude (667 m a.s.l.), 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 (Sect. 5.1.4). We also cannot exclude for this period a possible biais 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 sup-

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ports the mid-Holocene opposing summer precipitation hypothesis for the Mediterranean, that of a reduced summer precipitation for northern sites (above 40° N) and a maximum for southern sites (below 40° 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 (Sect. 5.1.1). In the late Holocene, the summer precipitation in the Burmarrad catchment area decreases to below previous levels, but can be potentially biaised 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

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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. Around 4250 BP Weiss and Bradley (2001) suggest that 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 undersestimated 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 eastern region underwent a period of increased winter precipitation up until 6000 BP followed by a decline. 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). 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 vs. 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

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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.

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

Vegetation Community	Selected Main Taxa
Garrigue	*Thymus capitatus, Erica multiflora, Euphorbia melitensis, Teucrium fruticans* and *Anthyllis hermanniae*
Steppe	*Lygeum spartum (clay slopes) Hyparrhenia hirta, Andropogon distachyus* and *Brachypodium retusum*. Also *Stipa capensis* and *Aegilops geniculata, Carlina involucrata, Notobasis syriaca, Galactites tomentosa, Asphodelus aestivuus*, and *Urginea pancration*.
Maquis	*Ceratonia siliqua, Olea europaea, Pistacia lentiscus, Rhamnus alaternus* and *Rhamnus oleoides*

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Table 2. Radiocarbon dates obtained from the Burmarrad BM2 core.

Depth	Radiocarbon date	Calibrated age at sigma range	Laboratory reference	Material
500 cm	3655 ± 35 BP	3888–4086 cal BP	Poz-42682	Wood Fragment
705 cm	3810 ± 30 BP	4090–4347 cal BP	Poz-42443	Grain
820 cm	4010 ± 35 BP	4416–4568 cal BP	Poz-42442	Charcoal
980 cm	6055 ± 35 BP	6797–6995 cal BP	Poz-42444	Charcoal

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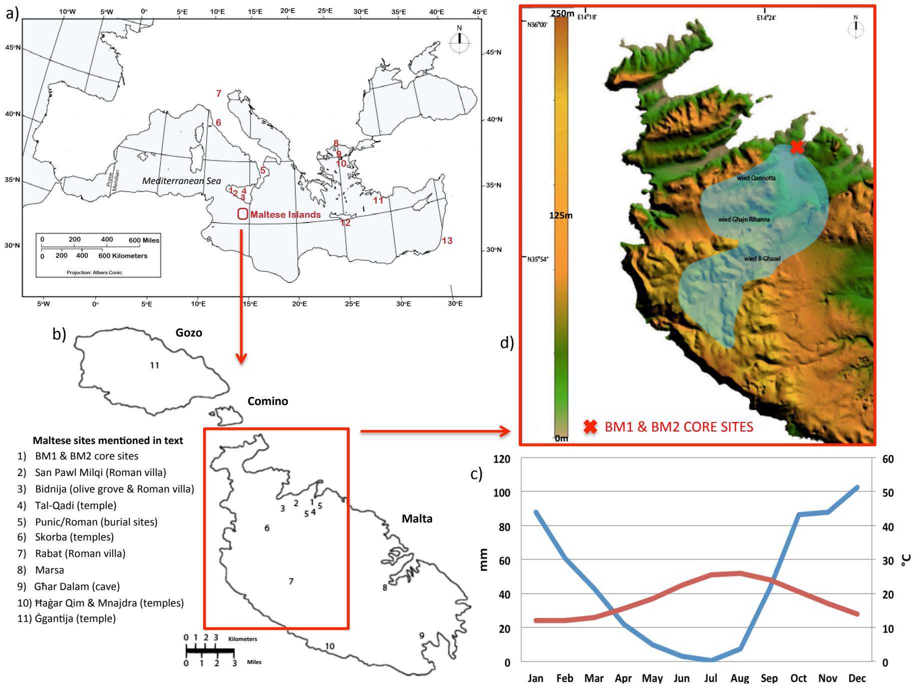

Figure 1. Study area. **(a)** Mediterranean region highlighting the Maltese Islands (selected regional sites mentioned in text: 1: Lago Preola, 2: Gorgo Basso, 3: Biviere di Gela, 4: Lago Pergusa, 5: Lago Trifoglietti, 6: Lago Accesa, 7: Lago Ledro, 8: Tenaghi P., 9: SL152, 10: MNB-3, 11: NS14, 12: HCM2-22, 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.

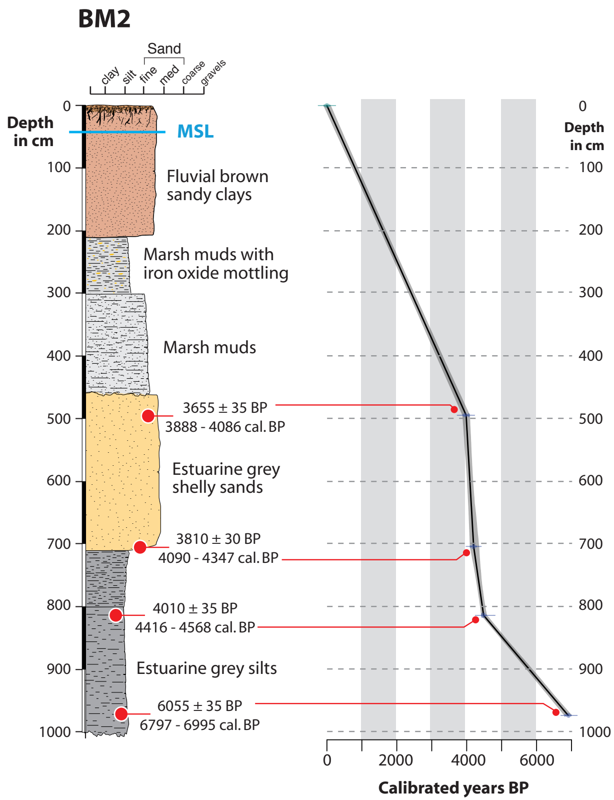

Figure 2. BM2 sedimentary profile and age-depth model interpolated curve.

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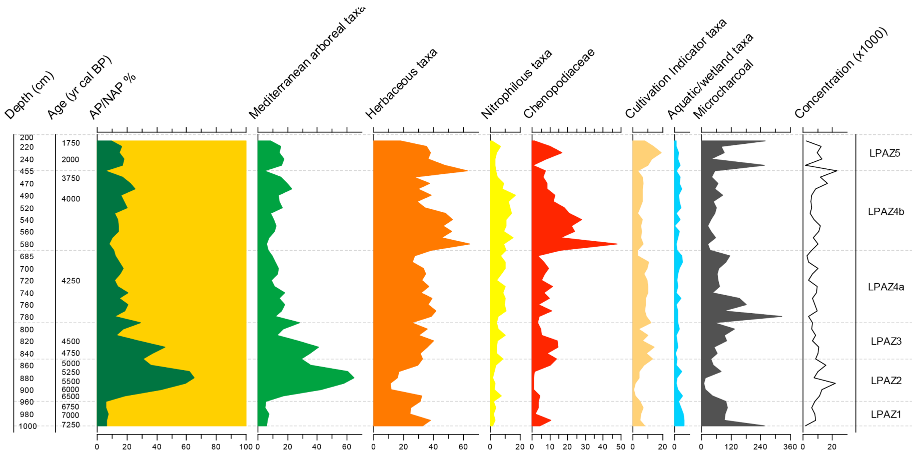

Figure 3. Burmarrad simplified pollen diagram: selected percentage curves and pollen concentration. Mediterranean arboreal taxa: *Ephedra, Erica, Juniperus, Olea, Phillyrea, Pinus* and *Pistacia*. Nitrophilous taxa: *Rumex, Urtica* and *P. lanceolata-type*. Cultivation indicator taxa: including crops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

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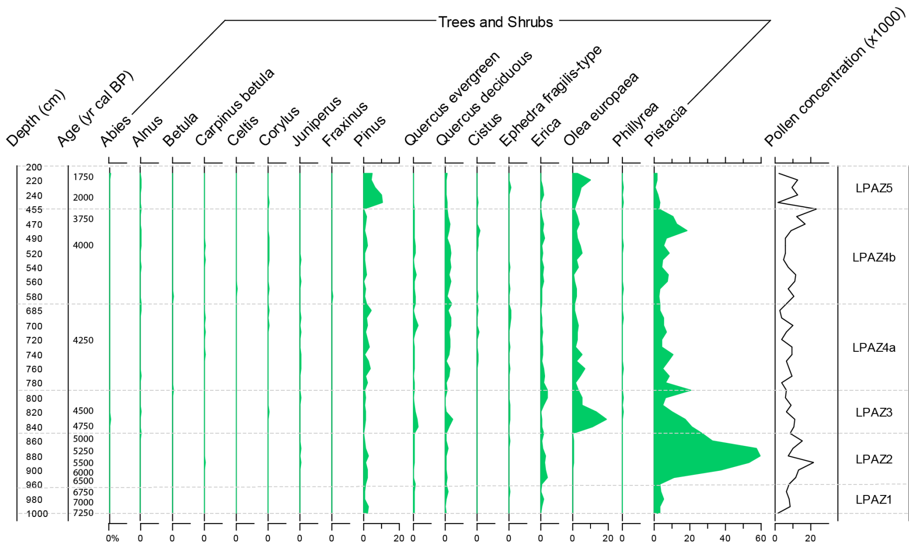

Figure 4. Burmarrad pollen percentage diagram: trees and shrubs.

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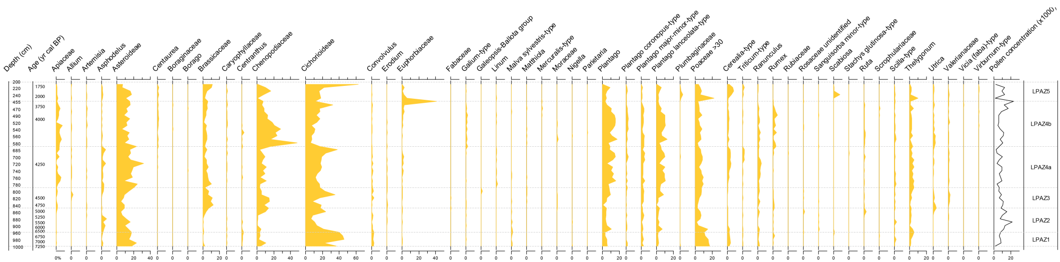

Figure 5. Burmarrad pollen percentage diagram: herbaceous taxa.

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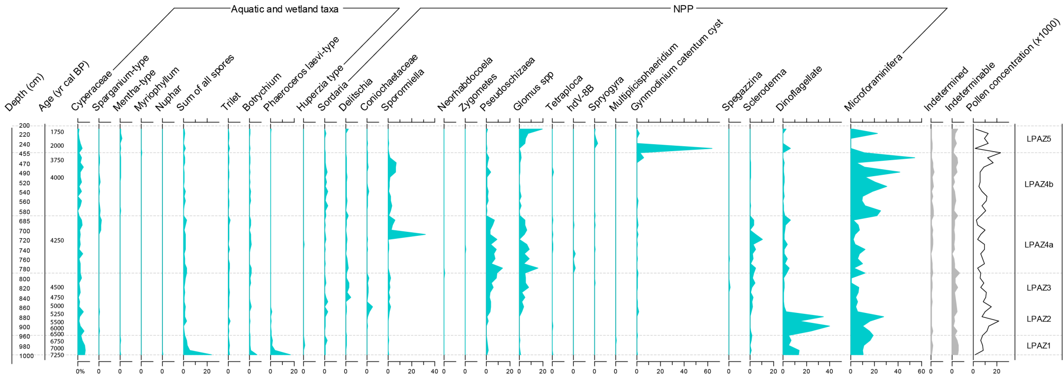

Figure 6. Burmarrad pollen percentage diagram: aquatic/wetland taxa and NPPs.

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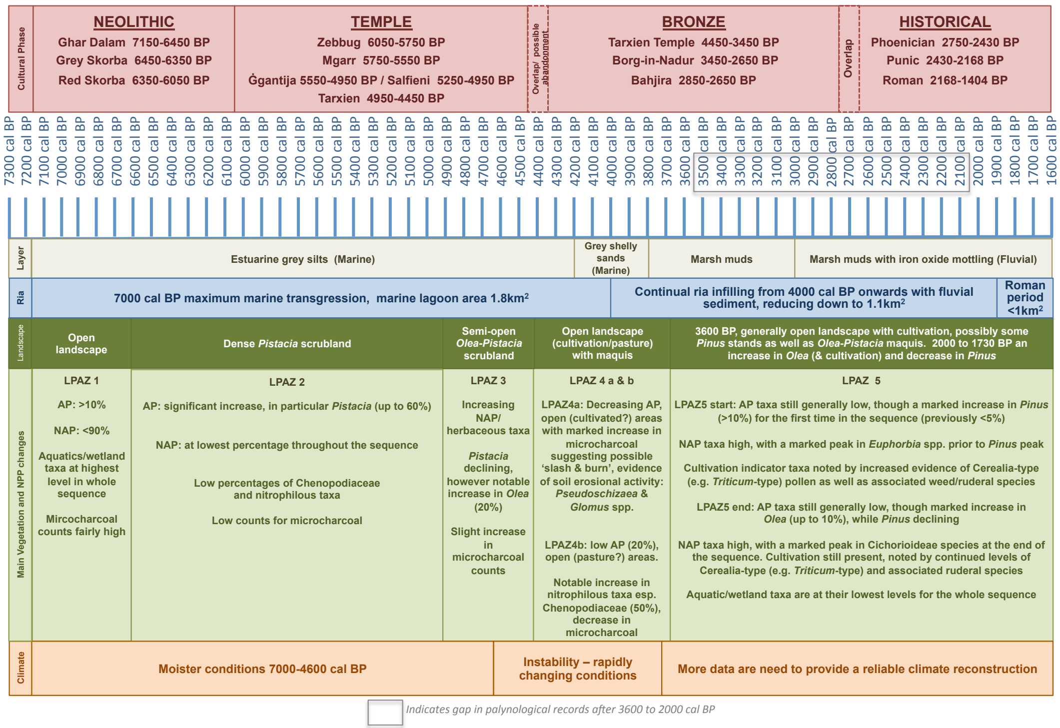

Figure 7. Synthesis of cultural phases, LPAZs, sediment and climatic reconstruction: BM2 core, Malta.

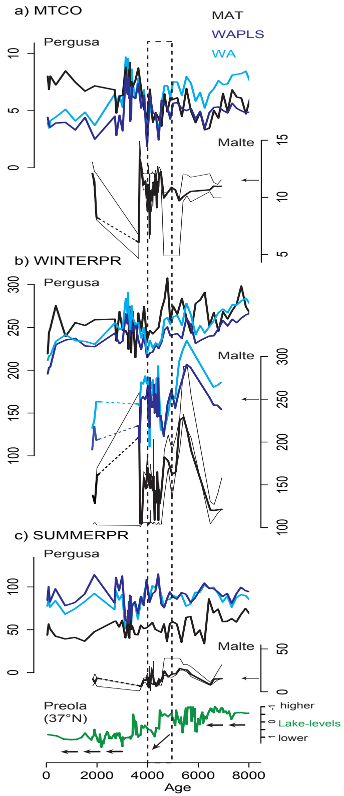

Figure 8. Comparison between pollen-inferred climate for Malte (35.9° N, Burmarrad, Malta) and Lago Pergusa (37.5° N, Sicily) using MAT, WAPLS and WA and lake levels for Lago Preola (37.4° N, Sicily). **(a)** Mean temperature of coldest month (MTCO), **(b)** winter precipitation, **(c)** summer precipitation.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

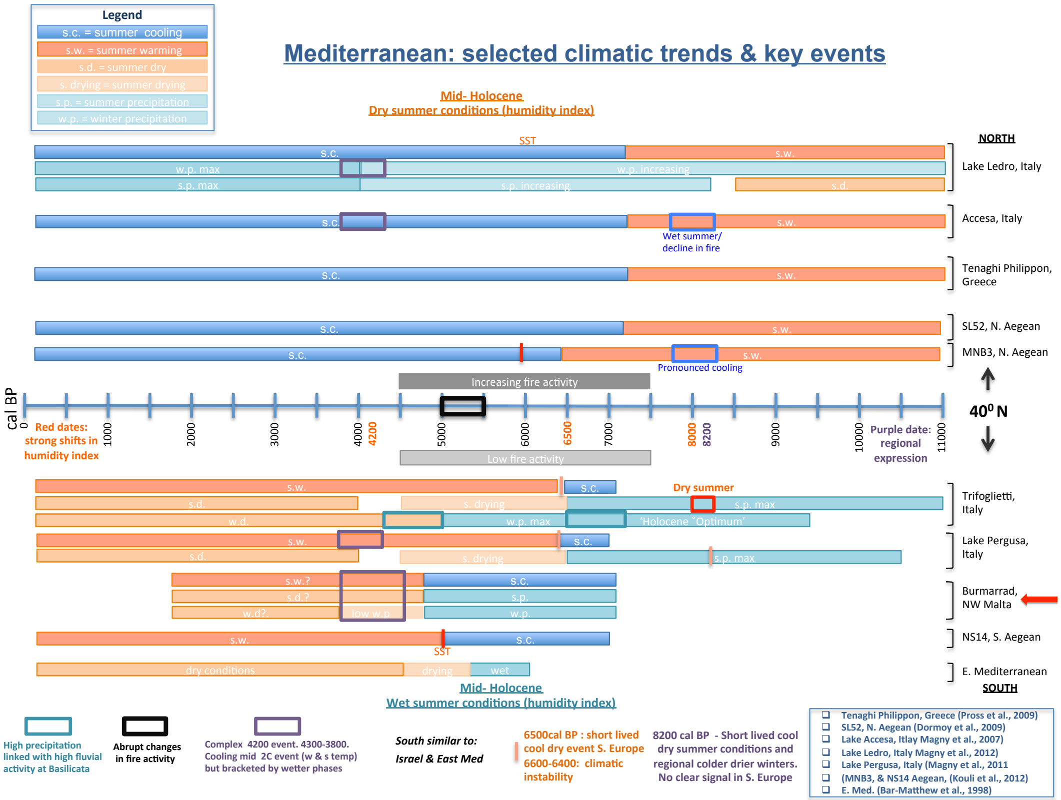

Figure 9. Synthesis of general trends and key events indicating Malta's reconstructed climatic position (all data, except Burmarrad, from Peyron et al., 2013).

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