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The late Holocene introduction of *Juglans regia* (walnut) to Cyprus

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Abstract

The island of Cyprus has a long history of human impacts, including the introduction of more than 250 plant species. One of these introduced species is *Juglans regia* (walnut), which is considered a naturalised non-native (introduced in last 500 years). Here we report the earliest occurrence of *Juglans regia* pollen grains from a sedimentary deposit on Cyprus. The pollen recovered from the Akrotiri Marsh provides an earliest introduction date of 3,100–3,000 cal yr BP. This Bronze Age occurrence of *Juglans regia* is sporadic. However, by 2,000 cal yr BP the pollen signal becomes more persistent and indicates that introduction or expansion of *Juglans regia* was highly likely in the Roman period. We integrate our new results with younger pollen occurrences of *Juglans regia* on Cyprus, the archaeobotanical record and documentary evidence to provide an overview of this archaeophyte. Our findings show that, following the conventions of the Flora of Cyprus, *Juglans regia* should be reclassified from naturalised non-native to indigenous.

Keywords Eastern Mediterranean · Introduced species · Palynology · Roman · Bronze age · Arboriculture

Introduction

The island of Cyprus is the third largest island in the Mediterranean, with diverse topography and a Mediterranean climate of hot, dry summers and relatively mild, moist winters (Delipetrou et al. 2008; Fall 2012). This unique combination means the island has a diverse flora within the Mediterranean biodiversity hotspot (Médail and Quézel 1999; Hand et al. 2019). The Flora of Cyprus contains 1,946 recorded taxa with 8.55% of these being endemic to the island, making it an important biodiversity hotspot within the Mediterranean basin (Médail and Quézel 1999; Hand et al. 2011, 2019). Due to a long history of human interaction with the landscape, the list also contains 254 naturalised and casual taxa (Hand et al. 2019).

One of these naturalised non-native taxa is *Juglans regia*, which is found in phytogeographical zone 2 of Cyprus, the Troodos Mountains (Hand et al. 2011; Fig. 1). Within

Europe, the geographical distribution of *Juglans regia* has been heavily influenced by anthropogenic activity (Pollegioni et al. 2017). At the end of the Last Glacial Maximum, *Juglans regia* inhabited refugia across southern Europe and Anatolia (Bottema 1980, 2000; Pollegioni et al. 2017). Genetic admixture between these refugia populations began in the Bronze Age and is coeval with increases in *Juglans* pollen within palaeoenvironmental archives of the Balkans, Levant and Anatolia (Bottema 1980, 2000; Eastwood et al. 1998; Izdebski et al. 2016). The increase in *Juglans* pollen is part of a wider assemblage indicating human impacts on the environment associated with increased agriculture and arboriculture (Eastwood et al. 1998; Woodbridge et al. 2019). Termed the Beyşehir Occupation Phase (3,500–1,350 BP), it has also been observed in the wider region, including the Caucasus, Georgia and Iran (Izdebski et al. 2016), leading to the proposal that this might represent a degree of homogenisation in agricultural practices, particularly during the Hellenistic and Roman empires (Izdebski et al. 2016).

When *Juglans regia* came to Cyprus is largely unknown. Izdebski et al. (2016) attributed *Juglans* pollen from the Larnaca Salt Lake to the Beyşehir Occupation Phase. However, *Juglans* is not present in this record until the Byzantine period – after the traditional dates for the Beyşehir Occupation Phase (Kaniewski et al. 2013). In this study we report the earliest occurrence of *Juglans regia* pollen in a

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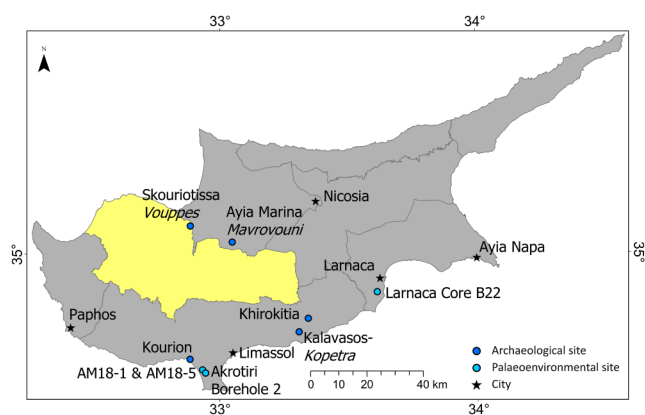


Fig. 1 The island of Cyprus showing the seven phytogeographical zones, major settlements, palaeoenvironmental records and archaeological sites with *Juglans* pollen or Roman – Byzantine archaeobotanical remains. Phytogeographical zone 2 (Troodos Mountains), where *Juglans regia* is mainly found today, is highlighted in yellow. Phytogeographical divisions follow Meikle (1977, 1985) and Hand et al. (2011)

palaeoenvironmental setting from southern Cyprus, provide an introduction date for this naturalised non-native species and link the palaeoenvironmental records to archaeological and historical occurrences of *Juglans regia*.

Methods

Six sediment cores were taken from the Akrotiri Marsh, a freshwater marsh located on the Akrotiri Peninsula that is part of the Akrotiri Wetlands Special Protection Area (Kassinis and Charalambidou 2021) on the south of the Island of Cyprus (Fig. 1). Pollen samples were treated with potassium hydroxide, hydrochloric acid, hydrofluoric acid and acetolysis before being mounted in silicon oil. Pollen concentration was determined using *Lycopodium clavatum* marker spores (Riding 2021). Chronological control comes from six radiocarbon dates (Hazell et al. 2022). Full details of the methodology, core sedimentology, details of radiocarbon dates, diatom results and pollen diagrams are available in Hazell et al. (2022). In this paper, we report *Juglans regia* pollen and the pollen concentration record from two cores AM18-1 and AM18-5 from the Akrotiri Marsh.

Results

Juglans regia pollen is first present in the Akrotiri Marsh sedimentary record at 3,010 cal yr BP (AM18-5) and 3,100 cal yr BP (AM18-1) (Fig. 2). This earliest presence is greater in core AM18-1 at 2.3% of the total pollen amount, however the overall pollen concentration is also substantially higher in this core at this time (Fig. 2). Following

this first occurrence in both cores, the abundance of *Juglans regia* in AM18-1 is low and sporadic for the remainder of the record (Fig. 2). In AM18-5, *Juglans regia* pollen is also sporadically present until 2,000 cal yr BP, after which the record becomes more constant and fluctuates between 1 and 4% until the end of this core at 1,380 cal yr BP (Fig. 2). These fluctuations in the *Juglans regia* record in core AM18-5 occur in tandem with the pollen concentration of the sediments. A final occurrence of *Juglans regia* pollen at 1,000 cal yr BP is found in core AM18-1. As both records show older peaks in pollen concentration without the presence of *Juglans regia*, the earliest occurrence in the Akrotiri Marsh is 3,100–3,010 cal yr BP (Fig. 2).

Discussion

Previously the earliest known presence of *Juglans regia* in a sedimentary archive on Cyprus was 840 cal yr BP (Fig. 2) from the Larnaca Salt Lake (Kaniewski et al. 2013). The Akrotiri Marsh record has an earliest occurrence during the Bronze Age: ca. 3,000 cal yr BP (Fig. 2). Bottema (1980) proposed *Juglans* was introduced to southeast Europe (Greece) at around 3,500 BP and it is considered part of the Beyşehir Occupancy Phase agroforestry signal in pollen data (Izdebski et al. 2016). Although more recent genetic work suggests it could have had diverse refugia across much of Eurasia between 30–45°N, but not Cyprus (Aradhya et al. 2017). The earliest dates of *Juglans regia* in the Akrotiri Marsh are consistent with a Beyşehir Occupation Phase introduction during the Bronze Age (Fig. 2, Izdebski et al. 2016). An increase in tree crops, at the expense of grain production, during the Bronze Age has been previously proposed and linked to engagement in wider trade networks in the Eastern Mediterranean (Lucas and Fuller 2020). However, *Juglans* remains have not been reported from Bronze Age archaeological sites on Cyprus (Lucas 2014; Lucas and Fuller 2020).

A combined study of ethnolinguistics and genetics suggested a spread of *Juglans* from the Early Bronze Age, driven by Greek, Roman and Persian expansion/trading (Pollegioni et al. 2020). The persistent presence of *Juglans* pollen from around 2,000 cal yr BP in AM18-5 would be consistent with a Roman expansion of walnut on Cyprus (Fig. 2). It was a luxury Roman commodity in Central Europe with archaeobotanical remains appearing in 72 archaeological sites (Bakels and Jacomet 2003). As well as being a food throughout the Roman world (Rowan 2019), the nuts had symbolic meaning at marriages and burials (Reed et al. 2019), young fruits were used for hair dye (Pliny the Elder), trees were used for timber (Allevato et al. 2009) and the plant was grown in gardens (Langgut 2022). Textual

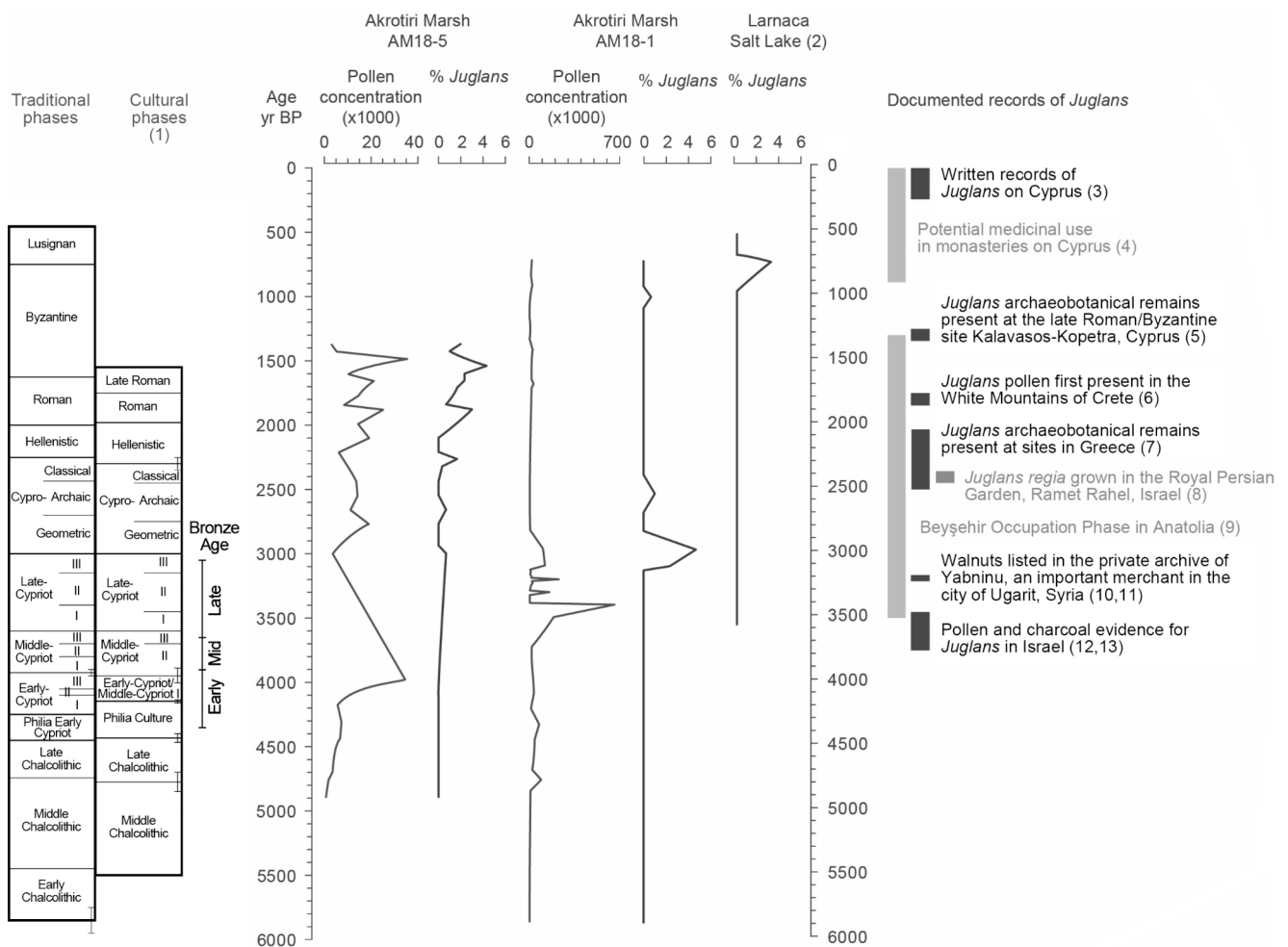


Fig. 2 The chronological distribution of *Juglans* pollen on Cyprus, pollen concentration values in the Akrotiri Marsh records and key pre-historical and historical events relating to *Juglans* on Cyprus and in the wider eastern Mediterranean region. (1) Kearns and Manning (2019); (2) Kaniewski et al. (2013); (3) Harris (2007); (4) Lardos (2006); (5) Rautmann (2003); (6) Jouffroy-Bapicot et al. (2016); (7) Douché et al. (2021); (8) Langgut et al. (2013); (9) Eastwood et al. (1998); (10) Bell (2012); (11) Broodbank (2013); (12) Langgut (2015); (13) Benzaquen et al. (2019)

evidence from Greek, Roman and Jewish sources also testifies to widespread *Juglans regia* cultivation throughout the Mediterranean at this time (Zohary et al. 2012); this is also attested by archaeobotanical and palynological remains from Roman Petra, Jordan (Bouchaud et al. 2017) and Salagassos, Turkey (Baeten et al. 2012). In the Akrotiri Marsh, the largest and most persistent presence of *Juglans* pollen comes during the Roman archaeological periods on Cyprus (Fig. 2). Archaeobotanical remains from Cyprus that post-date the Bronze Age are not common and even from earlier periods the island is considered to have an under-investigated botanical record (Butzer and Harris 2007; Falconer and Fall 2013; Lucas 2014; Kofel et al. 2021). Returning to the Roman periods, the Earthquake House (1,700-1,585 year BP) at nearby Kourion (Fig. 1) has a limited archaeobotanical record, but no *Juglans* reported (Soren et al. 1986). Charcoal found in Roman slag heaps dating from 1,980 to 1,300 cal yr BP in Skouriotissa *Vouppes* and Ayia Marina

Mavrovouni contain only local tree taxa (Given et al. 2013). *Juglans* is reported from the Late Roman – Byzantine site of Kalavassos-*Kopetra* dated to 1,350-1,280 year BP (Rautman 2003). These archaeobotanical finds dated to the end of the AM18-5 record (Fig. 2) come from both residential and ecclesiastical settings (Rautman 2003). Whilst this provides some archaeobotanical support to our record, it is important to consider that these might also have been imported. Walnuts have been reported from shipwrecks from Roman Portus (near Rome) in Italy (Parker 1992) and the Byzantine port of Caesarea Maritima, Israel (Ramsay 2010).

The sedimentology of the Akrotiri Marsh changes at around 1,500 cal yr BP from peat/organic rich clay to a red-brown clayey silt. This is accompanied by a change in the diatom and pollen assemblages (Hazell et al. 2022). This sedimentology change leads to a barren record in the upper 20 cm of AM18-5, but *Juglans* pollen is present at 1,000 cal yr BP in AM18-1 (Fig. 2). Following this last occurrence

in the Akrotiri Marsh, *Juglans* pollen is reported from the Larnaca Salt Lake from 840–690 cal yr BP (Kaniewski et al. 2013). This youngest occurrence could be linked with continued walnut arboriculture on the island for food and timber and an increase in church and monastery construction (Butzer and Harris 2007). Walnuts were mentioned as a medicinal ingredient in the *Iatrosophikon* (written in 1849) from a monastery founded in the 12th century AD (Lardos 2006). Other documentary evidence also demonstrates a continued presence of walnut on Cyprus. Dummond, in the mid-1700s, reported seeing *Juglans* on Cyprus (Harris 2007) and an Ottoman property register from 1833 reported *Juglans* growing in a number of settlements from 300 to 700 m above sea level (a.s.l.) (Given and Hadjianastasis 2010). Thomson (1879) mentioned walnuts from Levka (inland from Morphou Bay) a settlement at around 200 m a.s.l., but did not state whether he saw the trees. Writing in the 20th century, Haji-Costa and Percival (1944) mentioned the quality of walnuts coming from the Pitsilia region in the Troodos Mountains (around 1,000 m a.s.l.). Using these historical observations as estimates of where *Juglans* could have grown, altitudes of 300 m and above are found 8–10 km from the Akrotiri Marsh in the lower slopes of Troodos Mountains and along the Kouris River.

Juglans pollen is not abundant in the palaeoenvironmental records of Cyprus, but this is not surprising as it is not well represented in pollen rain studies due to a low dispersal potential. *Juglans* pollen is typically under-represented in extra-local and regional pollen rain due to low pollen production for an anemophilous taxon and fall speed combining to make it an unlikely long-distance contaminant (Bodmer 1922; Tormo Molina et al. 1996; Beer et al. 2007). Investigations from orchards of *Juglans regia* showed that the proportion of pollen recovered falls below 0.5% within metres of the orchard edge (Bottema 2000; Langgut 2015). On Cyprus, airfall samples from lowland Nicosia reach 0.48% (Gucel et al. 2013; Fall 2012) did not report the pollen from soil samples even when trees were present in the study site. Bottema (2000) considered that pollen percentages of *Juglans* above 2% indicated a number of trees in the nearby vicinity. Using this indicator value would suggest the presence of *Juglans* trees in the vicinity of the Akrotiri Marsh (Fig. 2). Alternatively, material could have been washed in from the nearby Kouris River and originally have been from the Troodos Mountains.

A Bronze Age to Roman period spread of *Juglans* has been proposed from palynological, ethnolinguistic and genetic studies (Bottema 1980, 2000; Eastwood et al. 1998; Pollegioni et al. 2017, 2020). Genetics show refugia in southern Europe and Anatolia, which provides a starting point to consider how this important economic species spread (Pollegioni et al. 2017, 2020). In the Levant, pollen

and charcoal evidence are first reported from Israel dating to before 3,500 year BP (Fig. 2). Walnuts, as a commodity, are mentioned in the private archive of the merchant Yabninu from Ugarit (present-day Syria), who was involved in an extensive trade network across the eastern Mediterranean, including Cyprus, from 3,210 to 3,185 year BP (Bell 2012; Broodbank 2013). Both of these overlap with the earliest portion of the Beyşehir Occupancy Phase in Anatolia and might show an early period of walnut trade and, in the case of evidence from Israel and Cyprus, potentially early arboriculture (Fig. 2). The growing of *Juglans* in Israel is also evidenced from the Royal Persian Garden (at least 2,400 year BP) at Ramat Rahel (Langgut et al. 2013). Archaeobotanical studies from Greece show the presence of walnuts in sites dating to the Classical and Hellenistic periods (ca. 2,500–2,030 year BP) (Douché et al. 2021). On the island of Crete, *Juglans* pollen is first recorded from 1,900 cal yr BP (Jouffroy-Bapicot et al. 2016), a comparable date to the more constant presence in our AM18-5 record (Fig. 2). Combining these records would imply a spread out of refugia and into the Levant, perhaps through Bronze Age trading networks, and a spread through Greece after the Bronze Age and onto Crete following the Roman conquest.

Where Cyprus sits in this possible pattern is less clear. Using the earlier dates would imply a Late Bronze Age introduction (Fig. 2), whilst climate change during this interval might have made this challenging and potentially a failed arboriculture experiment (Hazell et al. 2022). In the mid-20th Century, walnuts were grown along watercourses or in places with irrigation in Cyprus (Christodoulou 1959); it is likely then that any period of aridity would adversely affect *Juglans* orchards. On Cyprus a peak in aridity is recorded at 2,800 cal yr BP (Kaniewski et al. 2020; Hazell et al. 2022), when the *Juglans* pollen disappears from the AM18-1 record (Fig. 2). A return of *Juglans* pollen at around 2,000 cal yr BP in AM18-5, also corresponds to an interval of greater water availability recorded in both the Akrotiri Marsh (Hazell et al. 2022) and higher winter precipitation recorded at Hala Sultan Teke (Kaniewski et al. 2020). The precise role that ambient climate played in the establishment of *Juglans* on Cyprus is speculative, but the current palaeoclimate records from the island do not show any major aridity peaks (comparable to those in the Late Bronze Age) over the last 2,000 years in which *Juglans* has been present on the island.

Pollen evidence from well-dated palaeoenvironmental archives suggests that *Juglans regia* has been present on Cyprus since ca. 3,000 cal yr BP (Fig. 2). Additional evidence comes from the Akrotiri Borehole 2 (Fig. 1), which was taken from the Akrotiri (Limassol) Salt Lake (Allen et al. 2009). Here, *Juglans* pollen is present in low percentages at 160–180 cm depth. However, only a single radiocarbon date from 453 cm depth provides chronological

context, showing the *Juglans* presence here to be younger than 6,890–6,640 cal yr BP (Allen et al. 2009). From an archaeological context, low amounts of *Juglans* pollen were reported in “Colonne 5bis” from Khirokitia (Fig. 1) in horizon D, with a recently recalibrated date for this occurrence of 6,590 ± 260 cal yr BP (Renault-Miskovsky 1989; Knapp 2013). At Kirokitia, it was suggested that Juglandaceae pollen (including *Carya*) could have been reworked from pre-Quaternary sediments (Renault-Miskovsky 1989). However, Juglandaceae pollen has not yet been reported from the limited palynology conducted on pre-Quaternary sedimentary rocks on Cyprus (Rouchy et al. 2001; Athanasiou et al. 2021). These tantalising data might attest to an earlier presence of small amounts of *Juglans regia* on Cyprus, but this is pure speculation without longer and older palaeoenvironmental records from phytogeographical zone 2 (Fig. 1).

Conclusions

Combined pollen records from the south coast of Cyprus show that *Juglans regia* has been present on the island of Cyprus for 2,000–3,100 years. Sporadic pollen occurrences during the Bronze Age could point to an introduction during this period and are consistent with findings from around the eastern Mediterranean. An increase in proportion and frequency of occurrence during the Roman period means that this would be a conservative introduction date. This conservative introduction date would be consistent with widespread Roman arboriculture aimed at nut and timber production. In the context of present day Cyprus, this would change the status of *Juglans regia* from a naturalised non-native species to an indigenous species.

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Author contributions The original pollen data from the Akrotiri Marsh were collected by CH. MP designed and drafted this paper in collaboration with CH and EH. All authors contributed to the writing, editing and figure design.

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