Landscape Change and Trade in Ancient Greece: Evidence from Pollen Data

Anton Bonnier, Uppsala University

Tymon Sloczynski, Brandeis University and IZA

Grzegorz Koloch, Warsaw School of Economics

Katerina Kouli, National and Kapodistrian University of Athens

Adam Izdebski, Jagiellonian University in Krakow and Max Planck Institute for the Science of Human History

Working Paper Series

2018 | 126

LANDSCAPE CHANGE AND TRADE IN ANCIENT GREECE: EVIDENCE FROM POLLEN DATA[*]

ANTON BONNIER[†] TYMON SŁOCZYŃSKI[‡] GRZEGORZ KOLOCH[§]
KATERINA KOULI[¶] ADAM IZDEBSKI[||]

Abstract

In this paper we use pollen data from a number of sites in southern Greece and Macedonia to study long-term vegetation change in these regions from 1000 BCE to 600 CE. Based on insights from environmental history, we interpret our estimated trends in the regional presence of cereal, olive, and vine pollen as proxies for structural changes in agricultural production. We present evidence that there was a market economy in ancient Greece and a major trade expansion several centuries before the Roman conquest. Our results are consistent with auxiliary data on settlement dynamics, shipwrecks, and ancient oil and wine presses.

JEL Classification: C81, F14, N53, N73, Q17

Keywords: agricultural production, ancient Greece, environmental history, market integration, pollen data, trade

---

[*] This version: November 8, 2018. For helpful comments, we thank Shameel Ahmad, Stephen Cecchetti, Alan Dye, George Hall, Robert Hunt, Michael McCormick, John Murray, Aldo Musacchio, Steven Nafziger, Şevket Pamuk, Davide Pettenuzzo, Peter Temin, Taco Terpstra, members of the PELOPS group, seminar participants at Brandeis, Harvard, LSE, and Northwestern, and conference participants at the European Historical Economics Society meeting, University of Tübingen, 2017; the "Human-Environment Dynamics in the Peloponnese and Beyond: Ideas–Methods–Results" conference, American School of Classical Studies at Athens, 2017; the Liberal Arts Colleges Economic History Workshop, Mount Holyoke College, 2018; the NBER Summer Institute, 2018; and the World Economic History Congress, Boston, 2018. We are grateful to Camille Hoge for outstanding research assistance. Bonnier acknowledges financial support from the Swedish Research Council (grant 421-2014-1181, "Domesticated Landscapes of the Peloponnese"). Izdebski acknowledges financial support from the Ministry of Science and Higher Education of the Republic of Poland (National Programme for the Development of Humanities, 2016–19). His contribution also benefited from a membership at the Institute for Advanced Study in Princeton, NJ, in the academic year 2017/18. Słoczyński acknowledges financial support from the Theodore and Jane Norman Fund.

[†] Uppsala University. Email: anton.bonnier@antiken.uu.se.

[‡] Brandeis University and IZA. Email: tslocz@brandeis.edu.

[§] Warsaw School of Economics. Email: gkoloch@sgh.waw.pl.

[¶] National and Kapodistrian University of Athens. Email: akouli@geol.uoa.gr.

[||] Jagiellonian University in Krakow and Max Planck Institute for the Science of Human History. Email: adam.izdebski@uj.edu.pl.

1 Introduction

Recent debates on the economic history of the ancient world have focused on both the structure and performance of Greco-Roman economies. While earlier scholarship argued that markets had played a minor role in the largely agricultural economies of Greek and Roman communities (see, *e.g.*, Polanyi 1968; Finley 1973; Polanyi 1977), recent research has highlighted the high volumes of trade and increasing market integration, particularly for the Roman Mediterranean (see, *e.g.*, Kessler and Temin 2008; Temin 2013). Although archaeological evidence from these periods documents the movement of goods, quantifiable data on market integration and structural changes in agricultural production have generally been limited. For example, settlement patterns derived from archaeological field surveys have previously been used to quantify changes in land use in several Mediterranean regions, but survey data as such provide no evidence on changes in the structure of regional agricultural output or the importance of different crops cultivated in a given period. In this paper we demonstrate how palynology—the study of pollen remains extracted from cored sediments—can be used to examine changes in the structure of agricultural production and to link these changes to periods of increasing market integration in the context of ancient pre-industrial economies. In doing so, we follow—and also extend—the methodology of Izdebski *et al.* (2016a), which allows us to combine evidence from a number of sites in southern Greece and Macedonia to estimate regional trends in the presence of pollen attributable to different plant taxa, including cereals, olive, and vine. These cultivars are particularly important in our empirical context, as wheat, olive oil, and wine formed the basis of ancient diets (see, *e.g.*, Sallares 1991; Isager and Skydsgaard 1992; Decker 2009). Consequently, our analysis of these data—which have not been previously used to study the economic history of Greco-Roman antiquity—provides novel evidence on structural changes in ancient Greek agriculture.

In fact, the need for new sources of quantifiable data on ancient economies—however elusive this might seem—has been highlighted in the recent literature. Temin (2006a) argued that "[t]here is a lot of information [about ancient economies], but hardly any of what economists call data." Thus, out of necessity, some studies have been based on unusually small samples. For example, Kessler and Temin (2008) studied the effects of the distance from Rome on local wheat prices. While the authors found evidence of an integrated grain market, their analysis involved only six observations. Bransbourg (2012) approached the same question with an enlarged sample of twelve prices—which is still, of course, remarkably small. Other papers have attempted to provide estimates of Roman GDP and income inequality (see, *e.g.*, Goldsmith 1984; Temin 2006b; Allen 2009; Scheidel and Friesen 2009; Milanovic *et al.* 2011), which again need to be derived from a very small number of data points. As Temin (2013) stated it: "All of the GDP estimates … rest on an exceedingly narrow evidentiary base. They are at best conjectural estimates based on a few observations, some about the early Roman Empire and some about modern economies."

Given the extremely limited quantitative data from the core regions of the Greco-Roman world, many scholars have analyzed much richer data from Babylon and Egypt. Because of the arid climate of the Nile valley, a wealth of economic information has been preserved in its papyri. See, for example, Manning (2003) and Bagnall (2005). In a recent paper, Harper (2016) studied the time series of wheat prices, land prices, rents, and wages in Roman Egypt. He concluded that the data provided clear evidence of both population growth and intensive economic growth. In Babylon, agricultural prices were recorded by diarists on clay tablets. See, for example, Slotsky (1997) and Grainger (1999). To evaluate whether these prices provided evidence of market activity, Temin (2002) tested whether they behaved like a random walk—and concluded that they did.

Many scholars have also studied the data on Mediterranean shipwrecks, originally collected by Parker (1992) and recently expanded by Wilson (2011), McCormick (2012), and Strauss (2013). These data have often been used as a proxy for seaborne trade or even for the overall level of economic activity (see, *e.g.*, Hopkins 1980; Geraghty 2007; Kessler and Temin 2007; Terpstra 2019). Following this interpretation, the shipwreck data are suggestive of an economic boom and a trade expansion in the early Roman Empire. Still, shipwreck-based studies have certain inherent limitations, as discussed by Wilson (2011) and McCormick (2012, 2016), among others.

Thus, in recent years, further sources of quantitative data have been introduced to ancient economic history. A number of studies, such as de Callataÿ (2005), Jongman (2007b), McConnell *et al.* (2018), and Terpstra (2019), discussed the implications of lead pollution recorded in Greenland ice cores for our understanding of ancient economic history over the long term. Brughmans and Poblome (2016) developed an agent-based model of tableware trade in the Eastern Mediterranean to compare actual data on tableware distributions with model predictions in different scenarios. They concluded that their model provided the best fit to the data in a scenario consistent with a high degree of market integration. Barjamovic *et al.* (2017) analyzed commercial records from the Old Assyrian trade network in the 19th century BCE. They estimated a gravity model of trade and used this model to predict locations of lost ancient cities. While the authors did not explicitly study the question of market integration, their data documented the importance of long-distance trade in the Bronze Age. Finally, Bakker *et al.* (2018) contributed to our knowledge about the link between trade (or, in fact, trade potential) and development by establishing a positive relationship between the connectedness of points on the Mediterranean coast and the presence of archaeological sites.[1]

In this paper we explicitly focus on the area with the highest trade potential in the Mediterranean, as measured by Bakker *et al.* (2018), namely the Aegean. We analyze quantitative data from thirteen pollen sites in southern Greece and Macedonia. For each site, we construct a separate panel data set with information about vegetation structure—namely, proportions of pollen grains attributable to selected plant taxa—at different points in time. Following Izdebski *et al.* (2016a), we then use these data to estimate regional trends in the presence of our taxa of interest. In some cases—say, cereals, olive, and vine—our focus on these components of vegetation is self-explanatory, given modern knowledge of ancient diets (see, *e.g.*, Sallares 1991; Isager and Skydsgaard 1992; Decker 2009). In other cases—say, coniferous trees, deciduous trees, and grasses—our interpretation of these trends will follow from important insights of environmental history. Methodologically, this paper extends the contribution of Izdebski *et al.* (2016a) in two main directions. First, we present a new method of estimating our regional trends of interest, based on simple panel data models and estimators. Second, unlike Izdebski *et al.* (2016a), we discuss inference on these trends and construct confidence intervals.

Using pollen data to study pre-modern economic history has a number of important advantages. First, unlike previous studies, we have access to a relatively large number of data points from southern Greece and Macedonia, two core regions of the Greco-Roman world.[2] Second, unlike many sources of data which offer a single snapshot from ancient economic history, pollen data allow us to study long-term change in an essential economic activity of ancient communities and to go further back in time than many previous studies. Indeed, in this paper we discuss structural changes in ancient Greek agriculture across sixteen centuries, from 1000 BCE to 600 CE. Third, the methodology of data collection in palynology is standardized; the procedures followed by palynologists are virtually identical from site to site, which is not generally true for archaeological data or ancient textual sources. As von Reden (2014) stated it in her review of Temin (2013): "One of the reasons why historians favor qualitative methods over quantitative ones is the fact that

---

[1] Several papers have also studied the persistence of ancient economic prosperity and urban networks. See, *e.g.*, Chronopoulos *et al.* (2017), Wahl (2017), Dalgaard *et al.* (2018), and Michaels and Rauch (2018). The problem of persistence was also discussed by Barjamovic *et al.* (2017) and Bakker *et al.* (2018).

[2] The one notable exception is Kaiser (2007) who analyzed individual data from Athens to identify determinants of the probability that a citizen had attempted to avoid participation in the provision of a public good. On the other hand, it is particularly suggestive of the scarcity of quantifiable data from ancient Greece that when Takeshi Amemiya, one of the most prominent econometricians of his generation, wrote a book about ancient Greek economic history (Amemiya 2007), the book did not contain a single regression table.

the data involved are both sparse and complex. Nor do we always know the conditions under which they were compiled and recorded, or even ultimately what they mean." In this paper we argue that our data allow us to overcome some of these problems. Finally, in the case of pollen data, it is possible, in principle, to obtain more and more information about regions and time periods that we wish to study. Palynological research is very labor intensive and many potential pollen sites await exploration. When more data become available, it will be possible to replicate existing studies—such as ours—and obtain more efficient estimates. On the other hand, of course, each source of data also has its limitations. In the case of pollen data, we cannot make inferences about the *levels* of economic activity; instead, we focus on the *structure* of agricultural production, as we only observe percentages of pollen attributable to different plant taxa. As we will see later, these proportions, however, will often be informative about general economic and population trends.

Our estimates enable us to establish a number of patterns in the economy of ancient Greece across sixteen centuries. We begin our study with a demonstration that our results are validated by auxiliary data on settlement dynamics (Weiberg *et al.* 2016). Based on insights from environmental history, we know that population growth should coincide with a decrease in the relative importance of forest trees and grasses. Clearly, growing populations tend to cut down forests and transform uncultivated terrain into fields and pastures. This is exactly what we observe in southern Greece in the Classical period. While there is strong evidence of increased settlement dynamics at this time, we also demonstrate a decrease in the importance of coniferous trees, deciduous trees, and grasses in regional vegetation structure. In fact, the estimated trends in the relative presence of these plant taxa are negatively correlated with the data on settlement dynamics from Weiberg *et al.* (2016) throughout the time frame of our study.

Our results for the Classical period in southern Greece are also suggestive of a particularly interesting development. Despite the population growth, we observe a clear *decrease* in the presence of cereal pollen. We argue that it is not possible to explain this finding without reference to trade, especially since we also observe a simultaneous increase in the relative importance of olive and vine.[3] Southern Greece had a comparative advantage in the production of olive oil and wine as well as a comparative disadvantage in grain. The growing demand for wheat could only have been satisfied by massive grain imports, perhaps from the Black Sea region, which were offset by exports of olive oil and

---

[3] A similar argument was made by Kussmaul (1985) in the context of agricultural change in 17th-century England. She suggested that the increasing specialization of regional economies must have resulted from trade. At a given location, when grain was no longer produced, it had to be imported from elsewhere, as grain consumption had to be sustained.

wine. These commodities were in high demand in, for example, Greek colonies and other neighboring areas—which needed them for cultural reasons but were not always able to produce them locally.

This finding constitutes one of our main contributions to the recent literature on ancient economic history. We corroborate the conclusions of Kessler and Temin (2008), Temin (2013), and many ancient historians, who have argued that markets were central to economic activity in the Greco-Roman world and that these markets were interconnected through trade. Most previous contributions, however, have focused on market integration during the expansion of the Roman Empire. In this paper we argue that this phenomenon can be predated to much earlier periods (cf. Bakker *et al.* 2018). At the same time, we do not dispute the economic impact of the Roman conquest. On the contrary, we demonstrate that the early Roman Empire can be associated with a dramatic increase in the presence of cereal, olive, and vine pollen in southern Greece. In Macedonia, we observe an increase in the relative importance of cereals and a decrease in the presence of olive and vine, which we again interpret through the lens of comparative advantage. However, this process seems to have started—in the case of Macedonia—over 150 years before the Roman conquest, during the times of Philip II and Alexander the Great.

Finally, we demonstrate that our results are consistent with two further sets of auxiliary data. First, we use the data on ancient shipwrecks from Strauss (2013) to show that the early Roman peak in the presence of cereal, olive, and vine pollen in southern Greece coincides with the period to which the greatest number of shipwrecks can be attributed. Second, the data on large-scale oil and wine presses in Gaul, Iberia, and the Black Sea region, introduced by Marzano (2013) and recently discussed by Erdkamp (2016), also reveal a peak that is consistent with our estimates.

The remainder of the paper is organized as follows. Section 2 discusses the historical and historiographical background of our study. Section 3 describes our data and estimation methods. Section 4 discusses our findings. Section 5 compares our results with auxiliary data on shipwrecks and ancient oil and wine presses. Section 6 concludes.

2 Historical Background

The pollen data used in this paper are derived from cored sediments (archives) in the southern Greek mainland, incorporating the Peloponnese and central Greece, and in various locations in the Macedonian region in northern Greece. Both of these regions can be understood as politically significant "core" areas in various phases of the first millennium BCE (Bintliff 1997). After the destruction of Bronze Age palace systems in the Greek mainland in the late 13th century BCE, major transformation occurred in terms of settlement structures and economic systems. From the 11th century onward Greece seems to have been organized through small-scale village systems engaged primarily in subsistence farming. By the 8th century BCE we see evidence of expanding settlements and more expansive land-use systems within large parts of southern mainland. In the eastern part of central Greece and the northeastern Peloponnese, rapid urbanization and development of autonomous and semi-autonomous city-states (*poleis*) occurs from the late 8th century BCE and onward with particular landscape developments occurring between the end of the Persian Wars in 480 BCE and the death of Alexander the Great in 323 BCE. By the late 4th century BCE, the southern mainland was a densely populated region of the Mediterranean dominated by urban communities comprised to a large extent of citizen farmers. It is also in the second half of the 4th century BCE that we can observe the growing importance of the Macedonian kingdom in the northern mainland. By the death of Alexander, Macedonia would control territories in all of the Greek mainland as well as regions formerly incorporated in the Achaemenid Persian Empire. In the 3rd and early 2nd century BCE, the Macedonian kingdom under the Antigonid dynasty would continue to dominate parts of the Greek mainland, though large areas of southern Greece were also controlled by Leagues of cities in Achaea and Aetolia, which incorporated agriculturally-based urban communities into broader federal political units.

By the early 2nd century BCE, Rome became increasingly involved in political and military affairs in the Greek mainland. In 168 BCE the Antigonid king Perseus was defeated at the battle of Pydna, with the subsequent establishment of the Roman province of Macedonia in the northern mainland. In 146 BCE the Achaean League was dismantled in the Peloponnese and the city of Corinth was destroyed by the Roman general Lucius Mummius. Further Roman military incursions in southern Greece occurred in 88 BCE following the war with Mithridates leading to the sacking of prominent Greek cities, such as Athens, by the Roman general Sulla. A formal imperial province of Achaea was established in southern Greece in 27 BCE but by then this part of Greece had already been under strong Roman political and military influence for over a century. In the following period, Greece was consolidated as part of imperial political and economic structures, without a strong military presence (Alcock 1993). By late antiquity the area of Greece started to become a more economically significant region, especially after seemingly destructive incursions of barbarian tribes in the 3rd century CE. In this context, rural developments in the Greek mainland seem to have taken place after the re-foundation of Constantinople (former Byzantion) as the new capital of the Eastern Roman Empire in 330 CE. The foundation of the city brought the landscapes and agricultural production systems of mainland Greece closer to the urban markets of the new imperial capital, prompting transformation of rural settlement structures and landownership.

This outline of political dynamics and geopolitical transformations highlights a process of shifting—but generally increasing—political integration with surrounding regions. Thus, the two regions examined in this paper—southern Greece and Macedonia—provide us with an opportunity to examine the possible environmental impact of market integration and its role in landscape change through transformation of the structure of agricultural production. Market integration during these periods can be characterized by regional markets that hitherto had no significant connection, but which become increasingly dependent on each other. Such market interdependencies can result in regional specialization in certain crops and other commodities.

The Ancient Economy as a Market Economy

Recent research has emphasized the degree to which ancient economies can be compared with early modern market economies. Economists, historians, and archaeologists specializing in the ancient world have argued that both the standard of living and the level of growth in the early Roman Empire were only surpassed by economic developments in 18th- and 19th-century Europe (Temin 2001, 2006a,b, 2013; Kron 2014; Erdkamp 2016). The interest in growth and performance as well as the broad characterization of the ancient economy as a market economy provide a break with the older trend in ancient economic history, dominant in the second half of the 20th century, of examining primarily the structure and social embedding of ancient economies. Early substantivist approaches, represented above all by Finley (1973), maintained that research on the performance of Greco-Roman economies was a dead end as the idea of economic performance was based on modern concepts which could not be applied to the study of ancient production and distribution systems. Such substantivist scholarship was further critical of the use of quantitative evidence for examining the structure of ancient economic systems as well as the performance of these systems, given the lack of available data. Finley argued that while some aggregated growth had occurred in antiquity, this had primarily been the result of demographic developments and had been very limited compared to recorded growth in early modern Europe. According to this view, markets existed but were not sufficiently integrated to be compared with those of later periods nor did they play a major role within the ancient economy as a whole.

In recent decades, this view of the ancient economy has been challenged by both historians and archaeologists, using both qualitative approaches and new quantitative data to explore aspects of both aggregate and per capita growth as well as the significant role of markets. The recognition of the sheer volumes of goods moved along regional and long-distance trade routes serves as evidence of the dynamic impact of market economies within the ancient Mediterranean.[4] Recent research has further stressed the link between markets, economic growth, and the impact of institutional developments, following the approaches of North (1990) and new institutional economics (see, *e.g.*, Scheidel *et al.* 2007; Bang 2009; Wilson and Bowman 2018). Indeed, in recent years, the Roman period has been characterized as a globalized society and economy due to the high degree of connectivity and integration suggested by both written and material sources (Hingley 2005; Geraghty 2007; Pitts and Versluys 2015). New models have at the same time been used to highlight general features of, for example, the Roman imperial economy as a pre-industrial market economy (Temin 2013).

Market Economies and Market Integration

An aspect which has been intensively debated in recent work is the degree of market integration and its effects on price fluctuations, agricultural production, and growth. In this context, Kessler and Temin argued that in the early Roman Empire the price of grain had been affected by the distance from Rome (Kessler and Temin 2008) and the integration of markets had been facilitated by imperial institutions (Kessler and Temin 2007). These studies highlight both a high degree of monetization and regularities in the price setting of grain within markets connected through imperial boundaries and well-traveled sea routes. At a basic level, market integration can be examined on the basis of trade in staple and food commodities directed at significant urban centers outside the producer region. In the early Imperial period, the capital at Rome would be a substantial consumption center for grain and other foodstuffs produced throughout the Roman Empire. Although some of these staples would be moved and distributed as part of government initiative, such as the *annona*, much would also be sold and transferred through markets and market sale (Temin 2001; Kessler and Temin 2007). Markets for agricultural products in the largest urban centers would attract commodities such as grain and wine from wider regions and would stimulate agricultural production throughout the empire.

While the scale of market exchange was larger in the early Imperial period, it can be argued that a high degree of connectivity and market integration had existed well before

---

[4] For a recent discussion of trade and the movement of goods in the Roman Empire, see the introductory chapter and various entries in Wilson and Bowman (2018). For earlier research on this topic through both archaeological evidence and historical texts, see Tchernia (1986), Woolf (1992), Erdkamp (2005), Kessler and Temin (2007), and Temin (2013).

the expansion of Roman power in the Mediterranean, though the evidence is less direct. The work of Horden and Purcell (2000) on ecology, environmental fragmentation, and microregional production strategies in the ancient and medieval Mediterranean stressed the role of connectivity as a way of countering risks in agricultural production. Although the focus of Horden and Purcell was primarily on small-scale transfers and exchanges through *cabotage*, the idea of fragmentation and connectivity emphasizes the degree to which markets could be increasingly interlinked both by economic developments and environmental impact. Environmental fragmentation could therefore have stimulated market integration and market-oriented production strategies even in a non-imperial setting. Both literary sources and inscriptions provide us with examples of grain transfers occurring over significant distances to major urban centers, such as Athens, already in the Classical period (Pounds 1973; Krotscheck 2006; Möller 2007; Moreno 2007; Bresson 2011, 2016). Bresson also argued for the increasing integration of markets facilitated by city-state/*polis* economies in the 5th, 4th, and 3rd centuries BCE, affecting the fluctuations of grain prices and occasional specialization of crop production (Bresson 2016).[5] Archaeological evidence also points to trade in food commodities (not just olive oil and wine) at quite long distances in the Classical period (Munn 2003), presenting a possible case for market integration in a wide geographical context already in the 5th century BCE. Earlier evidence, namely a positive relationship between the connectedness of points on the Mediterranean coast and the settlement density from *c.* 750 BCE, was also presented by Bakker *et al.* (2018).

In light of political developments in the Hellenistic period (3rd and 2nd centuries BCE) we should perhaps expect it to be associated with increasing market integration affecting production strategies, as both Greek city-states and former regions of the Persian empire were incorporated into new successor kingdoms after the death of Alexander the Great. During this period, we can also observe the growth of federal states (*koina*) consisting of multiple city-states, which facilitated the pooling of physical and agricultural resources in broader areas of the Greek mainland (Mackil 2013, 2015). We can therefore assume a higher degree of market integration compared to the preceding Archaic and Classical periods (*c.* 700–323 BCE), which were largely characterized by autonomous urban units populated by citizen farmers. This was also one of the conclusions reached by Rostovtzeff (1941), who emphasized the degree to which the Hellenistic economy was structured through increasingly integrated market systems in the Eastern Mediterranean and the Near East. Archaeological evidence further demonstrates the presence of large

---

[5] For a discussion of the significant role of markets in the Archaic, Classical, and Hellenistic Greek world, see also various entries in the recent volume edited by Harris *et al.* (2016).

agricultural estates in the Hellenistic period that clearly seem to have produced cash crops (*e.g.*, oil and wine) at high volumes intended for market sale (Margaritis 2016). The research carried out by Reger (1994, 2002) on the price setting of commodities on the island of Delos in the 3rd and 2nd centuries BCE nevertheless suggests a primarily local context for distribution and shifts in prices, with no immediate effects of integration with areas further east. Of course, this analysis of commodity prices in Delos is a very specific case study, despite the function of Delos as a major trading hub in the Hellenistic Aegean. This evidence cannot therefore be used to downplay market integration and its impact on agricultural production during the Hellenistic period, but it nevertheless highlights the complexities involved and the need for new data (Reger 2007, pp. 469–470), particularly on market integration, agricultural production strategies, and landscape change.

Market Integration, Agricultural Production, and Landscape Dynamics

Agriculture was fundamental for the Greco-Roman society. It provided for the basic subsistence strategies of urban and rural communities. At the same time, production could also be directed at markets through cash crops and surplus food commodities. In this paper we examine agricultural developments in the Greek mainland during a period of significant urbanization (between *c.* 600 and 300 BCE) and in periods of economic restructuring influenced by Macedonian rulers and federal political units (between *c.* 300 and 146 BCE) as well as the subsequent Roman conquest (in 146 BCE). Utilizing this long-term perspective on agricultural dynamics, we focus on two key regions: the southern Greek mainland—including the Peloponnese, Attica, and central Greece—and Macedonia. These areas are very rich in pollen data and provide us with an opportunity to explore socioeconomic transformation and dynamics in agricultural production. From the Classical period onward, the region provides us with a substantial wealth in textual sources which can provide evidence on modes and aspects of production, consumption, and distribution.

But there are limits to what the historical texts can provide. Only occasionally do the texts provide quantitative information and—generally for the Greek mainland—such data are anyway very scarce. Archaeology can in these instances supply us with further evidence on agricultural dynamics. For more than a century, mainland Greece has been subject to significant archaeological fieldwork and research, including excavation of both large settlement sites and smaller localities in a wide range of landscape settings. Advances in the methods of systematic archaeological survey over the past forty years have allowed for accumulation of further evidence on settlement dynamics and use of the rural landscapes (see, *e.g.*, Bintliff and Snodgrass 1985, 1988; Jameson *et al.* 1994; Wells 1996; Alcock *et al.* 2005; Caraher *et al.* 2006; Bintliff *et al.* 2007).

The late Hellenistic and Roman periods in mainland Greece provide a very interesting case study on landscape dynamics and economic shifts, as we can infer from several different sources. The increasing volume of archaeological research on Roman Greece has highlighted the changes occurring in landownership and economic organization of the Greek countryside. In her seminal study of the landscapes in the Roman province of Achaea, Alcock (1993) argued that dominant landlords had established larger estates focused on cash crop production in the Greek countryside, at the expense of smaller landholdings common in the Archaic to early Hellenistic periods. Written sources suggest that such changes in landownership and economic structures would in particular have accelerated with the establishment of Roman colonies and the provincial organization of Augustus in the late 1st century BCE (Rizakis 2014, pp. 243–245).

This model has to a certain extent also been highlighted by more recent investigations. Bintliff (2008, 2012b, 2013, 2014) emphasized that these changes had started to occur in the later Hellenistic period, due both to geopolitical shifts and increasing integration with non-local markets, followed by more rapid reorganization of the countryside in the Roman period. Bintliff also argued that the Roman period had seen an influx of "proto-capitalist" agents (such as *negotiatores* and freedmen) residing in the cities of the Greek mainland, facilitating trade in cash crops and other commodities produced on elite estates (Bintliff 2013, 2014). The significance of new elite landowners and market production can in particular be demonstrated in regions connected to urban centers, such as the colonies established at Corinth and Patras, while other areas of Roman Achaea seem to have suffered from population decline and land abandonment in the early Imperial period, a picture which is more or less corroborated by available archaeological survey data (Rizakis 2013, 2014). Investment in larger estates and *villae rusticae* aimed at market-oriented agricultural production would constitute a significant economic strategy of urban elites residing in the province. The new political structures enforced by the Roman rule would further open up the possibilities of landownership beyond the local community, thus making land investments attractive for groups such as merchants and wealthy freedmen (Rizakis 2013, p. 25; Kay 2014, pp. 139–140).

An established hypothesis is thus that market integration accelerated during the late Hellenistic and Roman periods due to the new imperial framework, resulting in significant landscape change through new landownership and economic structures. These changes led to increasing specialization and cash crop production at a scale not observed in previous periods, particularly from the late 1st century BCE and onward through land restructuring implemented by imperial authorities. Most scholars would therefore emphasize a large degree of market integration during the later Hellenistic and Roman periods, with more local distribution patterns, market integration, and a lower level of cash cropping and market-oriented agricultural production for the Archaic to early Hellenistic periods. To test this hypothesis, we need to examine changes in agricultural production throughout these periods. Although the archaeological record helps to outline rural and urban dynamics and shifts in settlements, it offers little data on changes in agricultural output and the importance of different crops over time. In this paper we argue that pollen records can provide us with exactly this: quantitative data that can be used to test our hypothesis and to identify significant shifts in agricultural production strategies visible through changes in vegetation cover in two regions of mainland Greece.

3 Data and Method

Environmental historians were the first to observe the direct connection between economic phenomena and landscape change. Environmental history as a field is based on the observation that nature is part of human history and thus it is transformed in parallel to the ways in which societies themselves evolve (Worster 1990; Merchant 1997). In their studies of the 19th- and early 20th-century American economic growth, Worster (1979) and Cronon (1991) showed that the development of capitalism had led to large-scale landscape change in many parts of central North America, and on the Central Plains in particular. The same holds true for earlier periods and places in US history, such as colonial New England. In this case, the emergence of commodified agriculture, integrated with markets in other European colonies around the Atlantic and in Europe itself, resulted in a complete destruction of the old landscape and the creation of new European-style ecosystems dominated by intensive agriculture (Cronon 1983; Merchant 1989). In fact, similar processes were occurring at the same time in other parts of the world, as demonstrated by Richards (2003) in his study of the global environmental history of the early modern world.[6] In the case of Europe, there is no doubt that such phenomena were occurring already much earlier, when Europe's economic system was developing in the Middle Ages, as argued by Hoffmann (2014) in his recent survey of medieval environmental history.

The ideas that environmental historians started developing almost half a century ago have recently gained popularity among evolutionary biologists and environmental archaeologists. The ecological niche construction theory, one of the cornerstones of the

---

[6] See also Crosby (1986) for a discussion of the consequences that new ecological connections between hitherto isolated regions—also through market integration—had for the local landscapes.

modern theory of evolution, places special emphasis on the capability of the human species to develop its own ecological niches in almost any conditions (Kendal *et al.* 2011). Contrary to other animals, humans are uniquely capable not only of transforming parts of the ecosystems in which they live but also of transforming and creating entire landscapes that consist of multiple ecosystems. The construction and maintenance of these complex ecological niches is part of human culture, and as such is related to the human productive behavior and exchange patterns (Laland and O'Brien 2010; Boivin *et al.* 2016).

The same phenomenon—the direct connection between economic activity and landscape change—has also been explored within the field of landscape studies. Among the different drivers of landscape change, socioeconomic forces have been singled out as the key factor, along with technological change (Bürgi *et al.* 2005). As demonstrated by Lieskovský and Bürgi (2018), crops and grasslands are the least resistant elements in any European landscape, as they are highly responsive to social and economic change. Several regional studies, such as a recent paper by Munteanu *et al.* (2014) on the landscapes of the Carpathians, have demonstrated that agricultural expansion and forest transformation are always related to changes that occur in local and regional economic systems.

In other words, several different disciplines of both the social and natural sciences have concluded that changes in economic systems, in particular the integration of isolated regions with new distant markets, lead to a number of transformations in the local landscapes. These include:

- changes in the composition of the cultivated species and in the relative importance of the associated ecosystems within the general regional landscape;
- the conquest of new land or abandonment of the existing fields and pastures, *i.e.* increases or decreases in anthropogenic pressure (the scale of the human exploitation of the landscape);
- increases in the focus on specific crops, usually those most adapted to local conditions and hence guaranteeing the highest yields, going as far as mono-cropping in modern economic systems;
- the introduction of new or even exotic species as a result of agricultural experimentation that responds to the demand observed in distant markets.

Importantly, it is generally possible to reconstruct these transformations in the local landscapes using pollen data, which we will now discuss.

Data

The study of pollen in lake and peat sediments, known as palynology, is one of the most detailed and reliable ways of studying landscape change in the past. Palynologists study pollen found in sediment cores taken from lakes, lagoons, peat bogs, and other anaerobic environments, where the organic material can be preserved for thousands of years. In each core, researchers take samples at regular intervals, ranging from a few millimeters to a dozen centimeters, depending on the core length and the desired temporal resolution of the final reconstruction. These samples are then processed in a laboratory in a way that allows the counting of pollen grains within each sample. In this way, a researcher gets snapshots of the vegetation structure surrounding a given site at a certain moment in time.[7] The sequence of such snapshots, or, more precisely, pollen assemblages, builds a pollen profile, which provides a detailed image of the landscape change in a given locality over time. For a more detailed discussion of palynology and its use for historians and economic historians, see Eastwood (2006), Izdebski (2013b), and Izdebski *et al.* (2016a).[8]

This relative pollen-based reconstruction of landscape change needs to be tied to historical time, and this is typically achieved by the means of radiocarbon (14C) dating. Usually, despite the fact that a pollen profile consists of at least one sample per a hundred years, only a few of these samples are actually radiocarbon dated. The number of radiocarbon dates is limited by their cost—much higher in the past than today—and the availability of organic matter—necessary for dating—in the cored sediments themselves. Moreover, as is the case with any laboratory measurement, the radiocarbon dating involves an error, expressed in confidence intervals. This error is further modified by the process of calibration. In this process, researchers recalculate raw radiocarbon dates into calendar years that take account of the annual and secular differences in solar activity.[9] In the end, using the radiocarbon dates obtained for a few core samples, researchers estimate the age of all the remaining samples with the use of formal models that approximate the process of sediment formation over time (Blaauw 2010).

Most of the palynological data for Europe are available online in the European Pollen

---

[7] The exact spatial representativeness of pollen data from a single site depends on the type of the site and the type of pollen. For example, pine and olive pollen can travel up to fifty kilometers, while cereal and vine pollen travels only a few kilometers.

[8] There is a long tradition in economic history of using knowledge from various scientific disciplines to answer historical questions. For example, Carlos and Lewis (1993) used a model of biological resource extraction to simulate the stock of beaver in the hinterlands of three Hudson's Bay Company posts. Then, they compared the simulated time series with the (known) time series of fur prices.

[9] The energy from the sun is the physical force behind the process of the 14C creation in the upper layers of the atmosphere. Thus, it determines the changing amounts of the 14C in the atmosphere and in the living organisms which take the 14C with breathing and whose remains provide the material for the dating.

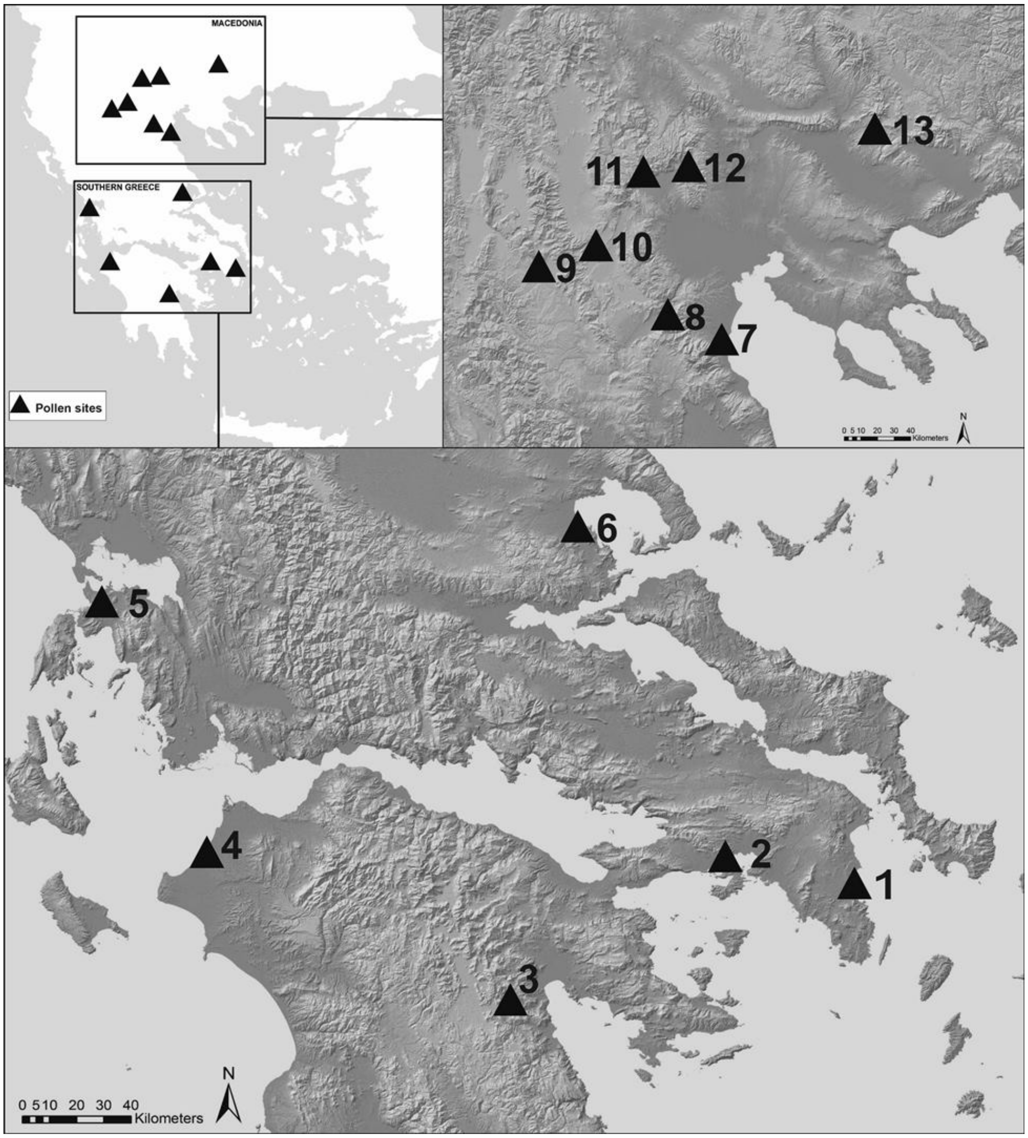


Figure 1: Pollen sites in southern Greece and Macedonia

Notes: The map has been created using the ASTER GDEM, a product of METI and NASA.

Database (EPD; Fyfe *et al.* 2009).[10] For the purpose of this paper, we select sites from Greece whose pollen profiles cover our period of study (1000 BCE–600 CE). Apart from using the data available in the EPD, we have also made efforts to contact all investigators whose data are not published in the EPD, and as a result our analysis is based on all the relevant palynological data available for Greece as of January 2018. As is visible in Figure 1, our sites cluster in two different regions, namely in mainland southern Greece—primarily composed of regions bordering the Gulf of Corinth—and historical Macedonia

---

[10] See `http://www.europeanpollendatabase.net/`, as of January 2018.

Table 1: Pollen sites in southern Greece and Macedonia

ID	Site name	Latitude	Longitude	Original publication	Age-depth model
	Southern Greece				
1	Vravron	37.92	24	Kouli (2012)	Triantaphyllou *et al.* (2010), Weiberg *et al.* (2016)
2	Elefsina	37.99361	21.30639	Kyrikou (2016)	Kouli *et al.* (2016)
3	Lerna	37.5	22.58333	Jahns (1993)	Izdebski *et al.* (2015)
4	Kotychi	38.01389	23.46333	Lazarova *et al.* (2012)	Weiberg *et al.* (2016)
5	Voulkaria	38.86667	20.83333	Jahns (2005)	Izdebski *et al.* (2015)
6	Halos	39.16667	22.83333	Bottema (1974)	Izdebski *et al.* (2015)
	Macedonia				
7	Litochoro	40.138	22.546	Athanasiadis (1975)	EPD cal BP model by S. Panajiotidis
8	Flambouro	40.259	22.171	Gerasimidis and Athanasiadis (1995)	Gerasimidis and Panajiotidis (2010)
9	Orestias	40.5	21.25	Kouli and Dermitzakis (2010)	Kouli and Dermitzakis (2010)
10	Khimaditis Ib	40.616	21.583	Bottema (1974)	Izdebski *et al.* (2015)
11	Mount Voras	41.02	21.91	Gerasimidis and Athanasiadis (1995)	Gerasimidis *et al.* (2009)
12	Mount Paiko	41.052	22.275	Gerasimidis and Athanasiadis (1995)	Gerasimidis *et al.* (2008)
13	Lailias	41.266	23.6	Gerasimidis and Athanasiadis (1995)	Gerasimidis and Athanasiadis (1995)

Notes: Site identifiers correspond to those in Figure 1.

(modern northern Greece). In the case of this latter region, our sites are located in highlands surrounding the plain of Thessaloniki in the west and the lower Strymon Valley in the east. It is worth emphasizing that both clusters are relatively homogeneous in terms of the type of sites, including their height a.s.l.: the southern cluster consists of more or less lowland sites, while the northern cluster is dominated by highland locations.

Moreover, for a pollen core to be included in our data set, it is not enough that it contains information about our period of interest. It also needs to be of satisfactory chronological reliability, so that the inferences we make about specific periods or centuries are not biased by errors of age estimation within a single core. Consequently, our data set includes only those pollen cores which are provided with at least one radiocarbon date for the last three and a half millennia. Fortunately, the majority of our sites have at least one radiocarbon date for the period we are interested in, which significantly increases the credibility of our results. Since several of our sites were originally analyzed more than two decades ago, we use new age-depth models that were recently developed in a study of the medieval economic history of these and neighboring regions (Izdebski *et al.* 2015). In Table 1, we present the location and bibliographical information about each site we use, including the source of each of the age-depth models we rely on for individual sites. The total number of samples in our data set is 160, with an average of 3.5 per century in Macedonia and 6.5 per century in southern Greece. Each sample documents the whole structure of vegetation around a given site at a particular point in time.

Pollen data are never interpreted as raw counts. Rather, one follows the change in percentage values for individual plant taxa from one sample to another, or studies the change in the overall composition of the sample. A plant taxon can be a species, a family, or a genus, depending on how precise a palynologist's attribution for a given pollen grain can be; some plants are identifiable to the level of a species (*e.g.*, olive), while others are grouped in more general categories (*e.g.*, grasses). For each sample, different amounts of pollen grains are counted, and this depends in particular on the preservation of the pollen itself. These percentage values are therefore calculated against the total sum of all pollen grains identified in a given sample. In this paper the pollen sum includes trees, shrubs, and herbs, unless the original investigator of a given site recommended exclusion of some taxa from the total sum (*e.g.*, local marsh vegetation); this sum also excludes unidentifiable pollen grains and non-pollen material. Although the pollen sum includes all the standard taxa, our analyses are focused on the anthropogenic indicators, as well as on the most important arboreal taxa.[11]

Method

Since palynological research typically focuses on local phenomena—a single site or a small number of neighboring sites—our interest in regional vegetation change requires the use of methods from outside the standard palynological tool kit. In this paper we use two methods of analyzing our pollen data. The first method ("weighting"), which was proposed and discussed in detail by Izdebski *et al.* (2016a), consists of three steps. In the first step, we use linear spline functions to interpolate missing observations for each site and each plant taxon. This step is necessary because there is limited overlap across sites in calendar years for which some measurements are available. In the second step, we smooth each time series with a low-pass filter or, specifically, with the Hodrick–Prescott filter; if necessary, we also impute the missing observations at the beginning and at the end of each time series.[12] We use y_{it} to denote the (transformed) percentage of pollen grains for a given plant taxon at site i in year t on a scale from 0 to 100. In the third step, we reweight observations from all sites within a given region to obtain a single estimate

---

[11] In some rare instances, such as olives in Macedonia, information about some plant taxa is missing from some sites in a given region.

[12] Izdebski *et al.* (2016a) suggested smoothing site-specific trends to erase high-frequency fluctuations from the time series, as they might potentially be attributed to measurement error. In practice, most pollen sites do not have sufficient frequency for this adjustment to make a difference. In this paper all site-specific trends are practically identical before and after smoothing.

of the regional trend. In other words, we postulate that

$$y_{jt} = \sum_{i \in \omega_j} y_{it} \cdot w_{it} \tag{1}$$

where y_{jt} is the regional trend for a given plant taxon in region j and year t, ω_j is the set of all pollen sites in region j, and our weights, w_{it}, are allowed to differ across i and t. In fact, the weights that we use are decreasing in both the spatial distance, ρ_{ij}, and the time distance, ψ_{it}. While the spatial distance is simply the Euclidean distance between a given site and the centroid of the corresponding region, the time distance is defined as the number of years between a given date and the nearest date for which pollen data were originally available at a given site (*i.e.*, before interpolation).[13] In this way, we decrease the relative importance of interpolated measurements. Formally, we postulate that

$$w_{it} \propto (1 - \theta) \cdot \rho_{ij}^{-\alpha} + \theta \cdot \psi_{it}^{-\beta} \tag{2}$$

where $\alpha \geq 0$, $\beta \geq 0$, and $\theta \in [0, 1]$ are free parameters. We use leave-one-out cross validation to choose the optimal values of α, β, and θ.[14]

One disadvantage of this method is that it is not straightforward to determine how to perform statistical inference on our regional trends. Hence, in this paper we also use an alternative method ("regression"), which was not discussed by Izdebski *et al.* (2016a). Namely, we estimate panel data models which have a simple form:

$$\log(y_{it} + 1) = \sum_{k=1}^{K} \tau_k t^k + c_i + u_{it} \tag{3}$$

where c_i is the individual effect of a given site and u_{it} is the error term. In this way, we approximate our regional trends of interest using flexible polynomials in time. We estimate our models using ordinary least squares—treating the individual effects as parameters to be estimated—and we choose K, the degree of our polynomial, using the Akaike information criterion (AIC). Inference in such models is straightforward; we calculate standard

---

[13] As centroids, we use the arbitrary locations of (38.09°N, 22.46°E) for southern Greece and (41.05°N, 23.00°E) for Macedonia.

[14] We use a grid search and consider the following values for the respective three parameters: $\alpha = 0, 0.1, 0.2, \ldots, 3.9, 4$; $\beta = 0, 0.1, 0.2, \ldots, 0.9, 1$; and $\theta = 0, 0.1, 0.2, \ldots, 0.9, 1$. For southern Greece, this procedure has resulted in the following values of the parameters: $\alpha = 1.4$; $\beta = 0$; and $\theta = 0.3$. For Macedonia, the values are: $\alpha = 2.8$; $\beta = 0$; and $\theta = 0.5$. Following Izdebski *et al.* (2016a), we also control for the chronological quality of each site. We use the values of the quality indexes from Izdebski *et al.* (2015). Unlike Izdebski *et al.* (2016a), we do not attempt to correct our estimates using the pollen productivity of different plants, as we do not compare the relative importance of different cultivars. None of our results in this paper could be in any way affected by this correction.

errors using the Newey–West estimator with a maximum lag of 50 years. Finally, it is important to note that in this framework all sites within a region share a common trend and differ only by an additive constant, c_i. To make regression estimates roughly comparable to weighting estimates, we estimate regional trends as convex combinations of site-specific estimated trends, with weights inversely proportional to ρ_{ij}. Clearly, this only amounts to shifting our regional trends up or down in the intercept—but does not in any way affect their overall shape and our interpretation.

4 Empirical Results

Prior to discussing our results in the context of our hypotheses (presented in Section 2), we comment on their overall robustness and reliability. Unlike Izdebski *et al.* (2016a), we use two different methods—weighting and regression—for estimating our trends in the presence of all plant taxa of interest (see Section 3). While we focus on regression-based estimates in the body of the paper, we present the results of both approaches in the Appendix, where we provide figures with both trend estimates and the confidence intervals for every taxon discussed in this paper.[15] A comparison of the results obtained with weighting and regression leaves no doubt about the interpretation of our trend estimates. There are only minimal differences in the timing and the scale of change in specific plant taxa, and no meaningful differences if the overall structural change in the landscape, involving a number of different plant groups, is considered.

As a more general check on the reliability of our results we also consider comparisons of these estimates with auxiliary sources of data. In this section we compare our trend estimates for selected plant taxa with data from independent archaeological investigations which allow us to approximate demographic change and anthropogenic pressure in the Peloponnese. We return to such comparisons in Section 5, where we compare our main results with data on Mediterranean shipwrecks and ancient oil and wine presses.

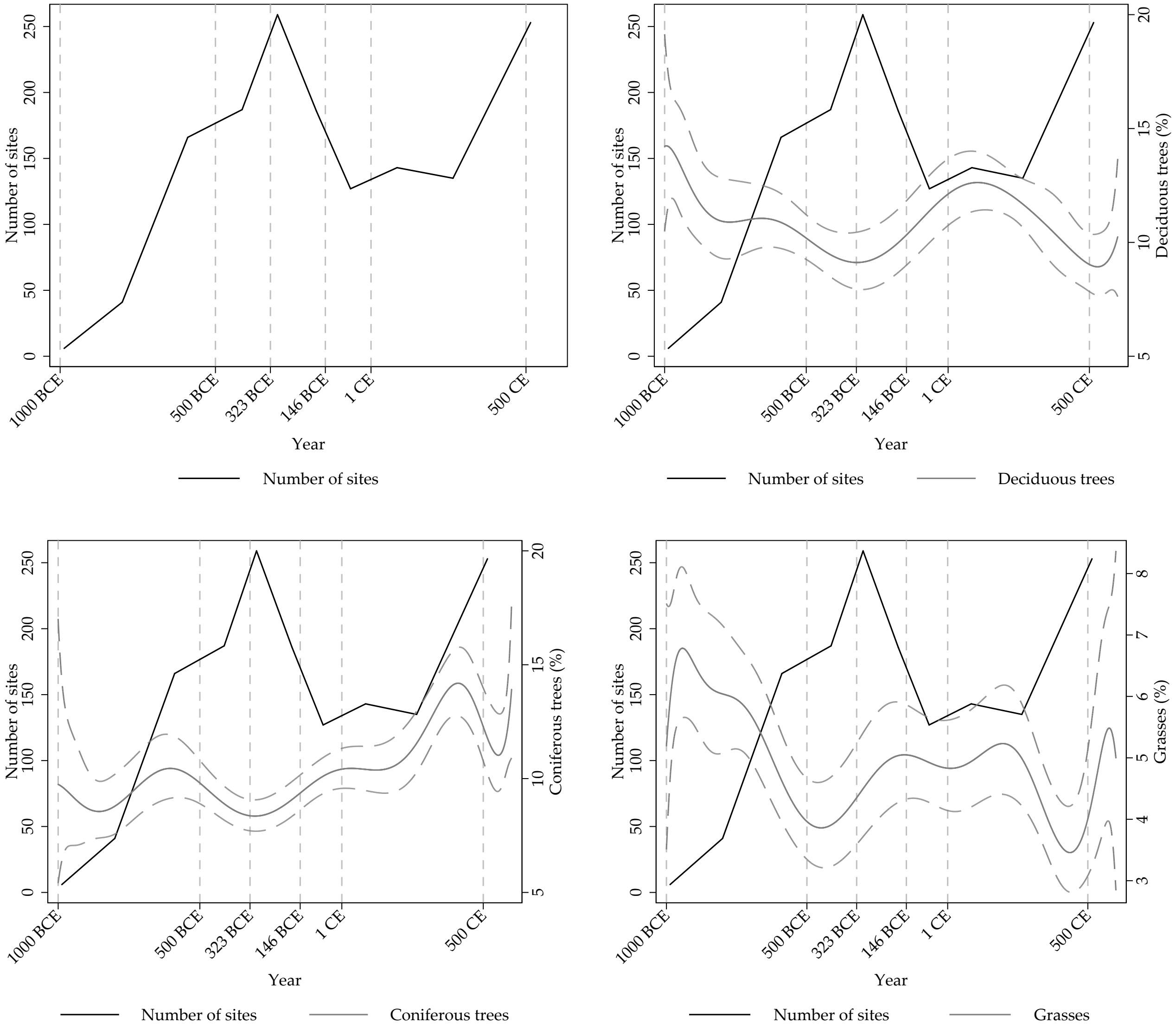
Validating the Methodology

Figure 2 presents a comparison of two different sources of data—environmental and archaeological—that make it possible to approximate the scale of human impact on the landscape of southern Greece. The environmental data are represented by our pollen-based trends. For the purpose of this comparison, we select the summary indicators for

---

[15] Because interpolation leads to an artificial increase in the sample size, it is likely that the actual coverage rates of these confidence intervals are lower than the nominal coverage rate of 95%. Thus, we recommend that our confidence intervals are interpreted with caution.

Figure 2: Pollen data *vs* demography in southern Greece



Notes: The upper left panel displays the total number of sites from archaeological survey projects in the Peloponnese (based on Weiberg *et al.* 2016). The remaining panels compare these data with pollen-based regional trends in the presence of deciduous trees, coniferous trees, and grasses in southern Greece.

the two types of forest dominant in southern Greece—coniferous, consisting of pine and fir, and deciduous, consisting of alder, hazel, hornbeam, and deciduous oak—as well as the grasses.[16] Together, these variables reflect the proportion of land that remained un-

---

[16] There is a slight difference between weighting and regression in how we construct our composite variables for coniferous and deciduous trees. In the case of weighting, we estimate regional trends for each of the underlying plant taxa and sum these estimates. In the case of regression, we construct both of the summary indicators at the level of each site—if some values are missing, we still sum the non-missing

cultivated and did not receive direct inputs of human labor. The archaeological data are represented by the total number of sites from all archaeological survey projects that have been conducted in the Peloponnese since the 1960s (based on Weiberg *et al.* 2016).[17] This variable approximates the overall trend in site density over the major part of southern Greece. Both indicators—our three pollen estimates and the total site count—should be negatively correlated, as an increase in the number and the density of settlements should lead to an increase in human exploitation of the land, and hence reduce the amount of land that is not cultivated (for a discussion of the relationships between surveys and palynology, see Izdebski 2013b and Weiberg *et al.* 2016).

In the case of our study, the expected correlation is evident for all historical periods: whenever we observe an increase in settlement numbers, there is a parallel decrease in uncultivated landscape, and vice versa. The only component of pollen-based trends that is inconsistent with archaeological data is the trend in the relative presence of coniferous trees in the period of *c.* 200–400 CE. At that time, the entire Roman Empire was experiencing a profound political crisis, and Greece was among the provinces that suffered from the barbarian raiding and political instability (Pettegrew 2007; Ziolkowski 2011). The increase in the presence of conifers, which quickly encroach on abandoned fields and pastures in the process of secondary ecological succession, would point to some decrease in the anthropogenic pressure, which, however, did not lead to a major episode of landscape change. Altogether, this comparison of two independent sources of data confirms the validity of our approach in the ancient Greek context: pollen data allow for a very good approximation of human activity and human impact on the landscape.

Pre-Roman Market Integration: Olives and Cereals

As discussed in Section 2, studies of market integration in antiquity have generally been focused on the Roman period. In this paper we are able to extend the study of agricultural production and market integration well into earlier periods, as our data permit the study of vegetation change throughout antiquity. Figures 3 and 4 demonstrate that it is possible to observe very interesting patterns in the structure of the southern Greek and Macedonian agriculture already in the Archaic and Classical periods.[18] For southern Greece, our

---

ones—and estimate regional trends in their presence. This approach allows us to easily construct confidence intervals for these trends. Figure 2 presents our regression estimates and confidence intervals.

[17] Survey projects do not involve excavations but instead focus on examining the land surface for visible remains of ancient rural sites and settlements from different periods.

[18] In Figure 4, and also in some figures that follow, one of the vertical scales includes negative values, even though the presence of plant taxa of interest is measured on a percentage scale. This is because our data include a number of zeros and therefore we cannot use the standard log transformation for our dependent

estimated trends demonstrate that, despite the probable demographic growth visible in Figure 2, cereals played an increasingly smaller role in the southern Greek agriculture and were becoming less and less visible in the landscape (Figure 3). At the same time, the importance of olive cultivation was steadily increasing, leading to the question of why local producers chose to plant olives instead of sowing grains, when the demand for this basic foodstuff must have been mounting.

There are at least two possible explanations of this phenomenon and they do not exclude each other. First, the southern mainland of Greece was developing an export economy based on cash cropping in the later Archaic period, primarily through olive cultivation, which would be consistent with the exploitation of the comparative advantage of this region (for a discussion of ancient olive cultivation and agricultural investment, see Foxhall 2007). Following the Athenian model, cereals were obtained from the Black Sea area (see, *e.g.*, Moreno 2007; Bresson 2016), while olive products were traded on both a local and interregional scale. Beyond the evidence of grain imports from the Black Sea region, we can also find further indications of grain being moved to mainland Greece from other areas of the Mediterranean under various circumstances (Bresson 2011; Bonnier 2016). Local cultivation of grain in the southern Greek mainland would naturally have occurred as part of local subsistence strategies but cash cropping and market production seem to have developed in these regions as well, as is indicated by our estimates. Changes from a basic subsistence economy primarily based on grain cultivation into a system based around more expansive investment in cash crops for export seem to occur already in the early Archaic period, and can potentially be linked with early urban developments taking place from the late 8th and early 7th century BCE onward.

In this context, the high degree of market production in southern Greece is particularly interesting. While much previous emphasis has been given to subsistence farming in the Archaic and Classical Greek world (Finley 1973; Garnsey and Morris 1989; Gallant 1991; Sallares 1991; Isager and Skydsgaard 1992), regional studies have also discussed olive cultivation in the context of broader market production and its effects on landscape developments in the Classical and early Hellenistic periods.[19] Previous arguments for increasing market production have usually been based on evidence from survey data as well as evidence from written sources. Thus, the palynological evidence used in the current study

---

variables; instead, as can be seen in equation (3), we use $\log(y_{it}+1)$, whose inverse, $\exp^{\log(y_{it}+1)} - 1$, can be negative. Such problems with the range of values taken by our estimates only appear in cases where we have many true zeros and/or low overall values of the dependent variable. Moreover, this is of little practical consequence for our empirical results, as we focus on the change in percentage values and not on percentage values themselves.

[19] For the southern Argolid, see van Andel *et al.* (1986). For a critique of the "economic explanation," see Acheson (1997).

Figure 3: Cereals and olive in southern Greece

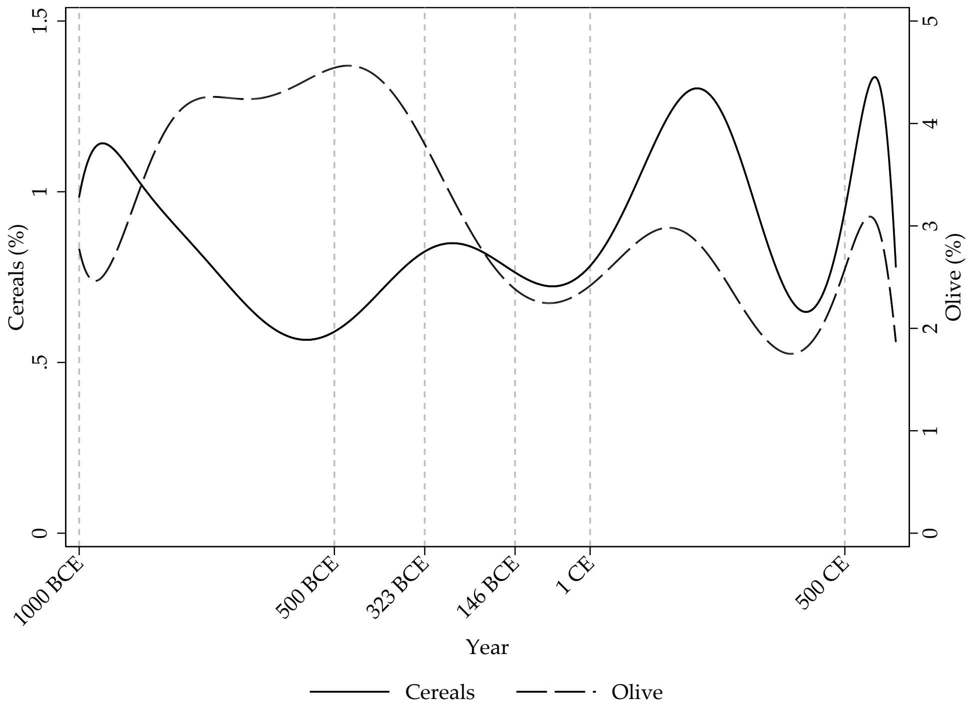
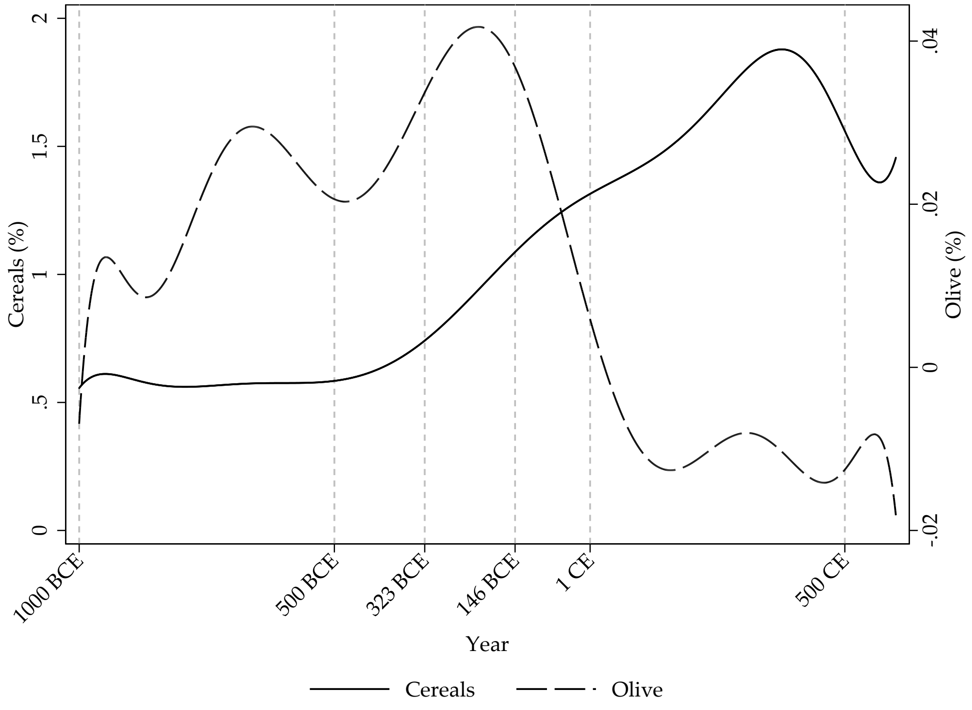


Figure 4: Cereals and olive in Macedonia



adds important new data to our understanding of cash cropping, while highlighting possible pre-Roman market integration in the southern Greek mainland. Investments in cash crops should not, of course, be understood as the sole driver behind landscape change in regions such as the southern Argolid. The palynological data nevertheless suggest a growing importance of olive cultivation which, in turn, suggests that cash cropping may have played a more considerable role in agricultural strategies of southern Greece in the Classical and early Hellenistic periods than was previously suggested.[20]

Second, the relative importance of olive cultivation in the Archaic and Classical periods may also have resulted from an increase in local demand, as the elites of the Greek city-states were increasing its consumption for both dietary and cultural reasons, including sports in the gymnasia. However, even if this were to be a major factor, the parallel decline in cereal cultivation, negatively correlated with the demographic expansion, would require an explanation. The most probable one is that there occurred large-scale imports of grain from other parts of the Mediterranean and the Black Sea littoral (as is suggested by the written evidence), particularly during the Classical period, allowing us to argue for some degree of interregional market integration.

In Macedonia, on the contrary, the trends in the relative presence of cereals and olives do not oppose each other (Figure 4). Rather, one observes a notable increase in olive pollen, which occurred in several phases before the Roman conquest in the 2nd century BCE. In fact, there is archaeological evidence for the introduction of olive cultivation to Macedonia in the middle of the first millennium BCE, and this phenomenon can be linked to the Greek colonization on the northern Aegean coast (Valamoti *et al.* 2018). Our estimates are consistent with these findings, while also showing that the local agriculture responded to the demand for olives and olive oil on the part of the local Greek colonists and perhaps also participated in the emerging Aegean olive oil market. Nevertheless, the abundance of olive pollen in Macedonia is much lower than in southern Greece as a result of the differences in bioclimatic conditions between the two regions (Weiberg *et al.* 2018).

In other words, our results suggest that the landscape change that was occurring in southern Greece and, to a lesser extent, in Macedonia went contrary to what we would expect of a regional subsistence economy and an isolated market. Rather, it is possible that there occurred first signs of interregional market integration with the grain-producing regions of the Mediterranean and the Black Sea area, which allowed for increasing investment and specialization in olive cultivation in Greece itself during the Classical period.

---

[20] Interestingly, the expansion of olive cultivation in southern Greece was most likely encouraged by climatic factors, as this region was becoming increasingly drier over the course of the first half of the first millennium BCE. Such climate conditions made olive cultivation a much more adaptive choice than the cultivation of cereals (Weiberg *et al.* 2016).

The Roman Conquest and Market Integration

A further aim of this paper is to examine the extent to which Greece became integrated into the Roman market economy after it had fallen under imperial rule in the middle of the 2nd century BCE. Our interest in this particular turning point in Greek history is motivated by the emergent consensus in the recent literature that ancient market integration was related to the development of the Roman imperial economy (Temin 2001; Geraghty 2007; Erdkamp 2016). Thus, when discussing our results, we examine whether major changes in the southern Greek and Macedonian landscapes co-occurred with or simply postdated the Roman conquest—and whether in this way they confirm the key role of the Roman imperial expansion for the emergence of integrated markets across the Mediterranean.

Of course, the implementation of new economic structures under the Roman rule was a long process. Thus, any possible correlation of the sociopolitical developments with the environmental dynamics needs to be understood in this respect. The impact of imperial authority on land-use patterns seems to have varied in the different stages of the Roman conquest, as can be inferred from textual sources. According to this model, we can observe an active engagement in the redistribution of land between 146 and 88 BCE, which was followed by more considerable land confiscation—*e.g.*, in regions bordering on the Corinthian Gulf—in the 1st century BCE and 1st century CE (Rizakis 2013, p. 23). Based on this chronological outline, we can expect significant landscape changes after 150 BCE with increasing restructuring of agricultural production from the late 1st century BCE onward. Looking beyond the area of Roman Greece, this period also saw the first climax in seaborne trade and exchange of goods in the Mediterranean, as is visible in the data on ancient shipwrecks (Parker 1992; see also Section 5).

Figures 5 to 8 present our main results for the key cultivated and synanthropic plant taxa.[21] In our interpretations, we focus in particular on the changes that occurred in both southern Greece and Macedonia after 146 BCE, which is the approximate time of the Roman conquest. In southern Greece, 146 BCE seems indeed to be the turning point for the relative importance of the three key Mediterranean cultivars: cereals, olive, and vine (Figure 5). The presence of vine in the southern Greek landscape started to increase around the time of the Roman conquest, in the 2nd century BCE. Olives and cereals started to be grown on a larger scale later on, within 50 to 150 years after the Roman conquest. All three cultivars are estimated to have achieved their highest relative importance within

---

[21] Synanthropic plant taxa, or secondary anthropogenic indicators, are those plants that thrive in ecosystems created by human agriculture, such as weeds of cereal fields and pastures (Behre 1981; Bottema and Woldring 1990).

the southern Greek landscape in the 1st to 2nd century CE, the high moment of the early Roman imperial economy. Interestingly, the presence of chestnut, while relatively stable since the later Classical age, declined in the 2nd century CE, as the Mediterranean triad of cultivars reached the climactic point of their dominance in the agricultural landscape of southern Greece. It is also important to note that, in the Roman period, both olive and cereals shared a similar trend, in contrast to their negative correlation in the Archaic and Classical periods. This would suggest that southern Greek communities were increasingly specialized in the production of agricultural products for export, such as olive oil, wine, and grain (which became the key cash and tax crop). The focus on all three cultivars instead of just olive and vine, whose relative presence was particularly great in the Classical period, could in fact be related to the impact of imperial taxation and tribute extraction. The state activity created both the infrastructural and political framework for market integration, while also exerting additional pressure on the production of grain. For discussions of the importance of grain and the role of tribute extraction in the Roman imperial economy, see Wickham (2005), Bang (2007, 2008, 2009), and Haldon (2016). In this respect, imperial institutions and infrastructures would have helped to both stimulate and facilitate production and transfer of grain for markets, throughout the Greek mainland as well as in other imperial provinces (Hopkins 1980, 2002; Wilson and Bowman 2018, p. 8).

Archaeological field surveys have suggested that many parts of the southern Greek region experienced a substantial drop in the number of smaller rural sites in the Roman period (Alcock 1993; Bintliff 1997, 2008, 2012b), although we can also observe exceptions to this general trend which highlight the importance of local settlement trajectories, particularly in the western Peloponnese (Alcock *et al.* 2005; Stewart 2013). At the same time, several archaeological studies have indicated the development of larger estates in rural areas, which would be consistent with the presence of new elite landowners (Alcock 1993; Bintliff 2008, 2012b; Rizakis 2013, 2014; Stewart 2013). The palynological evidence is therefore interesting. Despite the reduction in rural site numbers in several parts of southern Greece, our estimates are consistent with an increase in agricultural output, particularly of grains and wine.

The importance of grain cultivation is also visible in Figure 6, which shows that the synanthropic plant taxa associated with cereal fields began to increase their presence in southern Greek ecosystems right after the Roman conquest. Of equal interest is the relative decline of the Cichorieae, commonly considered to be a pastoral indicator (Florenzano *et al.* 2015), which suggests that the agriculture of the southern Greek mainland in this period was increasingly focused on the cultivation of the Mediterranean triad. Our

Figure 5: Cultivated plant taxa in southern Greece

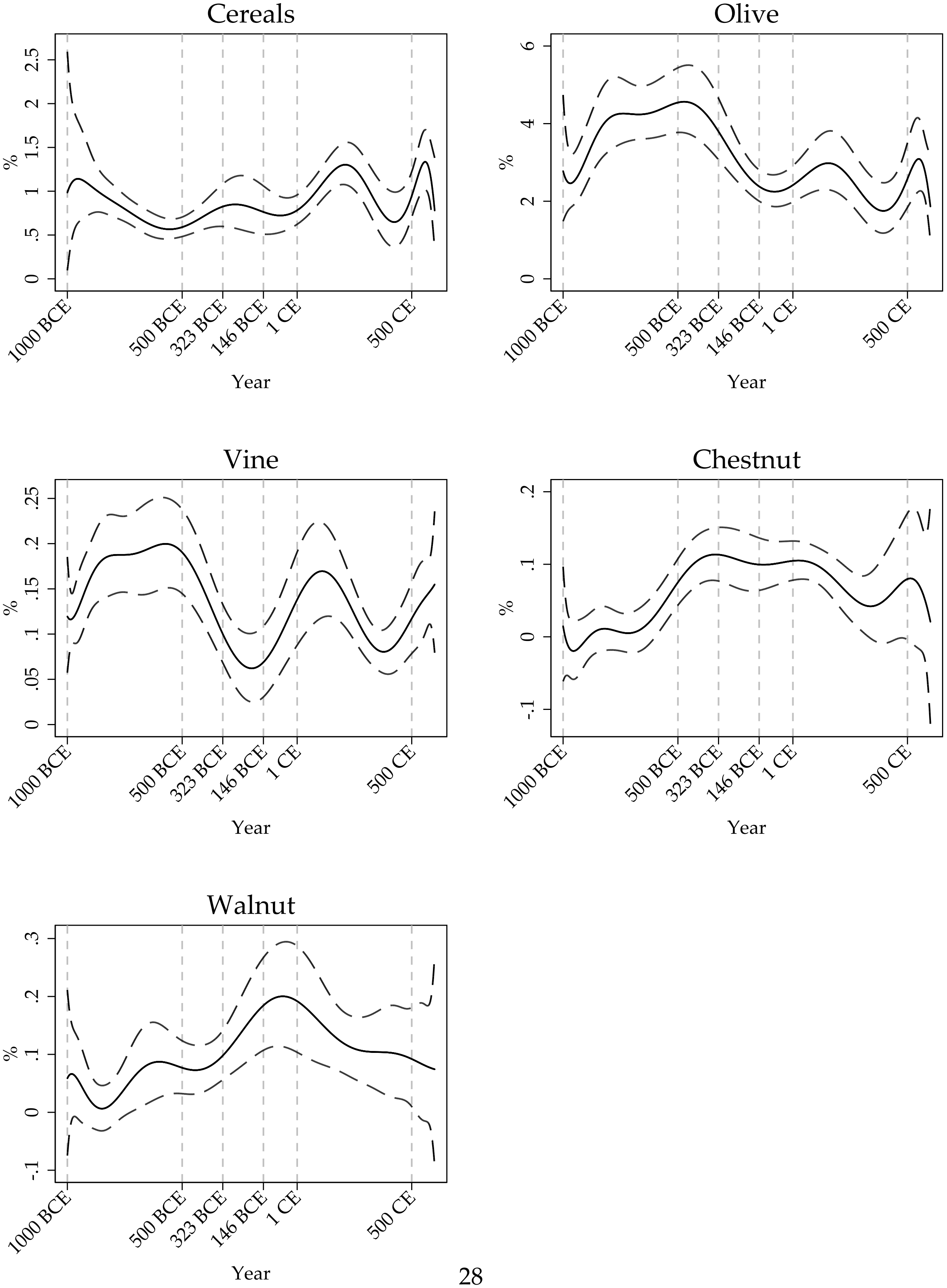
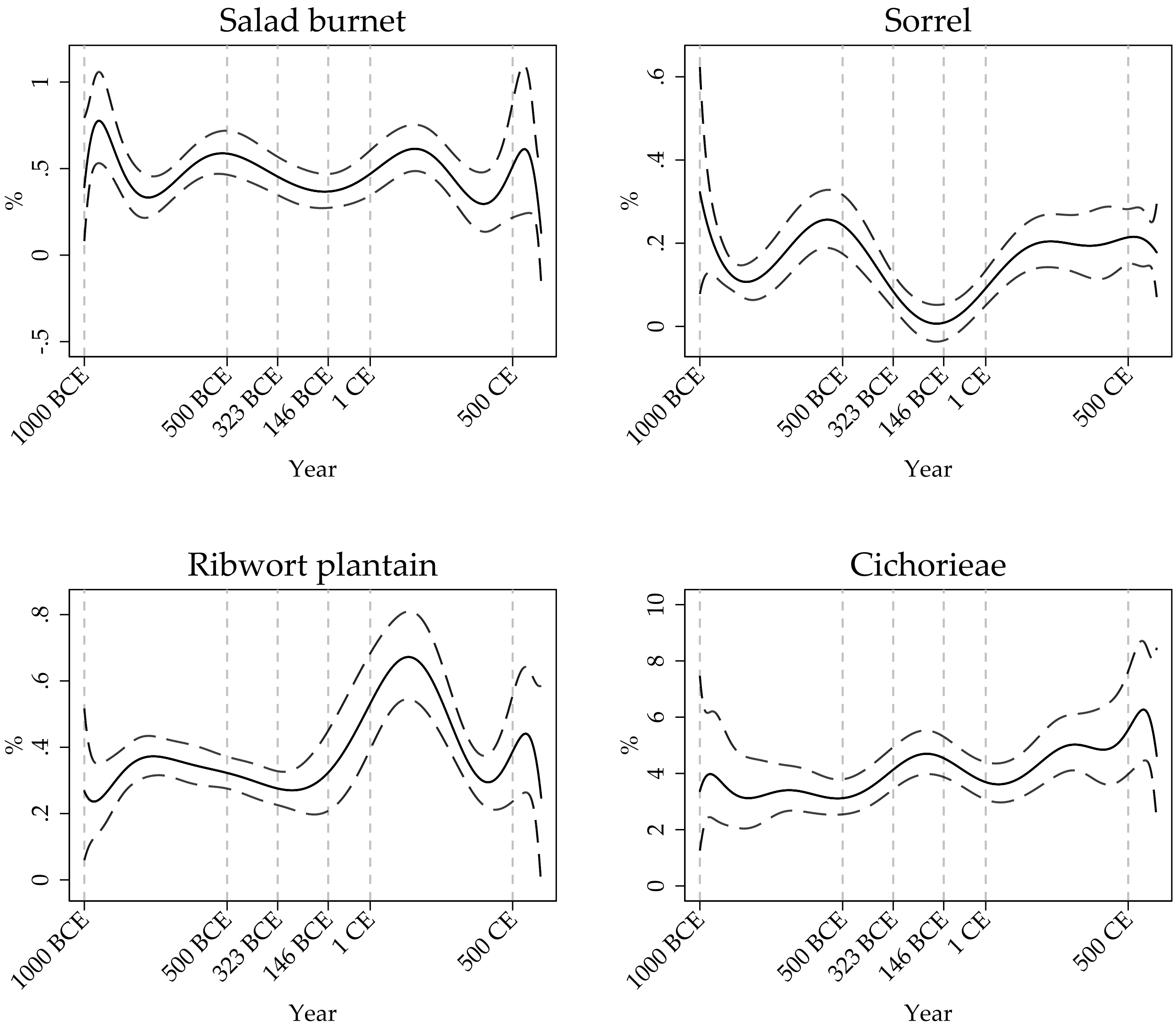


Figure 6: Synanthropic plant taxa in southern Greece


Salad burnet

Sorrel

Ribwort plantain

Cichorieae

estimates could thus be used to argue against the common hypothesis that husbandry and pastoral production became increasingly important in Roman Greece (Alcock 1993, pp. 87–88; Rizakis 2013, 2014, p. 257). According to this view, the breakdown of civic boundaries, the creation of larger elite estates, and increasing integration with regional and interregional markets provided an opportunity for landowners to invest more heavily in animal husbandry, as is suggested by a number of written sources (for an overview, see Alcock 1993). Of course, the chronological details are very important in this context. The presence of the Cichorieae started to increase again in the 1st century CE and continued to expand into late antiquity. Thus, the available data could possibly support a hypothesis that investment in husbandry started to increase following the final phases of landownership restructuring and land-use changes (including land abandonment) in the late 1st century BCE and 1st century CE.

In Macedonia, the Roman period was also characterized by a steady agricultural expansion and an increasing focus on cereal cultivation. The 2nd century BCE seems to have been a watershed in the landscape history of this part of the Balkans, as the entire composition of the regional agriculture changed dramatically (Figure 7). Instead of maintaining the Mediterranean triad of cereals, olive, and vine, which had gained in importance with the Greek colonization in the Archaic period (see above), local cultivators shifted their focus to grain as the main cultivar, revealing a drive for agricultural specialization. The declining interest in the cultivation of olive and vine makes particular sense in a region that constitutes the northern margin for the profitable cultivation of both plants, and for olive in particular. It is notable that, at the same time, we observe an increase in the relative importance of walnut, previously a hardly noticeable presence in the Macedonian landscape. This phenomenon might be related to possible agricultural experimentation in the new, Roman context. Interestingly, contrary to southern Greece, the rise in the presence of cereal pollen was accompanied by an increase in the relative importance of chestnut. This tree produces fruits which were consumed locally in antiquity and the Middle Ages, and which provided a source of calories for populations experiencing unstable political conditions, limited access to calories from grain, or rapid population growth (Bottema 2000; Mercuri *et al.* 2013; Squatriti 2013). This would also suggest that those who managed local agriculture placed special emphasis on the production of grain for export, as the rise in the importance of chestnut suggests that local populations might have had to resort to this source of calories in their diets. An expansion is also visible in the synanthropic indicators (Figure 8), all of which were increasing their relative importance throughout the Roman period.

However, not only does the Macedonian case confirm that the Roman period was an era of agricultural expansion in this part of the Mediterranean, but it also offers some qualifications as to whether the Roman conquest was indeed a major turning point in the landscape and agricultural history of this region. It is important to notice that the trend of expanding cereal cultivation started already in the 4th century BCE, during the times of Philip II and Alexander the Great, and the same is visible in all of the synanthropic indicators (sorrel in particular). This suggests that the process that was taking place after the Roman conquest had commenced much earlier, already at the very beginning of the Hellenistic period. What follows, the processes of market integration that

Figure 7: Cultivated plant taxa in Macedonia

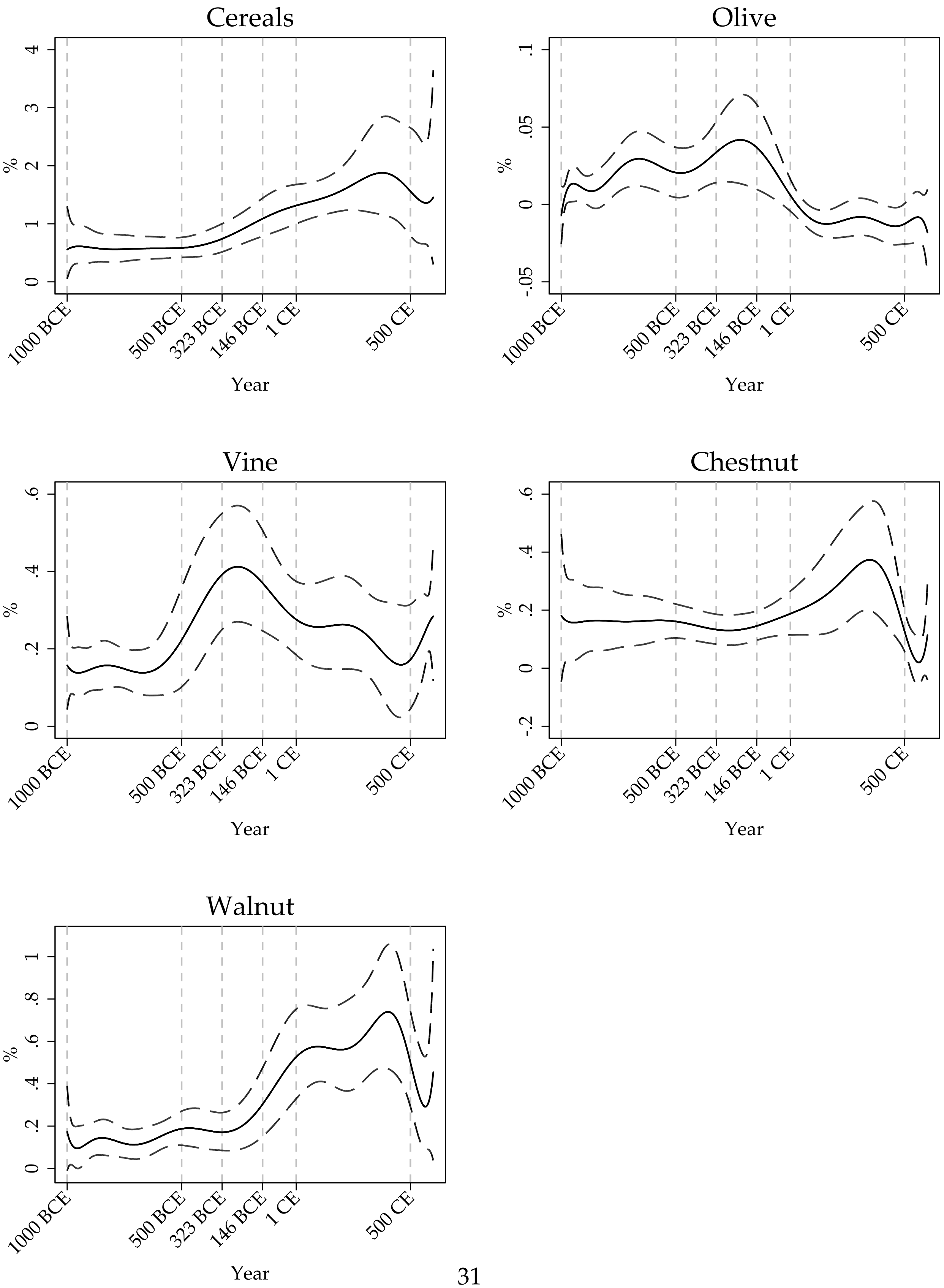
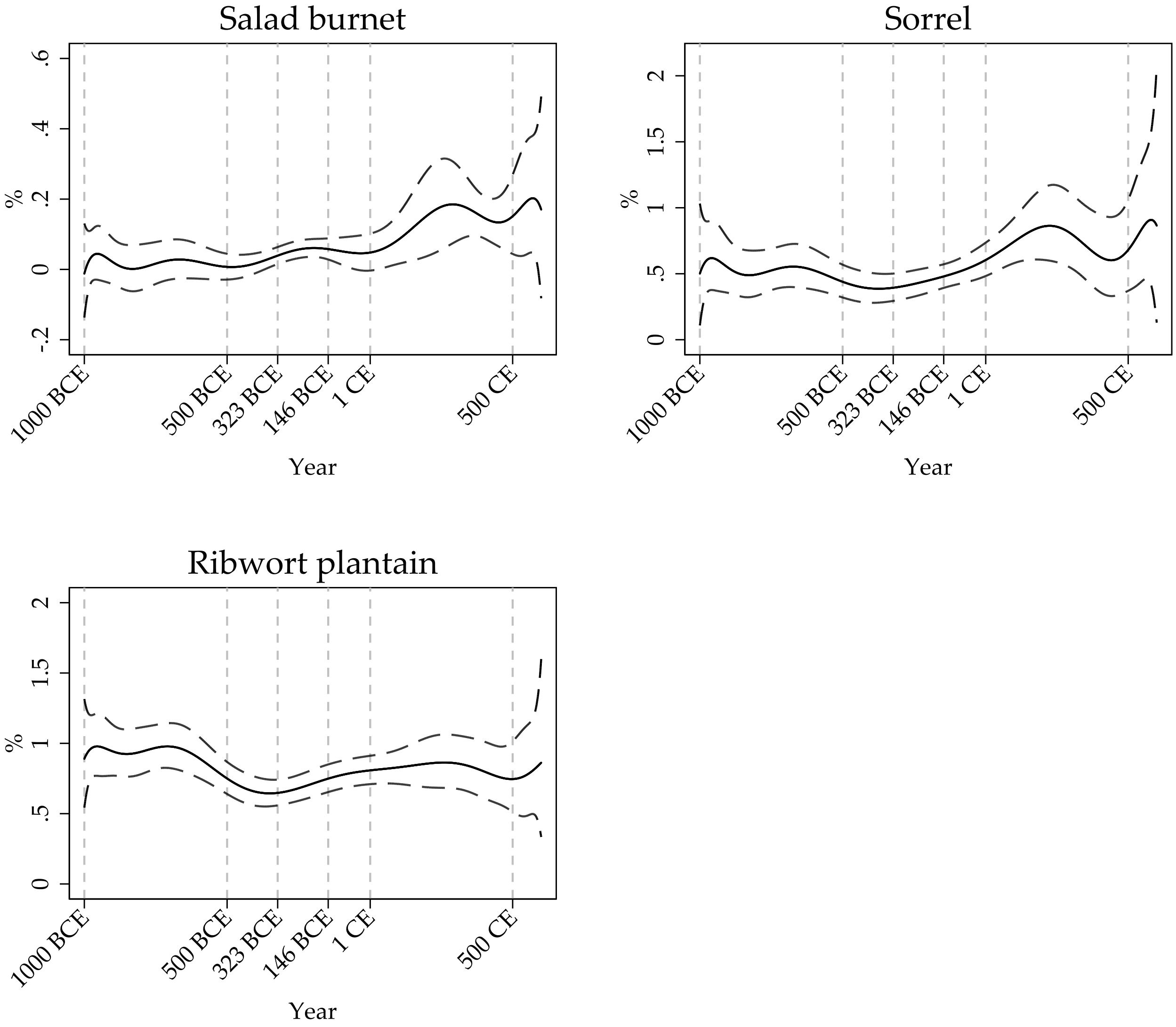


Figure 8: Synanthropic plant taxa in Macedonia



achieved their full potential in the Roman period—as visible in the vegetation structure of Roman Macedonia—had already been underway for more than a century when the Romans conquered this region in the middle of the 2nd century BCE. While initially surprising, this result can be connected to the ongoing historical and archaeological research on this period of Greek history, which has revealed a complex nature of the Hellenistic economic systems, at least in some of its constituent regions (Archibald 2005). Our estimates demonstrate that the Macedonian kingdom, largely neglected by modern research, had been an expanding agricultural economy that had been integrating with the broader

Mediterranean markets in a way that was later characteristic for the Roman period.

Broadly speaking, our results confirm that the Roman conquest in the middle of the 2nd century BCE constituted a watershed in the economic history of southern Greece. After this date, the southern Greek landscape changed in agreement with the models developed by environmental historians, ecologists, and landscape specialists; its evolution was consistent with what we would expect in a region that was responding to increasing market integration. However, we also observe ample evidence of cash crop production before the Roman period. Together with the evidence of grain imports to the Greek mainland, these results are suggestive of pre-Roman market integration, which accelerated and expanded after the Roman conquest. Similarly, in Macedonia, our estimates suggest that the process of market integration began with the military expansion of Philip II and Alexander the Great, 150 years prior to the Roman conquest of this region.

The Second Wave of Roman Market Integration?

Recent research on the economic history of late antiquity, or the later Roman period, has been increasingly focused on the phenomenon of the late antique agricultural expansion. As has been demonstrated in a number of studies on different parts of the Eastern Roman Empire, the 4th to 6th centuries CE experienced a major growth in site numbers in the countryside, while many of these settlements were founded on previously uncultivated, marginal land.[22] These developments have been connected to a number of factors, including the foundation of the city of Constantinople, which became a major consumer market for grain and other foodstuffs in the Eastern Mediterranean, a factor that was especially relevant for Greece and the broader Aegean region. Climatic changes, not so well understood in the case of first-millennium Greece, have been demonstrated to be important in the Anatolian and Levantine contexts (Izdebski *et al.* 2016b). Finally, a structural factor that played a key role in the entire Eastern Roman Empire was the development of a new monetary system, based on gold, which allowed the late Roman elites to accumulate capital and invest on an unprecedented scale (Banaji 2007, 2016).

In the context of the regional landscape change in Greece, these phenomena were already discussed by Izdebski *et al.* (2015) in a recent study of environmental and economic developments in the Byzantine and Ottoman Empires (300–1800 CE). In this paper we restrict our attention to those changes in the Greek landscape that are relevant for our discussion of market integration in the Roman Empire. Notably, the late antique agri-

---

[22] For major overviews, see Pettegrew (2007, 2010) and Bintliff (2012a) on Greece; Izdebski (2013a,b) on Anatolia; as well as Decker (2009) and Avni *et al.* (2013) on the Levant.

cultural expansion was a phenomenon that did not occur in Macedonia. In this region, the collapse of the northern Balkan provinces of the Roman Empire led to an agricultural decline which started in the 4th century CE (see Poulter 2007 for a discussion of Balkan history in this period). In southern Greece, however, an upward trend in all the indicators of agricultural activity—except for walnut, but including chestnut and the "pastoral" Cichorieae—is well visible by 400 CE. This leaves no doubt that southern Greece indeed experienced a second wave of Roman market integration in the 4th and 5th centuries CE. Interestingly, contrary to the early Roman period, the economy of this region was not focused exclusively on the Mediterranean triad; instead, there are also signs of an increase in pastoral activities and chestnut cultivation for local consumption. This phenomenon might be related either to perceived insecurity—in particular among the local populations in the northernmost parts of the Greek mainland, more exposed to "barbarian" invasions—or to the limited access of local consumers to the grain that was destined for the distant markets of Constantinople and other large Mediterranean cities.

5 Comparisons with Other Sources of Data

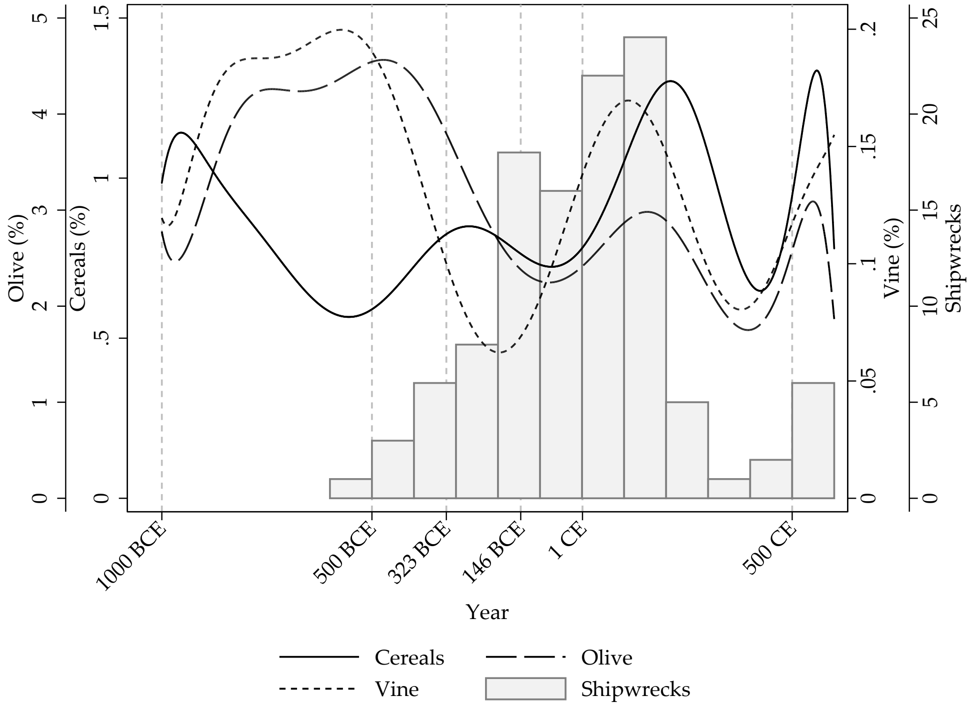
We have previously demonstrated that our empirical results for southern Greece are consistent with auxiliary data on settlement dynamics in the Peloponnese (see Section 4). There are, however, further sources of data with which our estimates can be compared, in particular on shipwrecks (Parker 1992; Wilson 2011; McCormick 2012; Strauss 2013) and large-scale oil and wine presses (Marzano 2013; Erdkamp 2016).

Ancient Shipwrecks (Parker 1992; Strauss 2013)

The data on Mediterranean shipwrecks, introduced by Parker (1992) and recently updated by Wilson (2011), McCormick (2012), and Strauss (2013), have routinely been used in ancient history as a proxy for maritime trade and the overall level of economic activity (see, *e.g.*, Hopkins 1980; Geraghty 2007; Kessler and Temin 2007; Terpstra 2019). In general, these data are suggestive of an economic boom and a trade expansion in the early Roman Empire. As Hopkins (1980) stated it: "The dated shipwrecks show that in the period of Roman imperial expansion and in the High Empire … there was more seaborne trade in the Mediterranean than ever before, and more than there was for the next thousand years."

Figure 9 presents our pollen-based trends in the presence of cereals, olive, and vine in southern Greece as well as a histogram for the shipwreck data (based on Strauss 2013). For

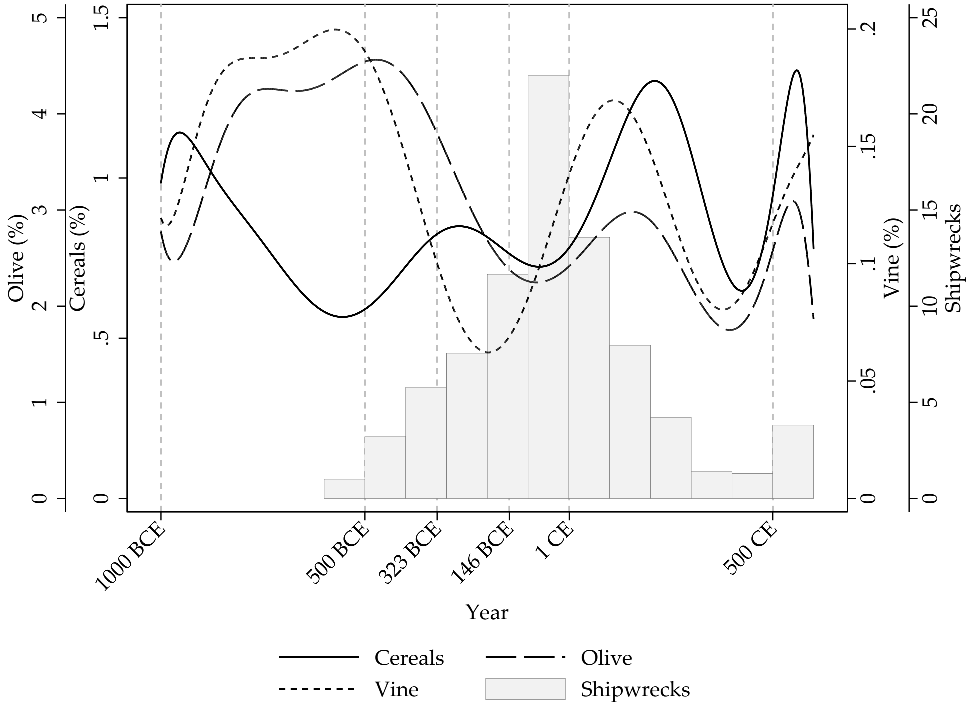
Figure 9: Pollen data in southern Greece *vs* shipwrecks in “Greece”



most shipwrecks, of course, it is not possible to determine the exact date of sinking, and we use the midpoint of the interval from the earliest to the latest possible date. We restrict our attention to those shipwrecks whose location is sufficiently close to our region of interest. More precisely, Strauss (2013) coded the location of shipwrecks in three different ways—based on sea area, country, and exact latitude and longitude—but there are many missing values for each variable. We consider all shipwrecks whose location is coded as *(i)* Aegean, Northern Aegean, or Southern Aegean, *(ii)* Greece, or *(iii)* in the latitude range 34° to 42°N and longitude range 20° to 30°E.

It is clear that our estimated trends are consistent with the shipwreck data in the Roman period and onward; both sources of data are suggestive of an economic boom in the 1st and 2nd century CE, a decline in the 4th and 5th century CE, and a smaller boom in the 6th century CE. On the other hand, these sources of data present conflicting pictures of pre-Roman trade. While there is only one shipwreck in our region which is dated prior to 500 BCE, our pollen-based trends are suggestive of a major trade expansion even before this date. Such a lack of consistency between both sources of data, however, is less surprising than it might seem. According to Parker (1990), “the oared ships of the earliest traders and explorers were lightly built, and so have not been preserved at all.” There

Figure 10: Pollen data in southern Greece *vs* shipwrecks in "Greece" (prorated)



may also be a number of other taphonomic and preservation issues that could have influenced the recovery pattern. What follows, we conjecture that our pollen-based trends are likely to present a more reliable picture of pre-Roman trade than the shipwreck data—while both sources are clearly in agreement in later periods.

As an important robustness check, we also consider the recent criticism of shipwreck-based studies by Wilson (2011) and McCormick (2012), who noted that many shipwrecks had been dated very imprecisely—with differences of several centuries between the earliest and the latest possible date of sinking—which might affect our conclusions from analyzing these data. Thus, McCormick (2012) recommended that we restrict our attention to shipwrecks that could be dated down to three centuries or less; he also suggested, as did Wilson (2011), that we prorate shipwrecks dated to multiple centuries.[23] We implement both of these recommendations in Figure 10, which is a revised version of Figure 9. The main difference between both figures is in the dating of the biggest economic boom. Using prorated data, the greatest number of shipwrecks appears to be dated to the 1st century BCE and—to a lesser extent—the 1st century CE. Consequently, there is a gap of

---

[23] For example, a shipwreck dating between 50 and 250 CE would be coded as 1/4 of a shipwreck in the 1st century, 1/2 of a shipwreck in the 2nd century, and 1/4 of a shipwreck in the 3rd century CE. See also McCormick (2016) for a further discussion of methodological issues in shipwreck-based studies.

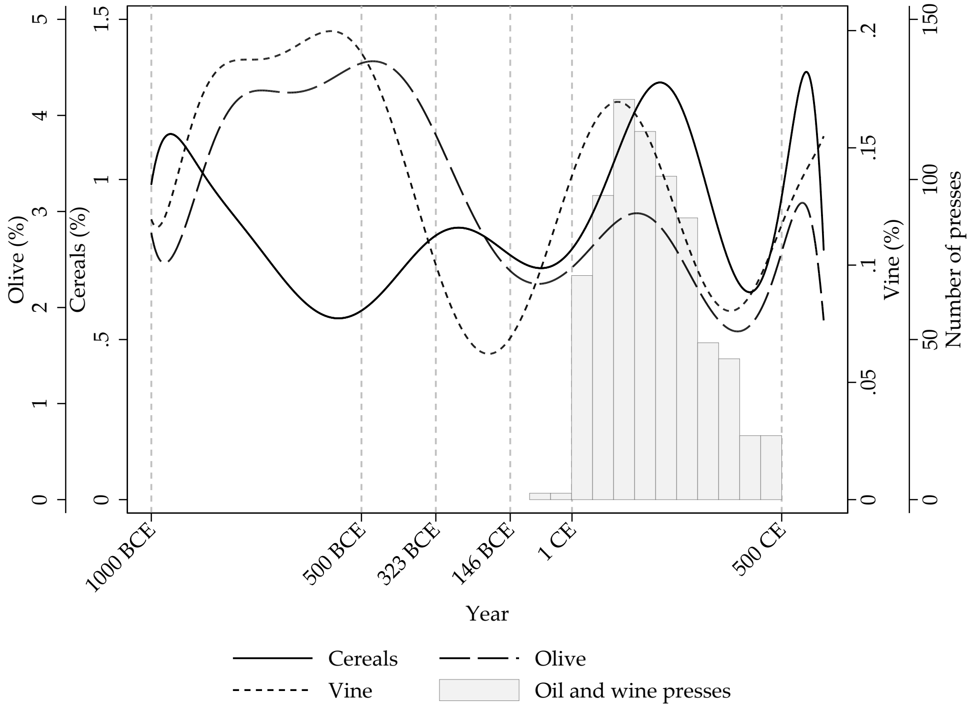
c. 100–200 years between the estimated peak of the economic expansion according to the pollen and shipwreck data. On the other hand, the remaining similarities between both sources of data—a decline in the 4th and 5th century CE and a smaller boom in the 6th century CE—are robust to prorating. As before, both sources of data suggest different pictures of pre-Roman trade, and we are inclined to trust the pollen-based estimates.

Ancient Oil and Wine Presses (Marzano 2013)

Similarly, in Figure 11, we compare our regional trends in the presence of cereals, olive, and vine with data on large-scale oil and wine presses in Gaul, the Iberian Peninsula, and the Black Sea region. These data were introduced by Marzano (2013) and recently discussed by Erdkamp (2016). As explained by Marzano (2013), large-scale oil and wine presses can proxy for capital investment in agricultural crop processing. Because these data do not, in fact, come from Greece, their role in our study is to indicate a pattern of broad Mediterranean trends stimulated by the imperial economic structures and incentives for the production of olive oil and wine. As before, our pollen-based estimates are consistent with these auxiliary data throughout the Roman period.

There are of course limitations of using specific classes of archaeological data in this

Figure 11: Pollen data in southern Greece *vs* Mediterranean oil and wine presses



capacity since the record is bound to be fragmentary depending to a large scale on where archaeological excavations have been carried out. The comparisons presented here nevertheless highlight trends that can be sufficiently matched with cash crop production in Greece during the Roman period. Since Marzano (2013) did not consider pre-Roman oil and wine presses, the lack of consistency between both sources of data before the Roman conquest is not at all troubling. The geographical context of the presses would further make such pre-Roman comparisons difficult since these different production systems would largely have operated within different political and cultural contexts before the Roman conquest. The trends highlighted for the Roman period may nevertheless be used to identify a stimulus towards production systems offered by the integration with new imperial structures. Interestingly, and perhaps coincidentally, when we present separate histograms for oil and wine presses in the Appendix, it turns out that both sources of data—palynological and archaeological—are suggestive of an earlier peak in the production of wine (in the early 2nd century CE) as compared with olive oil (in the late 2nd and early 3rd century CE).

6 Conclusions

The use of palynological data in the current study on market integration and landscape change demonstrates how environmental evidence can be utilized to explore the economic history of Greco-Roman antiquity. Our results highlight considerable dynamics in cultivation strategies which can be linked to historical periods that have been associated with increasing market integration in previous research. In particular, we conclude that the Roman conquest of Greece prompted substantial changes in agricultural production which were likely related to the integration of both southern Greece and Macedonia into the imperial economic structures. At the same time, market integration seems to have impacted agricultural production in both regions well before the Roman conquest. In fact, the first signs of landscape change occurred already in the Archaic period, when we observe an increasing focus on olive production, combined with a decreasing importance of cereal cultivation in southern Greece and a substantial demographic expansion. In this respect, increasing urbanization—in the 7th and 6th century BCE and onward—seems to have stimulated the production of cash crops and agricultural specialization in different parts of the Greek mainland.

Both the palynological evidence and the archaeological record are suggestive of apparent disruptions—perhaps an economic crisis—in the late Hellenistic period, primarily in southern Greece. These events, however, were followed by a major process of landscape change in the centuries that postdated the Roman conquest. Although the annexation of Greece proved to be a major turning point in the agricultural history of both regions, the processes that were characteristic for the Roman period—in the case of Macedonia—had already started in the second half of the 4th century BCE, during the reigns of Philip II and Alexander the Great. The patterns of change under the Roman rule indicate that both regions were increasingly becoming export economies, oriented towards the global markets and imperial economic structures of the Roman Empire. A second wave of market integration and associated landscape change occurred in the later Roman period, potentially caused by the foundation of the new capital of Constantinople, the fiscal expansion of the late Roman state, and the development of a new monetary economy, based on gold coinage, in the Eastern Roman Empire.

Importantly, our estimated trends are consistent with other archaeological and historical sources, particularly on settlement dynamics in the Peloponnese, shipwrecks, and oil and wine presses across the Mediterranean. By means of presenting such trends in the regional presence of cereal, olive, and vine pollen across sixteen centuries, we contribute to the emerging literature on ancient economic history over the very long term. See, for example, de Callataÿ (2005), Jongman (2007a,b), McConnell *et al.* (2018), and Terpstra (2019). Several of these previous studies have incorporated the data on lead pollution in Arctic ice to improve our understanding of the Roman economy. In this paper we use an alternative source of environmental data—pollen data—which allows us to shift attention to ancient Greece and provide a more detailed and more localized study of an ancient economy over the very long term.

References

ACHESON, P. E. (1997): "Does the 'Economic Explanation' Work? Settlement, Agriculture and Erosion in the Territory of Halieis in the Late Classical–Early Hellenistic Period," *Journal of Mediterranean Archaeology*, 10, 165–190.

ALCOCK, S. E. (1993): *Graecia Capta: The Landscapes of Roman Greece*, Cambridge: Cambridge University Press.

ALCOCK, S. E., A. BERLIN, A. B. HARRISON, S. HEATH, N. SPENCER, AND D. L. STONE (2005): "Pylos Regional Archaeological Project, Part VII: Historical Messenia, Geometric through Late Roman," *Hesperia: The Journal of the American School of Classical Studies at Athens*, 74, 147–209.

ALLEN, R. C. (2009): "How Prosperous Were the Romans? Evidence from Diocletian's Price Edict (AD 301)," in *Quantifying the Roman Economy: Methods and Problems*, ed. by A. Bowman and A. Wilson, Oxford–New York: Oxford University Press, 327–345.

AMEMIYA, T. (2007): *Economy and Economics of Ancient Greece*, London: Routledge.

ARCHIBALD, Z. H. (2005): "Markets and Exchange: The Structure and Scale of Economic Behaviour in the Hellenistic Age," in *Making, Moving and Managing: The New World of Ancient Economies, 323–31 BC*, ed. by Z. H. Archibald, J. K. Davies, and V. Gabrielsen, Oxford: Oxbow Books, 1–26.

ATHANASIADIS, N. (1975): "Zur postglazialen Vegetationsentwicklung von Litochoro Katerinis und Pertouli Trikalon (Griechenland)," *Flora*, 164, 99–132.

AVNI, G., N. PORAT, AND Y. AVNI (2013): "Byzantine–Early Islamic Agricultural Systems in the Negev Highlands: Stages of Development as Interpreted through OSL Dating," *Journal of Field Archaeology*, 38, 332–346.

BAGNALL, R. S. (2005): "Evidence and Models for the Economy of Roman Egypt," in *The Ancient Economy: Evidence and Models*, ed. by J. G. Manning and I. Morris, Stanford: Stanford University Press, 187–204.

BAKKER, J. D., S. MAURER, J.-S. PISCHKE, AND F. RAUCH (2018): "Of Mice and Merchants: Trade and Growth in the Iron Age," NBER Working Paper no. 24825.

BANAJI, J. (2007): *Agrarian Change in Late Antiquity: Gold, Labour, and Aristocratic Dominance*, Oxford–New York: Oxford University Press.

——— (2016): *Exploring the Economy of Late Antiquity: Selected Essays*, Cambridge: Cambridge University Press.

BANG, P. F. (2007): "Trade and Empire – In Search of Organizing Concepts for the Roman Economy," *Past & Present*, 195, 3–54.

——— (2008): *The Roman Bazaar: A Comparative Study of Trade and Markets in a Tributary Empire*, Cambridge: Cambridge University Press.

——— (2009): "The Ancient Economy and New Institutional Economics," *Journal of Roman Studies*, 99, 194–206.

BARJAMOVIC, G., T. CHANEY, K. A. COŞAR, AND A. HORTAÇSU (2017): "Trade, Merchants, and the Lost Cities of the Bronze Age," NBER Working Paper no. 23992.

BEHRE, K.-E. (1981): "The Interpretation of Anthropogenic Indicators in Pollen Diagrams," *Pollen et Spores*, 23, 225–245.

BINTLIFF, J. (1997): "Regional Survey, Demography, and the Rise of Complex Societies in the Ancient Aegean: Core–Periphery, Neo-Malthusian, and Other Interpretive Models," *Journal of Field Archaeology*, 24, 1–38.

——— (2008): "The Peloponnese in Hellenistic and Early Roman Imperial Times: The Evidence from Survey and the Wider Aegean Context," in *Le Péloponnèse d'Épaminondas à Hadrien: Colloque de Tours, 6–7 octobre 2005*, ed. by C. Grandjean, Bordeaux: Ausonius, 21–52.

——— (2012a): "Central Greece in Late Antiquity: The Evidence from the Boeotia Project," *Late Antique Archaeology*, 9, 189–203.

——— (2012b): *The Complete Archaeology of Greece: From Hunter-Gatherers to the 20th Century A.D.*, Malden–Oxford–Chichester: Wiley-Blackwell.

——— (2013): "The Hellenistic to Roman Mediterranean: A Proto-Capitalist Revolution?" in *Economic Archaeology: From Structure to Performance in European Archaeology*, ed. by T. Kerig and A. Zimmermann, Bonn: Dr. Rudolf Habelt GmbH, 285–292.

——— (2014): "Mobility and Proto-Capitalism in the Hellenistic and Early Roman Mediterranean," in *Mobilität in den Kulturen der antiken Mittelmeerwelt: Stuttgarter Kolloquium zur Historischen Geographie des Altertums 11, 2011*, ed. by E. Olshausen and V. Sauer, Stuttgart: Franz Steiner Verlag, 49–53.

BINTLIFF, J., P. HOWARD, AND A. SNODGRASS (2007): *Testing the Hinterland: The Work of the Boeotia Survey (1989–1991) in the Southern Approaches to the City of Thespiai*, Cambridge: McDonald Institute for Archaeological Research.

BINTLIFF, J. AND A. SNODGRASS (1985): "The Cambridge/Bradford Boeotian Expedition: The First Four Years," *Journal of Field Archaeology*, 12, 123–161.

——— (1988): "Mediterranean Survey and the City," *Antiquity*, 62, 57–71.

BLAAUW, M. (2010): "Methods and Code for 'Classical' Age-Modelling of Radiocarbon Sequences," *Quaternary Geochronology*, 5, 512–518.

BOIVIN, N. L., M. A. ZEDER, D. Q. FULLER, A. CROWTHER, G. LARSON, J. M. ERLANDSON, T. DENHAM, AND M. D. PETRAGLIA (2016): "Ecological Consequences of Human Niche Construction: Examining Long-Term Anthropogenic Shaping of Global Species Distributions," *Proceedings of the National Academy of Sciences*, 113, 6388–6396.

BONNIER, A. (2016): "Harbours and Hinterland Networks by the Corinthian Gulf, from the Archaic to the Early Hellenistic Period," in *Ancient Ports: The Geography of Connections. Proceedings of an International Conference at the Department of Archaeology and Ancient History, Uppsala University, 23–25 September 2010*, ed. by K. Höghammar, B. Alroth, and A. Lindhagen, Uppsala: Acta Universitatis Upsaliensis, 65–94.

BOTTEMA, S. (1974): "Late Quaternary Vegetation History of Northwestern Greece," Ph.D. thesis, University of Groningen.

——— (2000): "The Holocene History of Walnut, Sweet-Chestnut, Manna-Ash and Plane Tree in the Eastern Mediterranean," *Pallas*, 52, 35–59.

BOTTEMA, S. AND H. WOLDRING (1990): "Anthropogenic Indicators in the Pollen Record of the Eastern Mediterranean," in *Man's Role in the Shaping of the Eastern Mediterranean Landscape*, ed. by S. Bottema, G. Entjes-Nieborg, and W. van Zeist, Rotterdam: Balkema, 231–264.

BRANSBOURG, G. (2012): "Rome and the Economic Integration of Empire," Institute for the Study of the Ancient World (ISAW) Paper no. 3.

BRESSON, A. (2011): "Grain from Cyrene," in *The Economies of Hellenistic Societies, Third to First Centuries BC*, ed. by Z. H. Archibald, J. K. Davies, and V. Gabrielsen, Oxford: Oxford University Press, 66–95.

——— (2016): *The Making of the Ancient Greek Economy: Institutions, Markets, and Growth in the City-States*, Princeton–Oxford: Princeton University Press.

BRUGHMANS, T. AND J. POBLOME (2016): "Roman Bazaar or Market Economy? Explaining Tableware Distributions through Computational Modelling," *Antiquity*, 90, 393–408.

BÜRGI, M., A. M. HERSPERGER, AND N. SCHNEEBERGER (2005): "Driving Forces of Landscape Change – Current and New Directions," *Landscape Ecology*, 19, 857–868.

CARAHER, W. R., D. NAKASSIS, AND D. K. PETTEGREW (2006): "Siteless Survey and Intensive Data Collection in an Artifact-Rich Environment: Case Studies from the Eastern Corinthia, Greece," *Journal of Mediterranean Archaeology*, 19, 7–43.

CARLOS, A. M. AND F. D. LEWIS (1993): "Indians, the Beaver, and the Bay: The Economics of Depletion in the Lands of the Hudson's Bay Company, 1700–1763," *Journal of Economic History*, 53, 465–494.

CHRONOPOULOS, D. K., S. KAMPANELIS, D. OTO-PERALÍAS, AND J. O. S. WILSON (2017): "Spreading Civilisations: Ancient Colonialism and Economic Development along the Mediterranean," Unpublished.

CRONON, W. (1983): *Changes in the Land: Indians, Colonists, and the Ecology of New England*, New York: Hill and Wang.

——— (1991): *Nature's Metropolis: Chicago and the Great West*, New York: W. W. Norton.

CROSBY, A. W. (1986): *Ecological Imperialism: The Biological Expansion of Europe, 900–1900*, New York: Cambridge University Press.

DALGAARD, C.-J., N. KAARSEN, O. OLSSON, AND P. SELAYA (2018): "Roman Roads to Prosperity: Persistence and Non-Persistence of Public Goods Provision," Unpublished.

DE CALLATAŸ, F. (2005): "The Graeco-Roman Economy in the Super Long-Run: Lead, Copper, and Shipwrecks," *Journal of Roman Archaeology*, 18, 361–372.

DECKER, M. (2009): *Tilling the Hateful Earth: Agricultural Production and Trade in the Late Antique East*, Oxford–New York: Oxford University Press.

EASTWOOD, W. J. (2006): "Palaeoecology and Eastern Mediterranean Landscapes: Theoretical and Practical Approaches," in *General Issues in the Study of Medieval Logistics: Sources, Problems and Methodologies*, ed. by J. F. Haldon, Leiden: Brill, 119–158.

ERDKAMP, P. (2005): *The Grain Market in the Roman Empire: A Social, Political, and Economic Study*, Cambridge: Cambridge University Press.

——— (2016): "Economic Growth in the Roman Mediterranean World: An Early Good-Bye to Malthus?" *Explorations in Economic History*, 60, 1–20.

FINLEY, M. I. (1973): *The Ancient Economy*, Berkeley–Los Angeles: University of California Press.

FLORENZANO, A., M. MARIGNANI, L. ROSATI, S. FASCETTI, AND A. M. MERCURI (2015): "Are Cichorieae an Indicator of Open Habitats and Pastoralism in Current and Past Vegetation Studies?" *Plant Biosystems*, 149, 154–165.

FOXHALL, L. (2007): *Olive Cultivation in Ancient Greece: Seeking the Ancient Economy*, Oxford–New York: Oxford University Press.

FYFE, R. M., J.-L. DE BEAULIEU, H. BINNEY, R. H. W. BRADSHAW, S. BREWER, A. LE FLAO, W. FINSINGER, M.-J. GAILLARD, T. GIESECKE, G. GIL-ROMERA, E. C. GRIMM, B. HUNTLEY, P. KUNES, N. KÜHL, M. LEYDET, A. F. LOTTER, P. E. TARASOV, AND S. TONKOV (2009): "The European Pollen Database: Past Efforts and Current Activities," *Vegetation History and Archaeobotany*, 18, 417–424.

GALLANT, T. W. (1991): *Risk and Survival in Ancient Greece: Reconstructing the Rural Domestic Economy*, Stanford: Stanford University Press.

GARNSEY, P. AND I. MORRIS (1989): "Risk and the Polis: The Evolution of Institutionalised Responses to Food Supply Problems in the Ancient Greek State," in *Bad Year Economics: Cultural Responses to Risk and Uncertainty*, ed. by P. Halstead and J. O'Shea, Cambridge–New York: Cambridge University Press, 98–105.

GERAGHTY, R. M. (2007): "The Impact of Globalization in the Roman Empire, 200 BC–AD 100," *Journal of Economic History*, 67, 1036–1061.

GERASIMIDIS, A. AND N. ATHANASIADIS (1995): "Woodland History of Northern Greece from the Mid Holocene to Recent Time Based on Evidence from Peat Pollen Profiles," *Vegetation History and Archaeobotany*, 4, 109–116.

GERASIMIDIS, A., N. ATHANASIADIS, AND S. PANAJIOTIDIS (2008): "Contributions to the European Pollen Database: 4. Mount Paiko (Northern Greece)," *Grana*, 47, 316–318.

——— (2009): "Contributions to the European Pollen Database: 8. Mount Voras (North-West Greece)," *Grana*, 48, 316–318.

GERASIMIDIS, A. AND S. PANAJIOTIDIS (2010): "Contributions to the European Pollen Database: 9. Flambouro, Pieria Mountains (Northern Greece)," *Grana*, 49, 76–78.

GOLDSMITH, R. W. (1984): "An Estimate of the Size and Structure of the National Product of the Early Roman Empire," *Review of Income and Wealth*, 30, 263–288.

GRAINGER, J. D. (1999): "Prices in Hellenistic Babylonia," *Journal of the Economic and Social History of the Orient*, 42, 303–325.

HALDON, J. (2016): *The Empire That Would Not Die: The Paradox of Eastern Roman Survival, 640–740*, Cambridge: Harvard University Press.

HARPER, K. (2016): "People, Plagues, and Prices in the Roman World: The Evidence from Egypt," *Journal of Economic History*, 76, 803–839.

HARRIS, E. M., D. M. LEWIS, AND M. WOOLMER, eds. (2016): *The Ancient Greek Economy: Markets, Households and City-States*, New York: Cambridge University Press.

HINGLEY, R. (2005): *Globalizing Roman Culture: Unity, Diversity and Empire*, London–New York: Routledge.

HOFFMANN, R. C. (2014): *An Environmental History of Medieval Europe*, Cambridge–New York: Cambridge University Press.

HOPKINS, K. (1980): "Taxes and Trade in the Roman Empire (200 B.C.–A.D. 400)," *Journal of Roman Studies*, 70, 101–125.

——— (2002): "Rome, Taxes, Rents and Trade," in *The Ancient Economy*, ed. by W. Scheidel and S. von Reden, Edinburgh: Edinburgh University Press, 190–230.

HORDEN, P. AND N. PURCELL (2000): *The Corrupting Sea: A Study of Mediterranean History*, London: Blackwell.

ISAGER, S. AND J. E. SKYDSGAARD (1992): *Ancient Greek Agriculture: An Introduction*, London–New York: Routledge.

IZDEBSKI, A. (2013a): "The Economic Expansion of the Anatolian Countryside in Late Antiquity: The Coast versus Inland Regions," *Late Antique Archaeology*, 10, 343–376.

——— (2013b): *A Rural Economy in Transition: Asia Minor from Late Antiquity into the Early Middle Ages*, Warszawa: Taubenschlag Foundation.

IZDEBSKI, A., G. KOLOCH, AND T. SŁOCZYŃSKI (2015): “Exploring Byzantine and Ottoman Economic History with the Use of Palynological Data: A Quantitative Approach,” *Jahrbuch der Österreichischen Byzantinistik*, 65, 67–110.

IZDEBSKI, A., G. KOLOCH, T. SŁOCZYŃSKI, AND M. TYCNER (2016a): “On the Use of Palynological Data in Economic History: New Methods and an Application to Agricultural Output in Central Europe, 0–2000 AD,” *Explorations in Economic History*, 59, 17–39.

IZDEBSKI, A., J. PICKETT, N. ROBERTS, AND T. WALISZEWSKI (2016b): “The Environmental, Archaeological and Historical Evidence for Regional Climatic Changes and Their Societal Impacts in the Eastern Mediterranean in Late Antiquity,” *Quaternary Science Reviews*, 136, 189–208.

JAHNS, S. (1993): “On the Holocene Vegetation History of the Argive Plain (Peloponnese, Southern Greece),” *Vegetation History and Archaeobotany*, 2, 187–203.

——— (2005): “The Holocene History of Vegetation and Settlement at the Coastal Site of Lake Voulkaria in Acarnania, Western Greece,” *Vegetation History and Archaeobotany*, 14, 55–66.

JAMESON, M. H., C. N. RUNNELS, AND T. H. VAN ANDEL (1994): *A Greek Countryside: The Southern Argolid from Prehistory to the Present Day*, Stanford: Stanford University Press.

JONGMAN, W. M. (2007a): “The Early Roman Empire: Consumption,” in *The Cambridge Economic History of the Greco-Roman World*, ed. by W. Scheidel, I. Morris, and R. P. Saller, Cambridge: Cambridge University Press, 592–618.

——— (2007b): “Gibbon Was Right: The Decline and Fall of the Roman Economy,” in *Crises and the Roman Empire: Proceedings of the Seventh Workshop of the International Network Impact of Empire (Nijmegen, June 20–24, 2006)*, ed. by O. Hekster, G. de Kleijn, and D. Slootjes, Leiden–Boston: Brill, 183–199.

KAISER, B. A. (2007): “The Athenian Trierarchy: Mechanism Design for the Private Provision of Public Goods,” *Journal of Economic History*, 67, 445–480.

KAY, P. (2014): *Rome's Economic Revolution*, Oxford: Oxford University Press.

KENDAL, J., J. J. TEHRANI, AND J. ODLING-SMEE (2011): “Human Niche Construction in Interdisciplinary Focus,” *Philosophical Transactions of the Royal Society B: Biological Sciences*, 366, 785–792.

KESSLER, D. AND P. TEMIN (2007): “The Organization of the Grain Trade in the Early Roman Empire,” *Economic History Review*, 60, 313–332.

——— (2008): “Money and Prices in the Early Roman Empire,” in *The Monetary Systems of the Greeks and Romans*, ed. by W. V. Harris, Oxford–New York: Oxford University Press, 137–159.

KOULI, K. (2012): “Vegetation Development and Human Activities in Attiki (SE Greece) during the Last 5,000 Years,” *Vegetation History and Archaeobotany*, 21, 267–278.

KOULI, K. AND M. D. DERMITZAKIS (2010): “Contributions to the European Pollen Database: 11. Lake Orestiás (Kastoria, northern Greece),” *Grana*, 49, 154–156.

KOULI, K., A. GOGOU, M. V. TRIANTAPHYLLOU, S. KYRIKOU, M. D. DIMIZA, C. ANAGNOSTOU, AND A. P. KARAGEORGIS (2016): “Late Glacial to Holocene Palaeoenvironment and Vegetation in the Area of Saronikos Gulf: The Elefsis Bay Sedimentary Record,” Unpublished.

KRON, G. (2014): “Comparative Evidence and the Reconstruction of the Ancient Economy: Greco-Roman Housing and the Level and Distribution of Wealth and Income,” in *Quantifying the Greco-Roman Economy and Beyond*, ed. by F. de Callataÿ, Bari: Edipuglia, 124–146.

KROTSCHECK, U. (2006): “Going with the Grain: Athenian State Formation and the Question of Subsistence in the 5th and 4th Centuries BCE,” Princeton/Stanford Working Paper in Classics no. 010603.

KUSSMAUL, A. (1985): “Agrarian Change in Seventeenth-Century England: The Economic Historian as Paleontologist,” *Journal of Economic History*, 45, 1–30.

KYRIKOU, S. (2016): “Holocene Plant Landscapes of West Attica (Greece): From a Climate Controlled Vegetation to the Modern Cultural Landscape,” Master’s thesis, National and Kapodistrian University of Athens.

LALAND, K. N. AND M. J. O’BRIEN (2010): “Niche Construction Theory and Archaeology,” *Journal of Archaeological Method and Theory*, 17, 303–322.

LAZAROVA, M., A. KOUTSIOS, AND N. KONTOPOULOS (2012): “Holocene Vegetation History of the Kotihi Lagoon (Northwest Peloponnesus, Greece),” *Quaternary International*, 261, 138–145.

LIESKOVSKÝ, J. AND M. BÜRGI (2018): "Persistence in Cultural Landscapes: A Pan-European Analysis," *Regional Environmental Change*, 18, 175–187.

MACKIL, E. (2013): *Creating a Common Polity: Religion, Economy, and Politics in the Making of the Greek Koinon*, Berkeley–Los Angeles–London: University of California Press.

——— (2015): "The Greek Polis and Koinon," in *Fiscal Regimes and the Political Economy of Premodern States*, ed. by A. Monson and W. Scheidel, Cambridge: Cambridge University Press, 469–491.

MANNING, J. G. (2003): *Land and Power in Ptolemaic Egypt: The Structure of Land Tenure*, Cambridge: Cambridge University Press.

MARGARITIS, E. (2016): "Agricultural Production and Domestic Activities in Rural Hellenistic Greece," in *The Ancient Greek Economy: Markets, Households and City-States*, ed. by E. M. Harris, D. M. Lewis, and M. Woolmer, Cambridge–New York: Cambridge University Press, 187–203.

MARZANO, A. (2013): "Capital Investment and Agriculture: Multi-Press Facilities from Gaul, the Iberian Peninsula, and the Black Sea Region," in *The Roman Agricultural Economy: Organisation, Investment, and Production*, ed. by A. Bowman and A. Wilson, Oxford: Oxford University Press, 107–141.

MCCONNELL, J. R., A. I. WILSON, A. STOHL, M. M. ARIENZO, N. J. CHELLMAN, S. ECKHARDT, E. M. THOMPSON, A. M. POLLARD, AND J. P. STEFFENSEN (2018): "Lead Pollution Recorded in Greenland Ice Indicates European Emissions Tracked Plagues, Wars, and Imperial Expansion During Antiquity," *Proceedings of the National Academy of Sciences*, 115, 5726–5731.

MCCORMICK, M. (2012): "Movements and Markets in the First Millennium: Information, Containers, and Shipwrecks," in *Trade and Markets in Byzantium*, ed. by C. Morrisson, Washington, D.C.: Dumbarton Oaks Research Library and Collection, 51–98.

——— (2016): "Navegación, naufragios y genes: consideraciones sobre Arqueología e Historia Económica Antigua y Medieval," in *Navegación institucional y navegación privada en el Mediterráneo medieval*, ed. by R. González Arévalo, Granada: La Nao, 11–40.

MERCHANT, C. (1989): *Ecological Revolutions: Nature, Gender, and Science in New England*, Chapel Hill: University of North Carolina Press.

——— (1997): "The Theoretical Structure of Ecological Revolutions," in *Out of the Woods: Essays in Environmental History*, ed. by C. Miller and H. K. Rothman, Pittsburgh: University of Pittsburgh Press, 18–27.

MERCURI, A. M., M. BANDINI MAZZANTI, A. FLORENZANO, M. C. MONTECCHI, AND E. RATTIGHIERI (2013): "Olea, Juglans and Castanea: The OJC Group as Pollen Evidence of the Development of Human-Induced Environments in the Italian Peninsula," *Quaternary International*, 303, 24–42.

MICHAELS, G. AND F. RAUCH (2018): "Resetting the Urban Network: 117–2012," *Economic Journal*, 128, 378–412.

MILANOVIC, B., P. H. LINDERT, AND J. G. WILLIAMSON (2011): "Pre-Industrial Inequality," *Economic Journal*, 121, 255–272.

MÖLLER, A. (2007): "Classical Greece: Distribution," in *The Cambridge Economic History of the Greco-Roman World*, ed. by W. Scheidel, I. Morris, and R. P. Saller, Cambridge: Cambridge University Press, 362–384.

MORENO, A. (2007): *Feeding the Democracy: The Athenian Grain Supply in the Fifth and Fourth Centuries BC*, Oxford: Oxford University Press.

MUNN, M. L. Z. (2003): "Corinthian Trade with the Punic West in the Classical Period," in *Corinth, the Centenary: 1896–1996*, ed. by C. K. Williams and N. Bookidis, Princeton: American School of Classical Studies at Athens, 195–217.

MUNTEANU, C., T. KUEMMERLE, M. BOLTIZIAR, V. BUTSIC, U. GIMMI, L. HALADA, D. KAIM, G. KIRÁLY, É. KONKOLY-GYURÓ, J. KOZAK, J. LIESKOVSKÝ, M. MOJSES, D. MÜLLER, K. OSTAFIN, K. OSTAPOWICZ, O. SHANDRA, P. ŠTYCH, S. WALKER, AND V. C. RADELOFF (2014): "Forest and Agricultural Land Change in the Carpathian Region – A Meta-Analysis of Long-Term Patterns and Drivers of Change," *Land Use Policy*, 38, 685–697.

NORTH, D. C. (1990): *Institutions, Institutional Change and Economic Performance*, Cambridge: Cambridge University Press.

PARKER, A. J. (1990): "Classical Antiquity: The Maritime Dimension," *Antiquity*, 64, 335–346.

——— (1992): *Ancient Shipwrecks of the Mediterranean and the Roman Provinces*, Oxford: Tempus Reparatum.

PETTEGREW, D. K. (2007): "The Busy Countryside of Late Roman Corinth: Interpreting Ceramic Data Produced by Regional Archaeological Surveys," *Hesperia: The Journal of the American School of Classical Studies at Athens*, 76, 743–784.

——— (2010): "Regional Survey and the Boom-And-Bust Countryside: Re-Reading the Archaeological Evidence for Episodic Abandonment in the Late Roman Corinthia," *International Journal of Historical Archaeology*, 14, 215–229.

PITTS, M. AND M. J. VERSLUYS, eds. (2015): *Globalisation and the Roman World: World History, Connectivity and Material Culture*, New York: Cambridge University Press.

POLANYI, K. (1968): *Primitive, Archaic, and Modern Economies: Essays of Karl Polanyi*, Boston: Beacon Press.

——— (1977): *The Livelihood of Man*, New York: Academic Press.

POULTER, A. (2007): "The Transition to Late Antiquity on the Lower Danube: The City, a Fort and the Countryside," in *The Transition to Late Antiquity on the Danube and Beyond*, ed. by A. Poulter, Oxford: Oxford University Press, 51–97.

POUNDS, N. J. G. (1973): *An Historical Geography of Europe: 450 BC–AD 1330*, Cambridge: Cambridge University Press.

REGER, G. (1994): *Regionalism and Change in the Economy of Independent Delos, 314–167 B.C.*, Berkeley: University of California Press.

——— (2002): "The Price Histories of Some Imported Goods on Independent Delos," in *The Ancient Economy*, ed. by W. Scheidel and S. von Reden, Edinburgh: Edinburgh University Press, 133–154.

——— (2007): "Hellenistic Greece and Western Asia Minor," in *The Cambridge Economic History of the Greco-Roman World*, ed. by W. Scheidel, I. Morris, and R. P. Saller, Cambridge: Cambridge University Press, 460–483.

RICHARDS, J. F. (2003): *The Unending Frontier: An Environmental History of the Early Modern World*, Berkeley: University of California Press.

RIZAKIS, A. D. (2013): "Rural Structures and Agrarian Strategies in Greece under the Roman Empire," in *Villae Rusticae: Family and Market-Oriented Farms in Greece under Roman Rule*, ed. by A. D. Rizakis and I. P. Touratsoglou, Athens: National Hellenic Research Foundation–Institute of Historical Research, 20–51.

——— (2014): "Town and Country in Early Imperial Greece," *Pharos*, 20, 241–267.

ROSTOVTZEFF, M. (1941): *The Social and Economic History of the Hellenistic World*, Oxford: Clarendon Press.

SALLARES, R. (1991): *The Ecology of the Ancient Greek World*, Ithaca: Cornell University Press.

SCHEIDEL, W. AND S. J. FRIESEN (2009): "The Size of the Economy and the Distribution of Income in the Roman Empire," *Journal of Roman Studies*, 99, 61–91.

SCHEIDEL, W., I. MORRIS, AND R. P. SALLER, eds. (2007): *The Cambridge Economic History of the Greco-Roman World*, Cambridge–New York: Cambridge University Press.

SLOTSKY, A. L. (1997): *The Bourse of Babylon: Market Quotations in the Astronomical Diaries of Babylonia*, Bethesda: CDL Press.

SQUATRITI, P. (2013): *Landscape and Change in Early Medieval Italy: Chestnuts, Economy, and Culture*, Cambridge: Cambridge University Press.

STEWART, D. R. (2013): *Reading the Landscapes of the Rural Peloponnese: Landscape Change and Regional Variation in an Early 'Provincial' Setting*, Oxford: Archaeopress.

STRAUSS, J. (2013): "Shipwrecks Database. Version 1.0." Accessed (March 7, 2018): oxrep.classics.ox.ac.uk/databases/shipwrecks_database/.

TCHERNIA, A. (1986): *Le vin de l'Italie romaine: Essai d'histoire économique d'après les amphores*, Rome: École française de Rome.

TEMIN, P. (2001): "A Market Economy in the Early Roman Empire," *Journal of Roman Studies*, 91, 169–181.

——— (2002): "Price Behavior in Ancient Babylon," *Explorations in Economic History*, 39, 46–60.

——— (2006a): "The Economy of the Early Roman Empire," *Journal of Economic Perspectives*, 20, 133–151.

——— (2006b): "Estimating GDP in the Early Roman Empire," in *Innovazione tecnica e progresso economico nel mondo romano*, ed. by E. Lo Cascio, Bari: Edipuglia, 31–54.

——— (2013): *The Roman Market Economy*, Princeton: Princeton University Press.

TERPSTRA, T. (2019): *Trade in the Ancient Mediterranean: Private Order and Public Institutions*, Princeton–Oxford: Princeton University Press.

TRIANTAPHYLLOU, M. V., K. KOULI, T. TSOUROU, O. KOUKOUSIOURA, K. PAVLOPOULOS, AND M. D. DERMITZAKIS (2010): "Paleoenvironmental Changes since 3000 BC in the Coastal Marsh of Vravron (Attica, SE Greece)," *Quaternary International*, 216, 14–22.

VALAMOTI, S. M., E. GKATZOGIA, AND M. NTINOU (2018): "Did Greek Colonisation Bring Olive Growing to the North? An Integrated Archaeobotanical Investigation of the Spread of Olea Europaea in Greece from the 7th to the 1st Millennium BC," *Vegetation History and Archaeobotany*, 27, 177–195.

VAN ANDEL, T. H., C. N. RUNNELS, AND K. O. POPE (1986): "Five Thousands Years of Land Use and Abuse in the Southern Argolid, Greece," *Hesperia: The Journal of the American School of Classical Studies at Athens*, 55, 103–128.

VON REDEN, S. (2014): "*The Roman Market Economy* by Peter Temin (review)," *Journal of Interdisciplinary History*, 44, 535–536.

WAHL, F. (2017): "Does European Development Have Roman Roots? Evidence from the German Limes," *Journal of Economic Growth*, 22, 313–349.

WEIBERG, E., A. BEVAN, K. KOULI, M. KATSIANIS, J. WOODBRIDGE, A. BONNIER, M. ENGEL, M. FINNÉ, R. FYFE, Y. MANIATIS, A. PALMISANO, S. PANAJIOTIDIS, N. ROBERTS, AND S. SHENNAN (2018): "Long-term Trends of Land Use and Demography in Greece: A Comparative Study," *The Holocene*, forthcoming.

WEIBERG, E., I. UNKEL, K. KOULI, K. HOLMGREN, P. AVRAMIDIS, A. BONNIER, F. DIBBLE, M. FINNÉ, A. IZDEBSKI, C. KATRANTSIOTIS, S. R. STOCKER, M. ANDWINGE, K. BAIKA, M. BOYD, AND C. HEYMANN (2016): "The Socio-Environmental History of the Peloponnese during the Holocene: Towards an Integrated Understanding of the Past," *Quaternary Science Reviews*, 136, 40–65.

WELLS, B., ed. (1996): *The Berbati–Limnes Archaeological Survey, 1988–1990*, Jonsered: P. Åströms.

WICKHAM, C. (2005): *Framing the Early Middle Ages: Europe and the Mediterranean, 400–800*, Oxford: Oxford University Press.

WILSON, A. (2011): "Developments in Mediterranean Shipping and Maritime Trade from the Hellenistic Period to AD 1000," in *Maritime Archaeology and Ancient Trade in the*

Mediterranean, ed. by D. Robinson and A. Wilson, Oxford: Oxford Centre for Maritime Archaeology, 33–59.

WILSON, A. AND A. BOWMAN, eds. (2018): *Trade, Commerce, and the State in the Roman World*, Oxford: Oxford University Press.

WOOLF, G. (1992): "Imperialism, Empire and the Integration of the Roman Economy," *World Archaeology*, 23, 283–293.

WORSTER, D. (1979): *Dust Bowl: The Southern Plains in the 1930s*, New York: Oxford University Press.

——— (1990): "Transformations of the Earth: Toward an Agroecological Perspective in History," *Journal of American History*, 76, 1087–1106.

ZIOLKOWSKI, A. (2011): "Background to the Third-Century Crisis of the Roman Empire," in *The Roman Empire in Context: Historical and Comparative Perspectives*, ed. by J. P. Arnason and K. A. Raaflaub, Chichester–Malden: Wiley-Blackwell, 111–133.

Appendix

Figure A1: Weighting *vs* regression in southern Greece

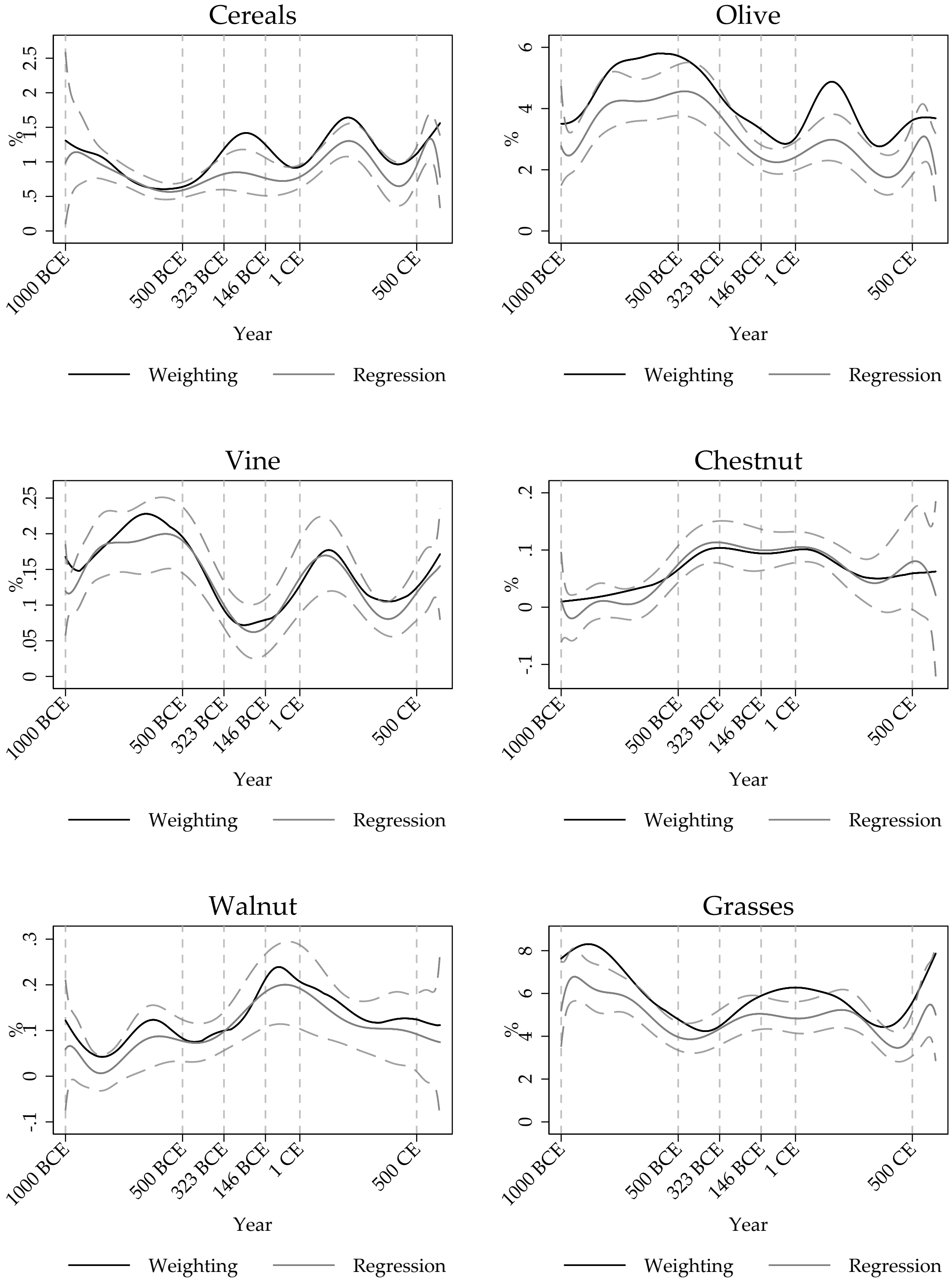


Figure A2: Weighting *vs* regression in southern Greece (cont.)

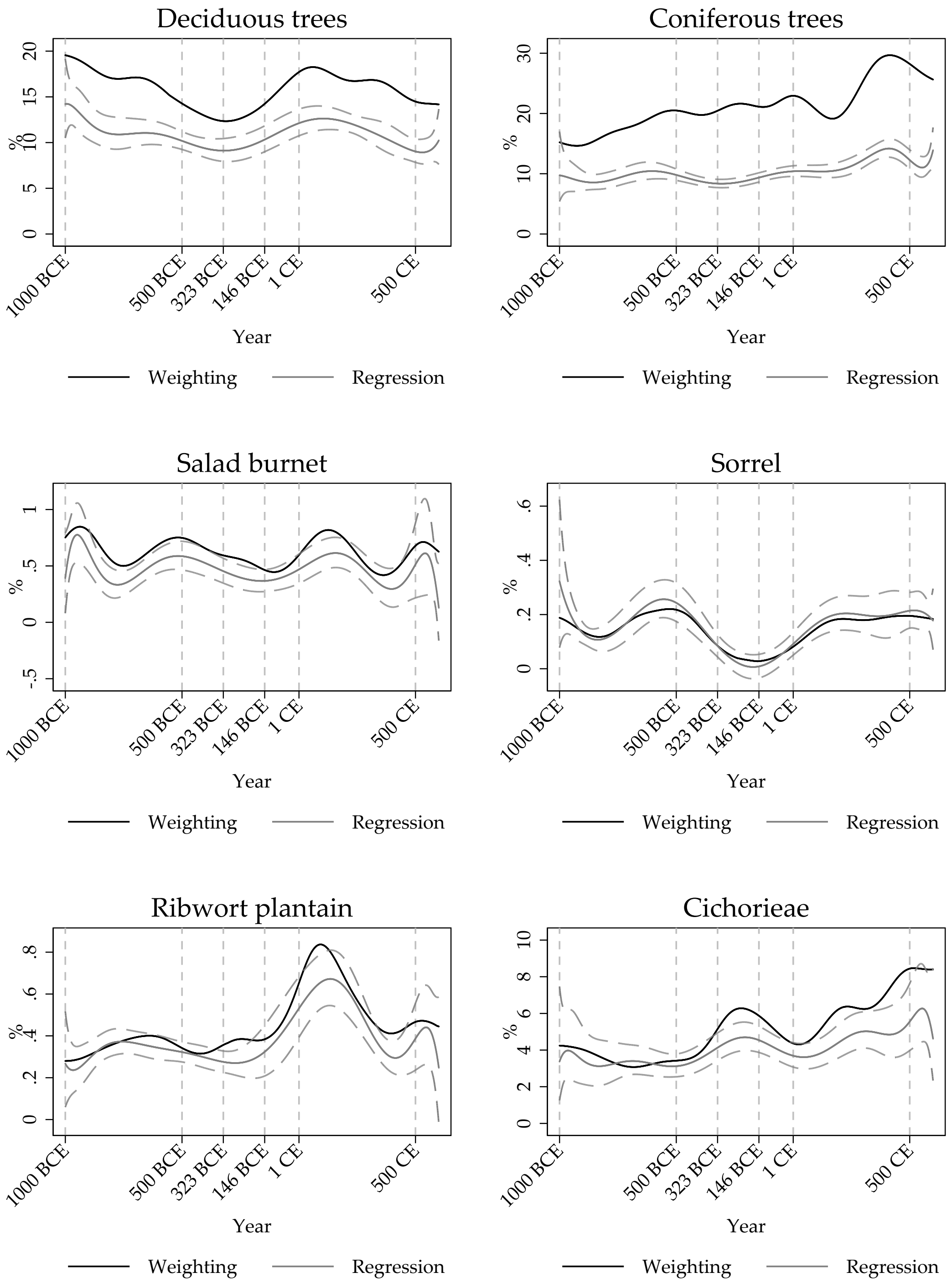


Figure A3: Weighting *vs* regression in Macedonia

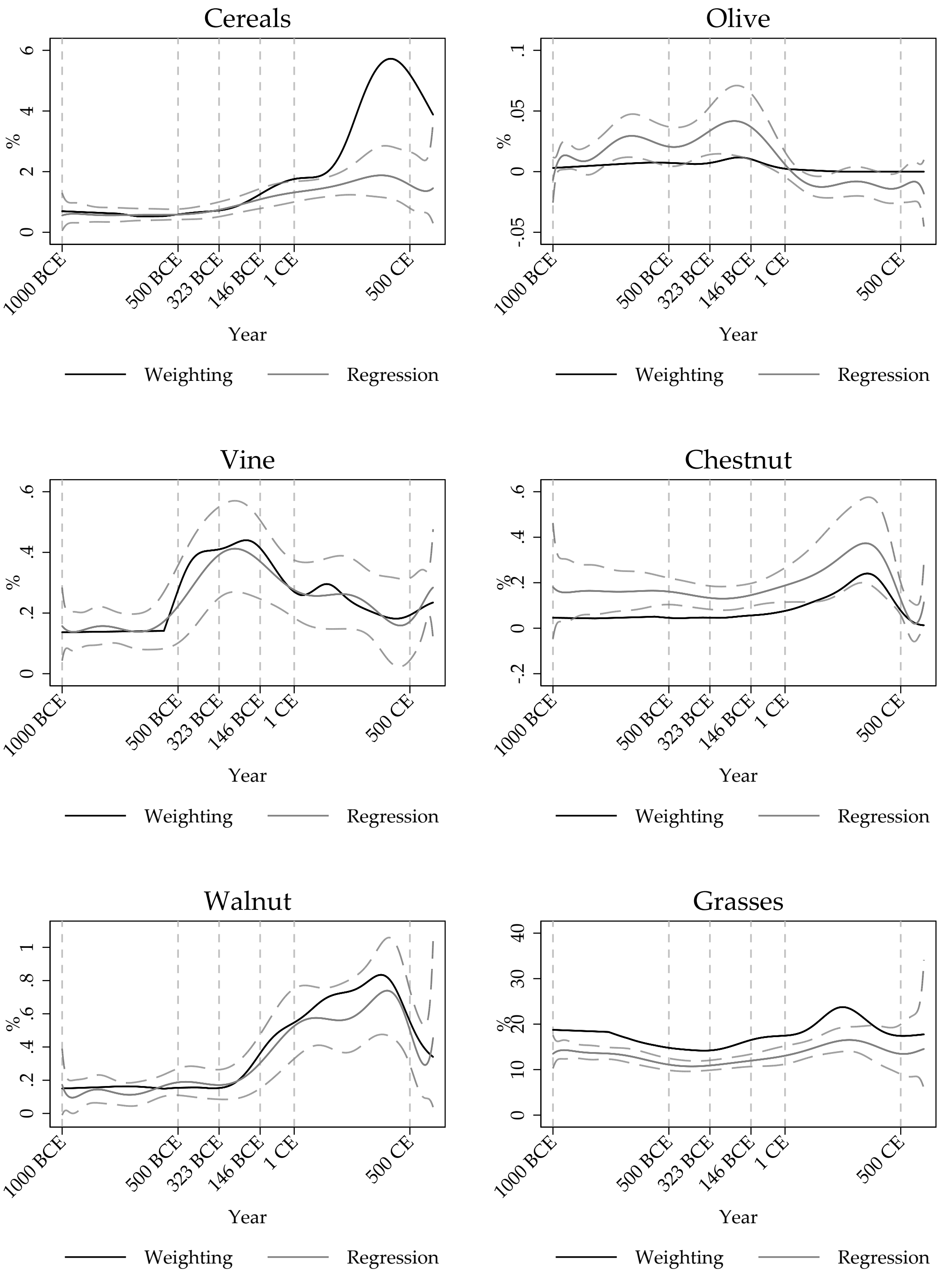
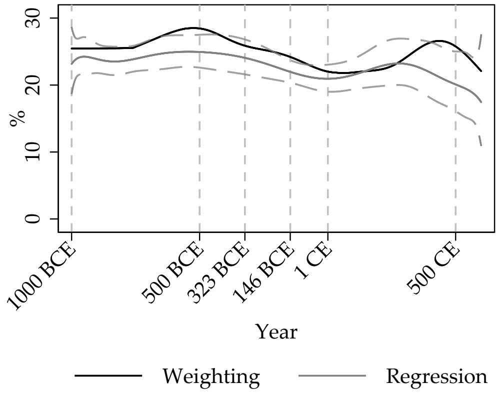
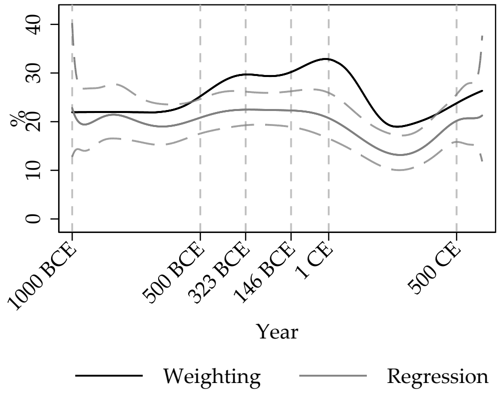
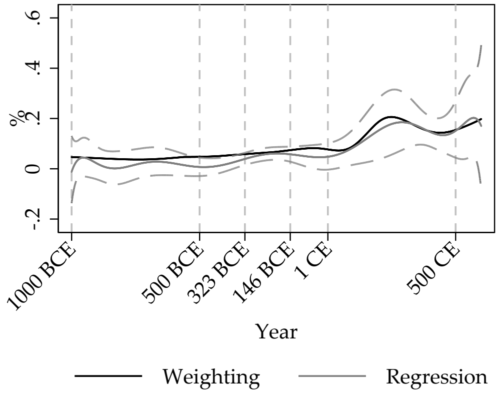
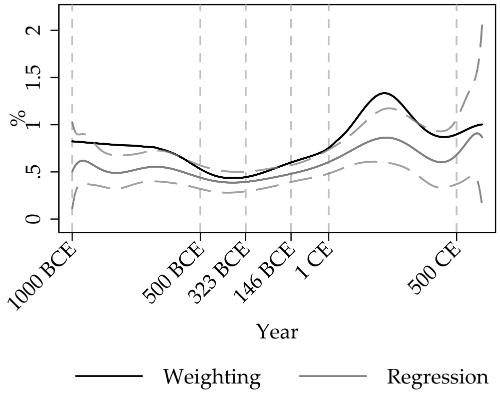


Figure A4: Weighting *vs* regression in Macedonia (cont.)


Deciduous trees


Coniferous trees


Salad burnet


Sorrel

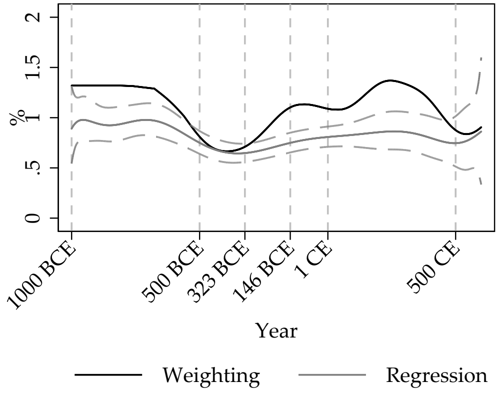

Ribwort plantain

Figure A5: Pollen data in southern Greece *vs* Mediterranean oil presses

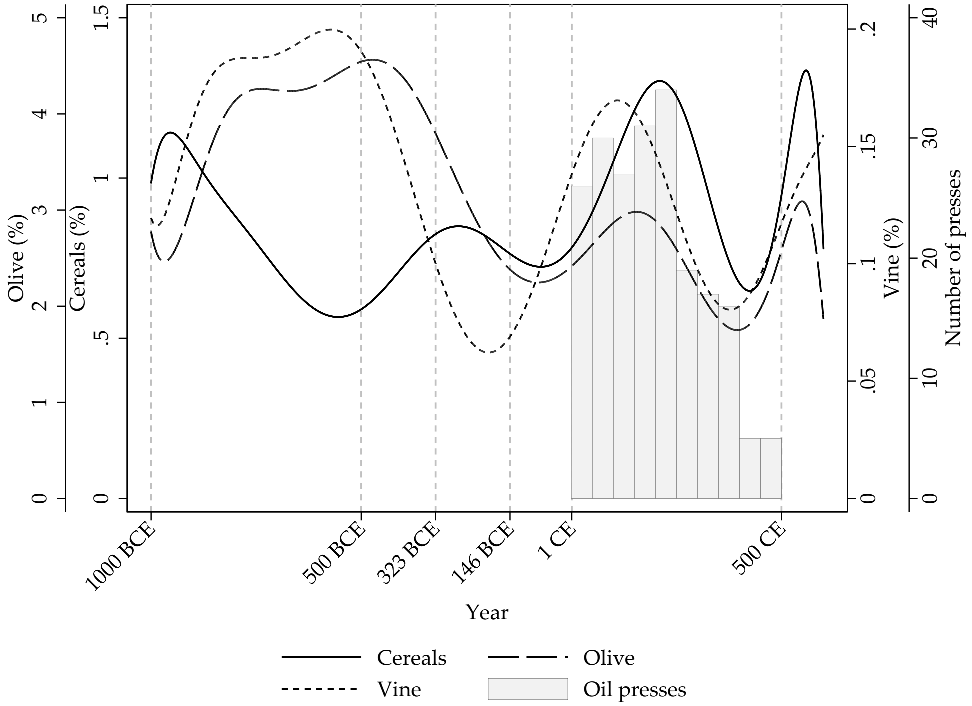


Figure A6: Pollen data in southern Greece *vs* Mediterranean wine presses