ONLINE APPENDIX FOR
"LANDSCAPE CHANGE AND TRADE IN ANCIENT GREECE: EVIDENCE FROM POLLEN DATA"

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Appendices

Appendix A Data

Our data set contains information about pollen proportions attributable to twenty-three different plant taxa. Table A1 reports the conventional names of these taxa, as used in palynology, and their English translations. For ease of interpretation, Table A1 also classifies the plant taxa into five broad categories: primary anthropogenic indicators, secondary anthropogenic indicators, open vegetation, deciduous trees, and evergreen trees.

In Izdebski *et al.* (2019), we focus exclusively on *(i)* cereals, olive, and vine, which all belong to primary anthropogenic indicators; and *(ii)* the summary indicators for grasses and the two types of forest dominant in southern Greece—coniferous, which consists of pine and fir, and deciduous, which consists of alder, hazel, hornbeam, and deciduous oak. Figure B2 in online Appendix B shows our trend estimates for the remaining primary anthropogenic indicators as well as for all secondary anthropogenic indicators available in our data. For clarity, we now briefly discuss the concept of secondary anthropogenic indicators as well as the indicators that are available in our data.

Secondary anthropogenic indicators, or synanthropic plant taxa, are plants—such as weeds of cereal fields and pastures—that thrive in ecosystems created by human agriculture despite not being actually cultivated (Behre, 1981; Bottema and Woldring, 1990).

As reported in Table A1, our data set contains information about four secondary anthropogenic indicators: Cichorieae, ribwort plantain, sorrel, and salad burnet. These plant taxa are regarded as human impact indicators in the Mediterranean ecosystems and are also referred to as wild synanthropic plants. They are weeds and ruderals, growing within farming contexts and on open disturbed ground, as they are involuntarily favoured by the spread of agricultural activities. These herbs are useful for reconstructing the dynamics of past and present anthropic ecosystems (see, *e.g.*, Kouli *et al.*, 2018).

Cichorieae are herbs belonging to the family of Asteroideae, including lettuce, chicory, dandelion, and salsify. The pollen of Cichorieae is abundant in pasture land and is linked to herbivore action and animal browsing leading to a certain selection of plants. Thus, palaeoecological studies in the Mediterranean consider the pollen of Cichorieae as one of the most important pastureland or grazing indicators (see, *e.g.*, Florenzano *et al.*, 2015).

Ribwort plantain (*Plantago lanceolata*) is a common weed of cultivated land. Sorrel (*Rumex acetosa*) is a perennial herb common in grasslands. Salad burnet (*Sanguisorba minor* or *Sarcopoterium*) is a perennial and drought-tolerant herb that is typically found in dry limestone-soil meadows. These plants are apophytes as described above, growing on disturbed land, while salad burnet is also one of the indicators used for pastoralism in the Mediterranean (see, *e.g.*, Bottema and Woldring, 1990; Eastwood *et al.*, 1999).

Table A1: *Plant Taxa*

Conventional name	English translation
Primary anthropogenic indicators	
Cerealia-type	cereals
Olea	olive
Vitis	vine
Castanea	chestnut
Juglans	walnut
Secondary anthropogenic indicators	
Cichorieae	a plant tribe incl. lettuce, chicory, dandelion, and salsify
Plantago lanceolata type	ribwort plantain
Rumex acetosa type	sorrel
Sanguisorba minor	salad burnet
Open vegetation	
Artemisia	a plant genus incl. mugwort, wormwood, and sagebrush
Chenopodiaceae	a plant family, also called the goosefoot family
Cyperaceae	sedges
Poaceae	grasses
Deciduous trees	
Alnus	alder
Carpinus betulus	common hornbeam
Corylus	hazel
Fagus	beech
Fraxinus ornus	manna ash
Quercus robur type	deciduous oak
Evergreen trees	
Abies	fir
Juniperus	juniper
Pinus	pine
Quercus ilex type	evergreen oak

Table A2: *Further Information About Pollen Sites in Southern Greece*

ID	Site name	Latitude	Longitude	Original publication	Age-depth model
1	Vravron	37.924979	24.000511	Kouli (2012)	Triantaphyllou *et al.* (2010), Weiberg *et al.* (2016)
2	Elefsina	38.006857	23.459553	Kyrikou *et al.* (2019)	Kyrikou *et al.* (2019)
3	Lerna	37.579213	22.72825	Jahns (1993)	Izdebski *et al.* (2015)
4	Kotychi	38.000171	21.302356	Lazarova *et al.* (2012)	Weiberg *et al.* (2016)
5	Voulkaria	38.875204	20.833328	Jahns (2005)	Izdebski *et al.* (2015)
6	Halos	39.16667	22.83333	Bottema (1988)	Izdebski *et al.* (2015)

Notes: Site identifiers correspond to those in Figure 1 and Table 2 in Izdebski *et al.* (2019).

Table A3: *Snippet of Our Data Set*

site	year	cereals	olive	vine	chestnut	walnut	…
Vravron	1069 BCE	5.1990	1.5290	0.3058	n/a	0	…
Vravron	971 BCE	3.8340	0.6390	0	n/a	0	…
Vravron	872 BCE	1.0310	6.5290	0.3436	n/a	0	…
Vravron	774 BCE	0.2387	5.9670	0	n/a	0	…
Vravron	676 BCE	0.9434	6.6040	0.3145	n/a	0	…
Vravron	578 BCE	0.4357	4.1390	0	n/a	0.2179	…
Vravron	479 BCE	0.2786	5.8500	0.2786	n/a	0	…
Vravron	381 BCE	0.3521	9.5070	0.3521	n/a	0.3521	…
Vravron	283 BCE	0.3268	1.6340	0	n/a	0.3268	…
Vravron	185 BCE	0.9646	1.2860	0	n/a	0.6431	…
Vravron	86 BCE	0.6098	0.6098	0	n/a	1.2200	…
Vravron	37 BCE	0.2288	1.1440	0.2288	n/a	0.4577	…
Vravron	61 CE	0.5882	1.1760	0	n/a	1.4710	…
Vravron	110 CE	0.4545	0.9091	0.2273	n/a	0.6818	…
Vravron	209 CE	0.7895	0.7895	0	n/a	0.2632	…
Vravron	307 CE	0.8475	0.8475	0	n/a	0	…
Vravron	405 CE	0.4587	0.6881	0	n/a	0	…
Vravron	503 CE	0.2252	0.6757	0	n/a	0	…
Vravron	730 CE	3.2000	3.0000	0.2000	n/a	0	…
…	…	…	…	…	…	…	…

Notes: All variables are measured in percentages, relative to the pollen sum. 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 (see also Izdebski *et al.*, 2019). The data on chestnut are not available at the pollen sites of Vravron and Elefsina.

Table A4: *Summary Statistics*

	No. of obs.	Mean	Std. dev.	Median
cereals	115	1.09	1.29	0.60
olive	115	4.86	3.64	4.57
vine	115	0.19	0.25	0.17
chestnut	73	0.05	0.10	0
walnut	115	0.15	0.26	0
Cichorieae	115	4.08	4.27	3.04
ribwort plantain	115	0.45	0.58	0.30
sorrel	74	0.20	0.30	0
salad burnet	115	0.70	1.06	0.33
Artemisia	115	0.67	0.66	0.56
Chenopodiaceae	115	4.00	7.91	1.19
sedges	115	5.66	12.94	0.90
grasses	115	5.41	3.51	5.12
alder	101	0.70	0.61	0.64
common hornbeam	115	0.74	0.92	0.35
hazel	115	0.36	0.38	0.25
beech	92	0.36	0.36	0.27
manna ash	115	1.95	4.07	0.37
deciduous oak	104	4.02	2.63	3.63
fir	115	2.30	5.17	0.52
juniper	115	0.25	0.49	0.11
pine	115	19.89	24.92	4.90
evergreen oak	104	29.48	19.79	26.50

Notes: All variables are measured in percentages, relative to the pollen sum. 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 (see also Izdebski *et al.*, 2019).

Appendix B Empirical Results

Figure B1: *Cereals, Olive, and Vine in Southern Greece*

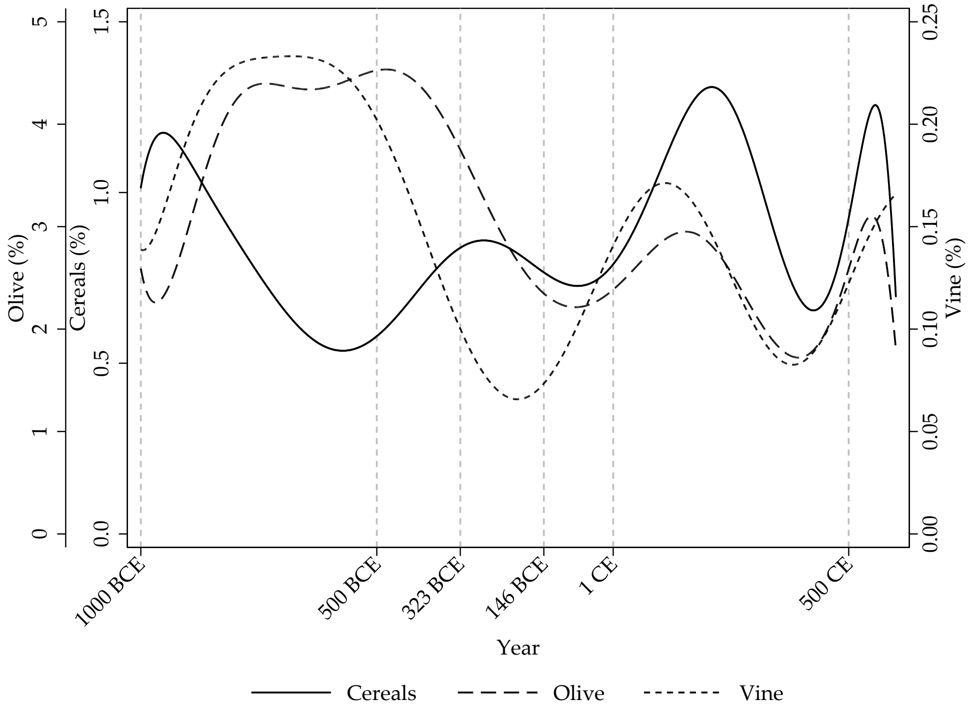
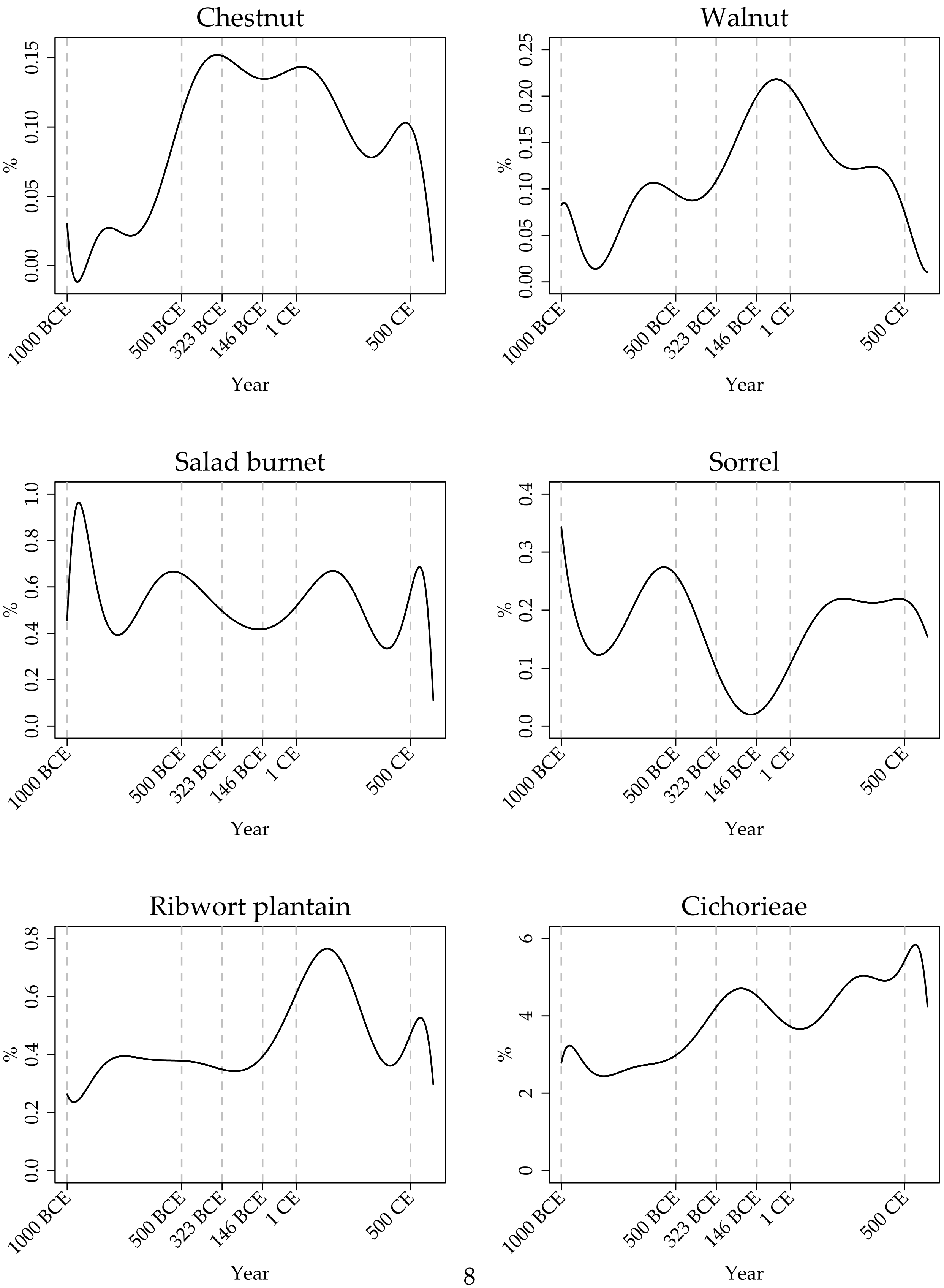


Figure B2: *Other Anthropogenic Indicators in Southern Greece*



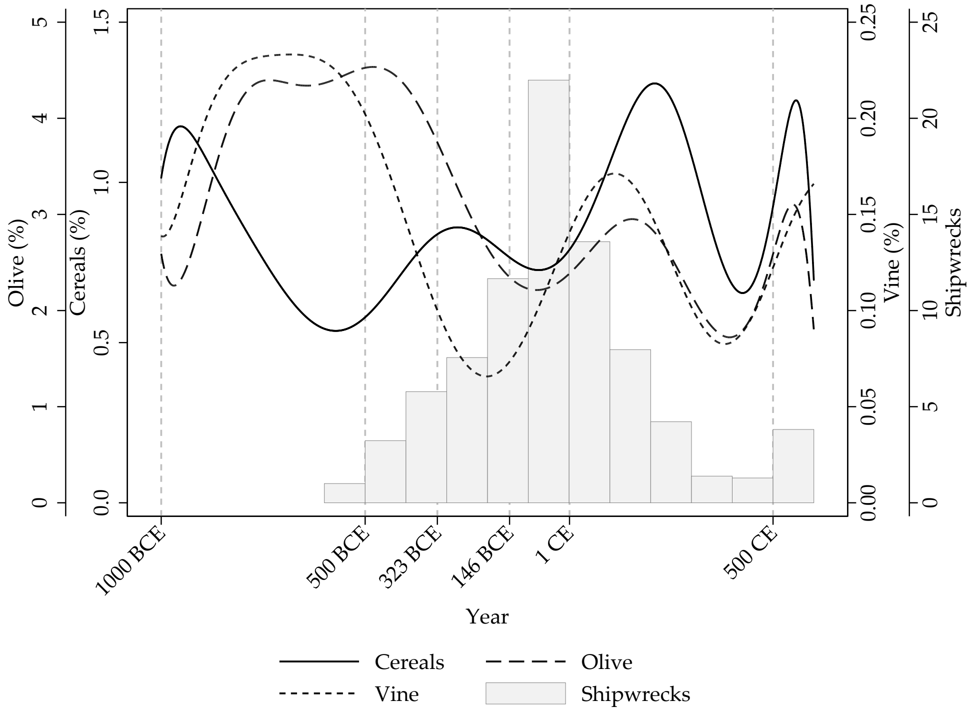
Appendix C Mediterranean Shipwrecks

As a robustness check, we 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 analysing 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. 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 in the 2nd century, and 1/4 in the 3rd century CE. See also McCormick (2016) for a further discussion of methodological issues in shipwreck-based studies.

We implement both of these recommendations in Figure C1, which is a revised version of Figure 4 in Izdebski *et al.* (2019). 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 *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.

Finally, we revisit the calculations reported in footnote 13 in Izdebski *et al.* (2019). We match the prorated number of shipwrecks in each century with our trend estimates for the midpoint of this century. Unsurprisingly, when we focus on the period from the 1st century BCE onward, the correlations become much lower than before; they are now equal to -0.2802, 0.0985, and 0.2774 for cereals, olive, and vine, respectively. However, if instead we focus on the period from the 1st century CE onward—dropping a single outlier—these values increase to 0.1684, 0.4904, and 0.8000, respectively.

Figure C1: *Pollen Data in Southern Greece vs Shipwrecks in Greece (Prorated)*



Appendix D Oil and Wine Presses

Figure D1: *Pollen Data in Southern Greece vs Mediterranean Wine Presses*

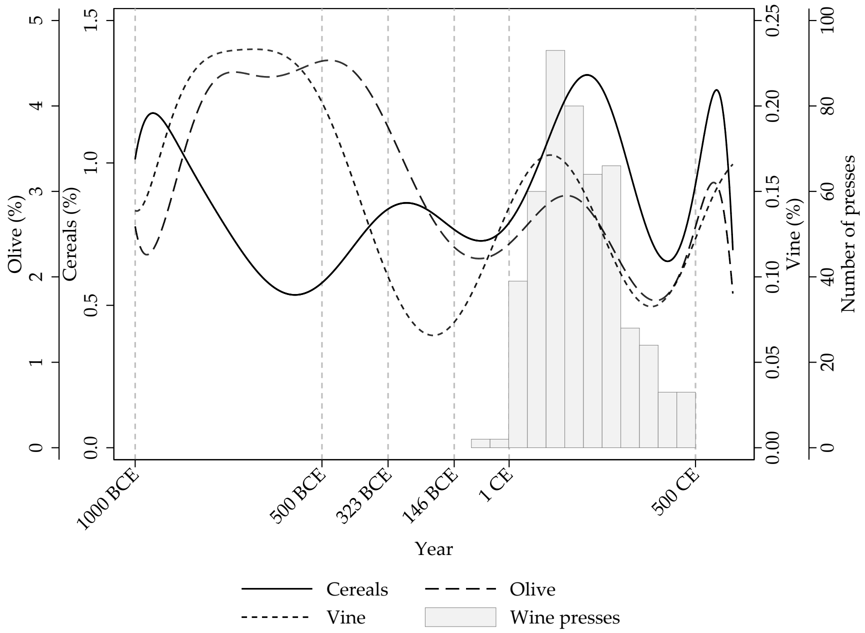
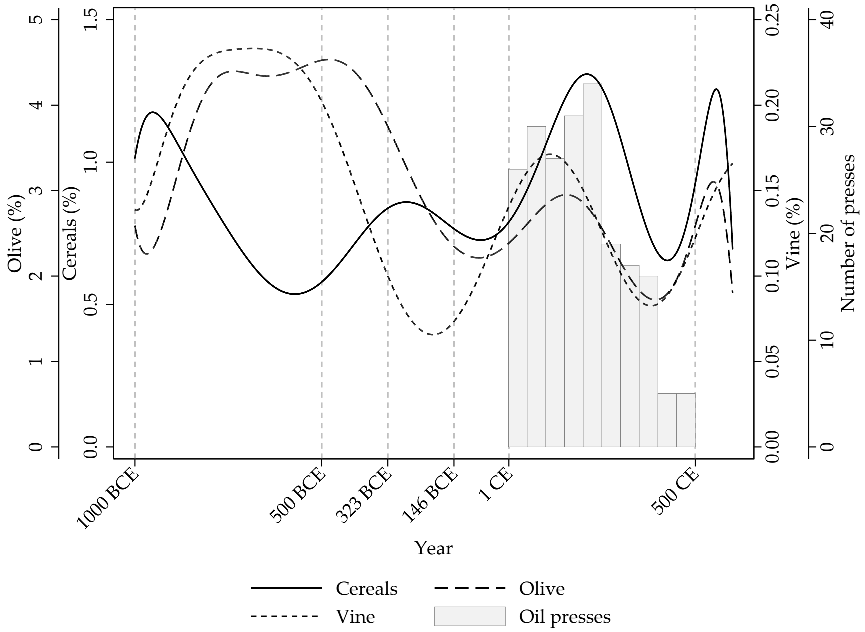
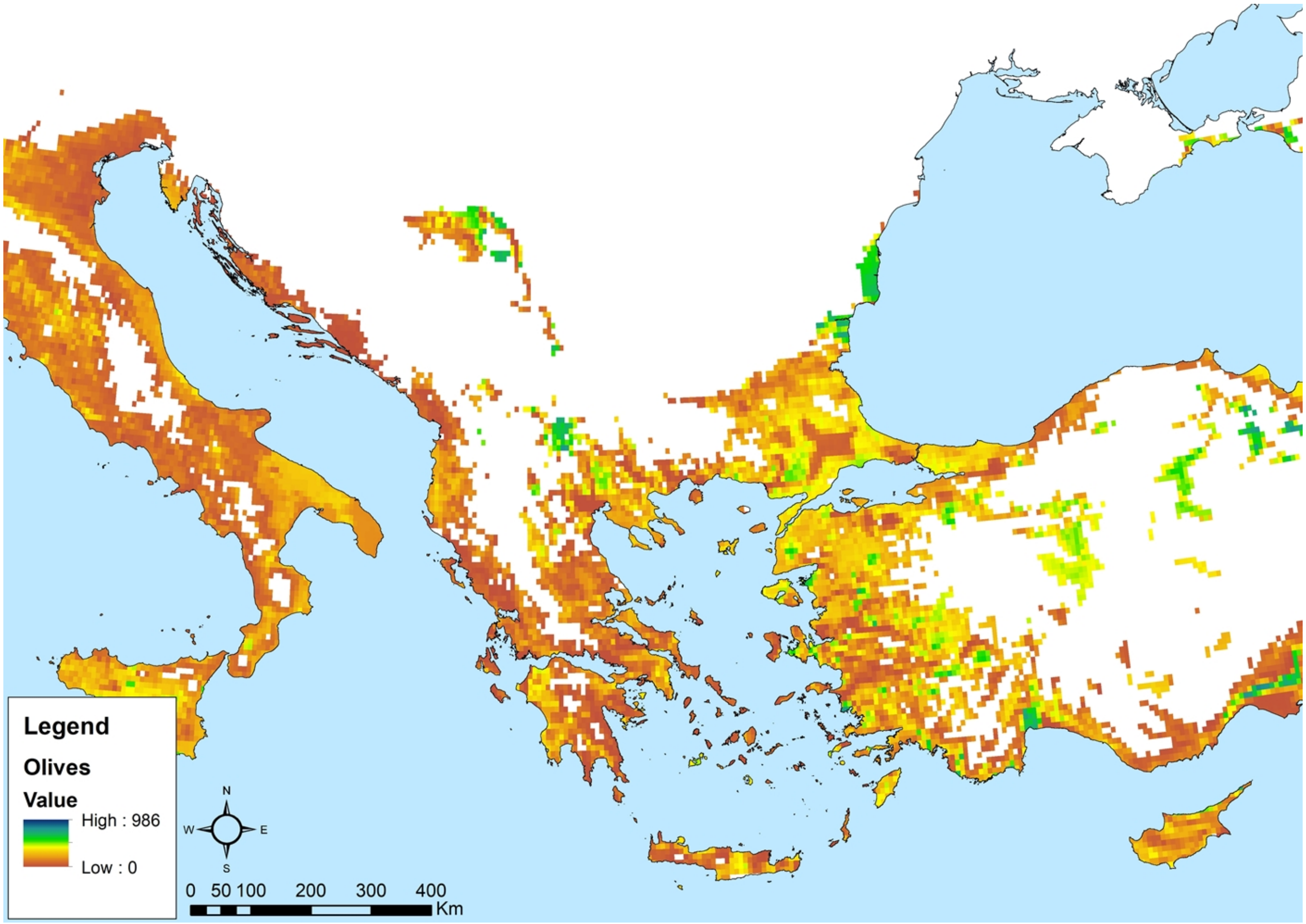


Figure D2: *Pollen Data in Southern Greece vs Mediterranean Oil Presses*



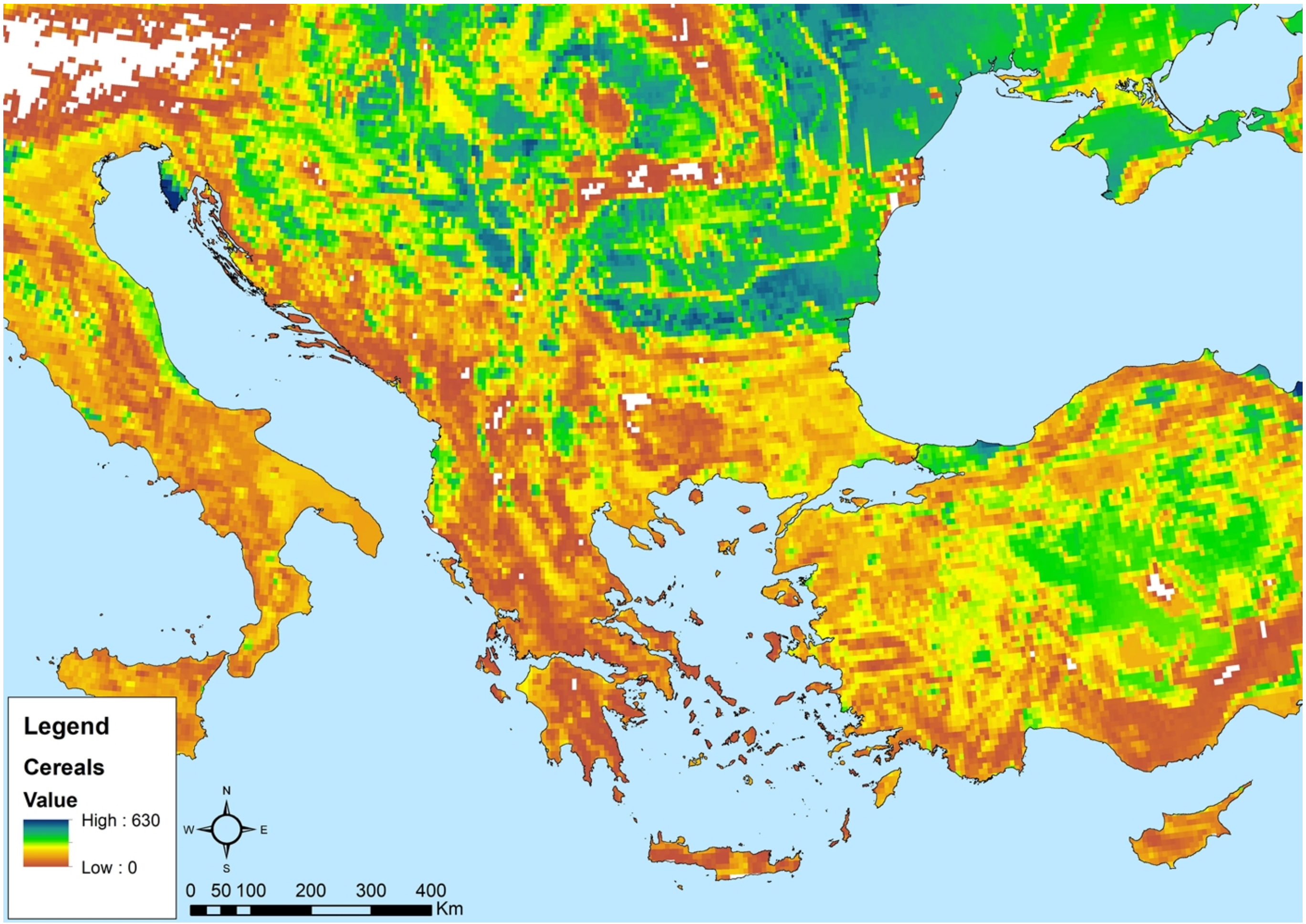
Appendix E Evidence on Comparative Advantage

Figure E1: *Suitability for Cultivating Olive in the North-Eastern Mediterranean*



Notes: The map shows micro-level information on the total production capacity (t/ha) for low input level rain-fed olive in the north-eastern Mediterranean. The data come from the Food and Agriculture Organization (FAO)'s Global Agro-Ecological Zones (GAEZ) project (FAO/IIASA, 2011). We use data for the baseline period 1961–1990 without CO2 fertilization.

Figure E2: *Suitability for Cultivating Cereals in the North-Eastern Mediterranean*



Notes: The map shows micro-level information on the total production capacity (t/ha) for low input level rain-fed cereals in the north-eastern Mediterranean. The data come from the Food and Agriculture Organization (FAO)'s Global Agro-Ecological Zones (GAEZ) project (FAO/IIASA, 2011). We use data for the baseline period 1961–1990 without CO2 fertilization.

Table E1: *Suitability for Cultivating Olive and Cereals Across the Mediterranean*

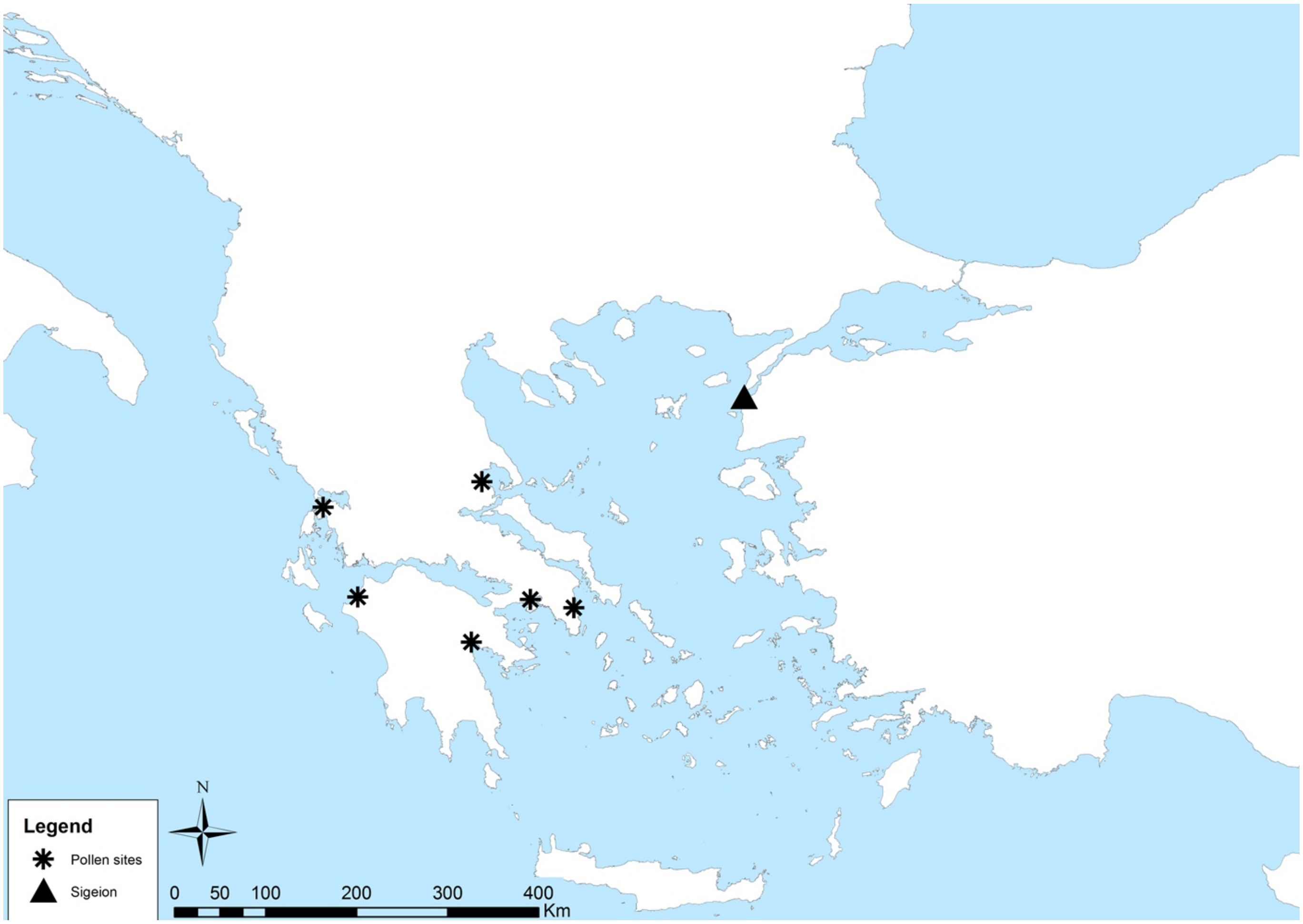
Location	Present-day country	Latitude	Longitude	Olive suitability		Cereal suitability		Ratio of means
				Mean	Std. dev.	Mean	Std. dev.	
Pollen sites								
Vravron	Greece	37.924979	24.000511	179.93	94.14	65.84	37.59	2.733
Elefsina	Greece	38.006857	23.459553	138.45	96.49	65.37	44.57	2.118
Lerna	Greece	37.579213	22.72825	76.55	72.17	44.51	43.35	1.720
Kotychi	Greece	38.000171	21.302356	198.79	137.30	137.08	40.66	1.450
Voulkaria	Greece	38.875204	20.833328	78.67	67.96	61.42	39.59	1.281
Halos	Greece	39.16667	22.83333	121.54	67.15	72.92	39.55	1.667
Mean				132.32		74.52		
Possible colonization targets and trading areas								
Marseille	France	43.2964	5.37	137.67	67.98	135.92	52.17	1.013
Carthage	Tunisia	36.853056	10.323056	205.18	100.40	136.63	26.77	1.502
Cumae	Italy	40.848611	14.053611	101.30	38.42	101.97	49.67	0.993
Syracuse	Italy (Sicily)	37.083333	15.283333	184.96	54.35	91.37	34.56	2.024
Metapontion	Italy	40.383333	16.824444	169.21	45.54	127.49	28.91	1.327
Cyrene	Libya	32.825	21.858056	277.71	117.82	106.54	51.11	2.607
Byzantion	Turkey	41.013889	28.955556	188.63	113.93	164.27	90.23	1.148
Chersonesus	Ukraine (Crimea)	44.611667	33.493333	0	0	334.75	79.36	0
Tyre	Lebanon	33.271944	35.194444	230.80	61.98	104.47	33.18	2.209
Mean				166.16		144.82		

Notes: The table presents information on six pollen sites, as in Figure 1 and Table 2 in Izdebski *et al.* (2019), and nine comparison locations across the Mediterranean. Summary statistics for olive and cereal suitability are based on micro-level information on the total production capacity (t/ha) for low input level rain-fed olive and cereals. The data come from the Food and Agriculture Organization (FAO)'s Global Agro-Ecological Zones (GAEZ) project (FAO/IIASA, 2011). We use data for the baseline period 1961–1990 without CO2 fertilization. The summary statistics are calculated within circles with a radius of 0.356 degrees (*c.* 30–40 kilometres) around each location.

Appendix F Distance to the Black Sea

Sigeion was an ancient Greek city-state located on the Aegean shore of Anatolia, close to the modern village of Kumkale and a few kilometres to the northwest of the legendary city of Troy. Sigeion marks the entrance to the Dardanelles, when coming from the Aegean Sea. Sigeion existed from the 8th/7th century BCE, when it was founded by Greek colonists, until *c.* 1st century BCE. However, the name continued to be used throughout the Roman period, and thus it represents the entry point to the Dardanelles in the ORBIS model. For more information on Sigeion, see Schwertheim (2008). The location of Sigeion is also presented in Figure F1.

Figure F1: *Location of Sigeion*



Notes: The map shows the location of six pollen sites, as in Figure 1 and Table 2 in Izdebski *et al.* (2019), and the location of the city of Sigeion (39.992624, 26.186336).

Table F1: *Distances and Trade Costs from Southern Greece to Sigeion*

Pollen site (*a*)	ORBIS site (*b*)	Latitude of *b*	Longitude of *b*	Distance from *a* to *b*	Distance from *a* to Sigeion	Trade cost from *b* to Sigeion
Vravron	Sounion Pr.	37.6544	24.01714	30	297	0.53
Elefsina	Eleusis	38.03251	23.54241	8	323	0.57
Lerna	Skyllaion Pr.	37.43339	23.51855	72	402	0.69
Kotychi	Patrae	38.25267	21.73379	47	476	1.08
Voulkaria	Leucas	38.83589	20.71275	11	476	1.11
Halos	Demetrias	39.2929	22.90537	15	301	0.61

Notes: The table presents information on six pollen sites (*a*), as in Figure 1 and Table 2 in Izdebski *et al.* (2019), and the nearest coastal destination points (*b*) in the Stanford Geospatial Network Model of the Roman World (ORBIS). Distances from *a* to *b* and from *a* to Sigeion are the great circle distances and are reported in kilometres. They were calculated using the Latitude/Longitude Distance Calculator, provided by the National Hurricane Center (NHC) and the Central Pacific Hurricane Center (CPHC) of the U.S. National Weather Service. Trade costs from *b* to Sigeion are the transport costs of one kilogram of wheat in July and are reported in denarii. They were calculated using ORBIS. We used the following settings in the ORBIS model: summer (season of departure); cheapest (priority); road, river, coastal sea, open sea (network mode); donkey on road, civilian boat on the river, slow sea (mode); and zero transfer costs. The correlation between the distance from *a* to Sigeion and the trade cost from *b* to Sigeion is 0.9531. The Latitude/Longitude Distance Calculator can be accessed at `https://www.nhc.noaa.gov/gccalc.shtml`. ORBIS can be accessed at `http://orbis.stanford.edu/`.

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