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The Establishment of the Agricultural Landscape of Central Sicily Between the Middle Neolithic and the Beginning of the Iron Age

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Abstract

The possible co-variation of human occupation and vegetation from the Middle Neolithic to the beginning of the Iron Age (7.5–2.8 ka BP) in Central Sicily in the context of the central Mediterranean between Middle and Late Holocene are analysed in this paper to provide new insights on Sicilian prehistoric demography. The demographic and economic trends during these millennia were reconstructed using archaeological, Accelerator Mass Spectrometry ^{14}C dates, palynological, archaeobotanical, and zooarchaeological data from the northern, central, and southern sectors of Central Sicily through a diachronic comparison with variation in Arboreal Pollen, Anthropogenic Pollen Indicators, *Olea-Juglans-Castanea* pollen, microcharcoals, and *Sporormiella* from four pollen cores from sites in different ecosystems. A very significant spread of farming activities was found at the end of the Neolithic, together with an apparent demographic gap during the Middle Copper Age, and the emergence of agricultural landscapes at the end of the Copper Age associated with a striking increase in population. A combination of cultural and climatic changes during the late phase of the Bronze Age resulted in a subsequent overall decrease in population.

Keywords Prehistory · Paleodemography · Paleoenvironment · Pollen · Botany · Zooarchaeology · AMS · Neolithic · Bronze Age · Agricultural landscapes · Human impacts · Central Sicily · Mediterranean

Introduction: Prehistoric Demography and Paleoenvironment of a Big Island

Due to their physical boundaries, islands evidence some ecosystems processes that are more difficult to isolate in continental areas (Kueffer et al., 2016; Whittaker et al., 2017). The central geographic location of Sicily and other Tyrrhenian islands in the Mediterranean Basin makes them a critical region for the study of Quaternary climates and environments (Lionello et al., 2006; Tinner et al., 2009; Guarino & Pasta, 2018) and as natural laboratories of plant evolution (Pasta & La Mantia, 2013; Thompson, 2020). The large islands have contributed to the conservation of middle Tertiary flora with a high degree of endemism (Magri et al., 2017), which in Sicily results also from its very complex geology and natural history (Quézel, 1995; Médail & Quézel, 1997) due to extremely varied lithographic and orographic features, hydrographic network, and morphogenetic processes (Catalano et al., 1996; Speranza et al., 2003).

Sicilian prehistory is an intriguing puzzle of several trajectories from the Eastern to the Western Mediterranean

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and, at the same time, from Central Europe and the Italian peninsula to Northern Africa. Its importance in the Mediterranean Basin is due not just to its geographical location but also to its ecological diversity, cultural heritage, and historical significance (Romano et al., 2021). Understanding the dynamics and interactions of human communities within their environment has become one of the most significant improvements of recent archaeological studies in Sicily (Pasta & Speciale, 2021; Pasta et al., 2022). Nevertheless, there has not been a comprehensive study to evaluate Sicilian sub-regional human patterns, the use of abiotic (water, soil) and plant resources, and the main climatic trends between the Middle Holocene and the beginning of the Late Holocene.

In a broader archaeological framework, studies on prehistoric demographic trends have exponentially increased over the last 20 years (Shennan & Edinborough, 2007), creating what is termed the "boom-and-bust" theory in prehistoric demography, whose causes are not always easy to disentangle from climate and sociocultural changes (Shennan & Saer, 2021) and human conflicts (Kondor et al., 2022). A specific focus has been on the relationships among environmental trends (Capuzzo et al., 2018) and the correlation between the increase in human population and arboreal pollen percentages, notably tree crops (Bevan et al., 2019). Roberts et al. (2019; 11) note: "The results show that most Mediterranean regions experienced a series of population 'cycles' starting with the first appearance of Neolithic farming societies, but that demographic trends were region-specific rather than pan-Mediterranean." The whole Mediterranean Basin as well as specific regions, have become the core area of demographic research based on large radiocarbon AMS datasets, their Summed Probability Distribution (SPD), and/or Kernel Density Estimation (KDE) models (e.g., Palmisano et al., 2021; Parkinson et al., 2021). Of course, SPD in demography should not be applied uncritically and should always be supported by the analysis of a very large dataset and, is ultimately mostly effective in evaluating multiregional trends (Crema, 2022). Using this framework for prehistoric Sicily is problematic because only a very small percentage of the many archaeological sites identified by surveys and/or archaeological excavations has been radiocarbon-dated (Giannitrapani, 2023). Thus, to preserve, evaluate, and exploit the considerable amount of archaeological data, any demographic estimate needs to rely on a network of relative chronology, whose precision can and must be profoundly enlarged. Even so, a picture of human occupation density based only on radiocarbon-dated sites could be severely misleading. We argue that discussion of not AMS-dated archaeological sites is necessary to gain further insight into demographic trends, revealing a crucial perspective on settlement spread and adding, when available, first-hand information on interactions between landscape and human communities' economic systems.

Paleodemography in Sicily and in some of its subregions has been approached by several authors, starting from the Paleolithic to the end of the Bronze Age. The island underwent a "late" process of human colonization, as an essential and recent line of research on the most ancient phases revealed (Lo Vetro & Martini, 2012; Di Maida et al., 2020; Romano et al., 2021). The human presence and its spread in some limited areas have been topics of several dedicated investigations from the Neolithic and/or Copper Age (CA) (Natali & Forgia, 2018; Giannitrapani & Iannì, 2020) to the Bronze Age (BA) (Bietti Sestieri, 2013; Pacciarelli et al., 2015; Battaglia et al., 2020; Martinelli, 2020; Speciale, 2021) to prehistoric diachronic occupation (Forgia et al., 2012; Cultrera, 2014; Giannitrapani, 2017), in some cases applying Bayesian methods (Alberti, 2013).

The literature on the occupation of the island before the historical Greek colonization (9.0–3.0 cal ka BP) (Tusa, 1999; Leighton, 1999; Albanese, 2003; Pasta et al., 2022) records intriguing oscillations, displacements, and occupation patterns that can be evaluated within the regional context but also into the broader Mediterranean context. Human genetic data are opening interpretations of prehistoric migrations that sometimes challenge previous archaeological assumptions about the timing and modes of population displacements among regions and can be crucial in the evaluation of demographic changes in Sicily (Sarno et al., 2017; Fernandes et al., 2020).

Human activity can be one of the main factors of landscape disturbance. Archaeobotanical research facilitates the identification of reciprocal influences of human and plant communities (Marignani et al., 2017; Mercuri & Florenzano, 2019; Michelangeli et al., 2022), notably on islands (Nogué et al., 2021), to improve our understanding of demographic patterns (Mercuri et al., 2019a). Although limited, archaeobotanical analyses for prehistoric Sicily provide insights into human communities' economic and cultural strategies, including local woodland management practices and agricultural choices and techniques (e.g., Mercuri et al., 2020; Speciale et al., 2020). Ultimately, zooarchaeological analyses may contribute to reconstructing past human economies, evaluating landscape degradation, and improving our knowledge of past ecology (Steele, 2015).

Research on the Holocene on the island has also focused on the collection of datasets from the lacustrine sediments in Central Sicily (Sadori & Narcisi, 2001; Sadori et al., 2008, 2013, 2015; Zanchetta et al., 2007, 2022), southern coastal Sicily (Calò et al., 2012; Tinner et al., 2009; Noti et al., 2009; Magny et al., 2011), northern mountainous Sicily (Bisculm et al., 2012; Tinner et al., 2016) for the reconstruction of the paleoenvironment and human impacts on vegetation. Pollen and marine calcareous nannofossils extracted from marine

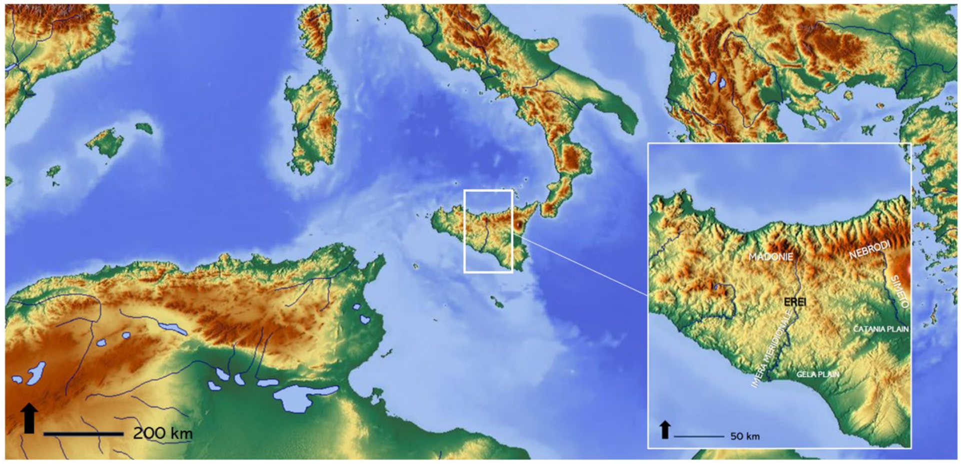


Fig. 1 Position of Sicily within the Mediterranean Basin and main geographical areas cited in the text

sediment cores and stable isotopes of speleothems have served as proxies to quantify climate parameters and climate variability for the broader paleoclimatic picture (Incarbona et al., 2008, 2010; Frisia et al. 2006; Desprat et al., 2013).

We present an analysis of the variation in human occupation and vegetation in Central Sicily from the Middle Neolithic (MN) to the beginning of the Iron Age (7.5–2.8 cal ka BP).[1] We focus on three specific questions on establishing the agrarian landscape (i.e., the extensive reliance on crop resources) and detecting the human impacts: 1) Can we identify such human impacts in the Middle Neolithic period, or were the agrarian landscapes structured later? 2) Can we positively relate demographic oscillations during the Copper Age and Bronze Age to crucial climatic variations, such as increased aridity? and 3) did coastal and inland human communities adopt different settlement strategies?

Geological, Geomorphological, and Vegetational Framework

Sicily (36°N to 38° N and from 12°E to 15° E.) is the largest island of the Mediterranean Basin, with an approximately triangular shape and a distance of ca. 250 km east to west and varying between 80 km (east) and 190 km (west) north to south. It is characterized by a Mediterranean climate, with average annual temperatures of 17–18 °C in the coastal areas, decreasing to 10 °C in the higher mountain areas (Viola et al., 2014). The island hosts about 3,200 native species, of which 10% are endemic (Brullo & Brullo, 2021), 23–25 vegetational bioclimatic assemblages (Bazan et al., 2015), and 250 biotopes and biotope complexes of fauna and vegetation (Piano Territoriale Paesistico Regionale Sicilia, 1996). The study area is a longitudinal transect of ca. 9000 km^2 spanning the mountainous areas of Madonie and Nebrodi in the north to the hilly landscape of the Erei's uplands to the southern coastal Gela Plain (Figs. 1 and 2).

Materials and Methods

To assess paleodemography, we used a main grid of AMS-dated sites. We evaluated the demographic spread in the study area based on the chronology of relative cultural elements (mostly pottery). We then compared the demographic data with the vegetational trends recorded on four lacustrine sites selected from those providing local and regional signals belonging to different phytoecological districts and with appropriate AMS dates correlated to the sedimentary sequence. When possible, we included the available data from wood charcoal remains, seeds, and faunal remains from the sites. We defined four chronological periods, divided according to major cultural changes: Phase A (Middle Neolithic, MN, 7.5–6.4 cal ka BP), Phase B (Late Neolithic - LN/Early and Middle Copper Age – ECA and MCA, corresponding for the discussion into B1 (6.4–5.3 cal ka BP, LN-ECA) and B2 (5.3–4.6 cal ka BP, MCA)), Phase C (Late Copper Age - LCA/Early Bronze Age - EBA, 4.6–3.6 cal ka BP), and Phase D (Middle Bronze Age - MBA/Late Bronze Age - LBA, 3.6–2.8 cal ka BP). We follow Leighton (1999) as well as Maniscalco (2007), Giannitrapani (2009), and Adamo and Gullì (2012), who argue that the Copper Age is divided into only two phases – Early and Late– as opposed to the traditional three sub-phases, and engage with Giannitrapani's (2020, 2023) proposal of the possible existence of a single phase bridging the Late Neolithic and the Early Copper Age in central Sicily. Similarly, Phase C combines the traditional Late Copper Age and Early Bronze Age (see also Procelli, 2001; Alberghina & Gullì, 2011; Giannitrapani & Iannì, 2011, 2020; Giannitrapani et al., 2023).

[1] We do not address the Early Neolithic here because of the lack of data on the research area.

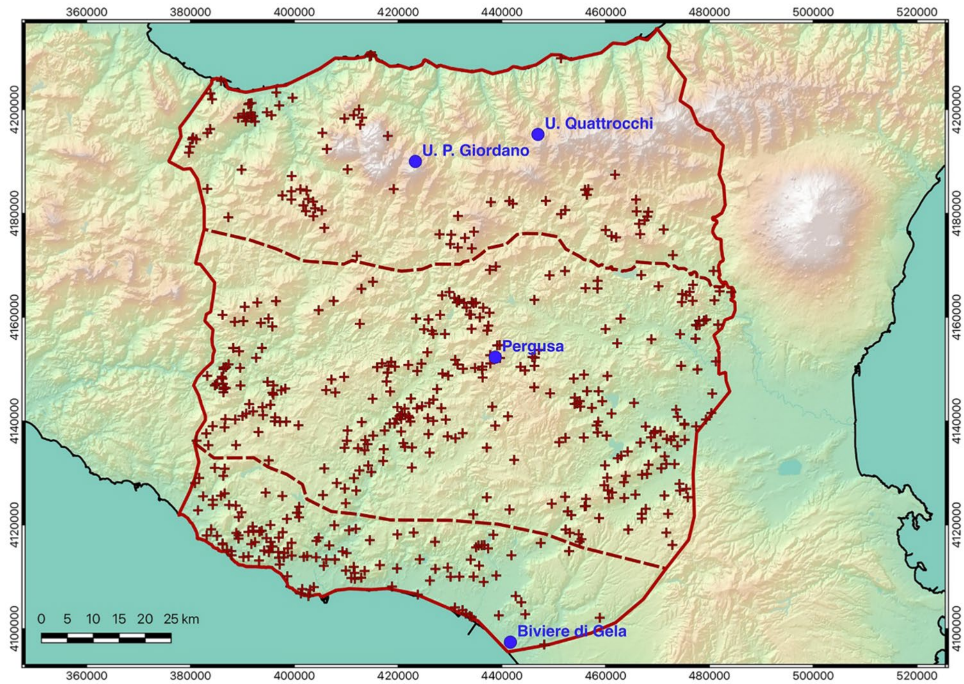


Fig. 2 Map of Sicily with indication of the study area, the archaeological sites of all the phases (crosses) and the 4 pollen sites (circles)

Archaeological Sites

Based on our research of the vast literature[2] on Sicily's prehistory, we include 524 archaeological sites (Fig. 2, Supplementary Materials: Table S1) divided according to their sector (northern, central, southern), indicating their phase(s) of occupation and the reliability of their chronological attribution (from 1 to 3). When a specific chronological span was not indicated in the original bibliographic source (i.e., only "prehistoric" or "Copper Age"), sites were not listed in the dataset. Beyond the issue of non-homogenous studies of the territory, where different archaeological investigations influenced the degree and significance of known archaeological remains, it is also essential to consider the change in coastlines during the Holocene that might have affected several kilometres of the southern sector (e.g., Pasta et al., 2022). Finally, it is noteworthy that the mountainous area of the northern sector currently has less archaeological data due to the scarcity of systematic investigations on the Nebrodi mountains. For the paleovegetational framework, in all sectors the archaeological sites are an average of between 30 and 50 km distant from the pollen sequence of reference, with the exception of the sites near Agrigento that are up to 70 km from the site of Biviere di Gela; nevertheless, the homogeneity of the coastal area and its vicinity between Gela and Agrigento allowed us to consider the sites at the westernmost part of the sector as comparable with the Biviere di Gela sequence.

We gathered our data from the relevant archaeological sections of the PTP (Piano Territoriale Paesaggistico), the regional landscape catalogue produced by the Sicilian Regional Office for Cultural Heritage, integrated by the results of past and recent extensive survey projects (northern sector: Belvedere, 2002; Mannino, 2008; Forgia, 2019; central sector: La Rosa, 1997; Thompson, 1999; Agodi et al., 2000; Iannì, 2004; Procelli et al., 2007; Ayala & Fitzjohn, 2007; Giannitrapani, 2017; Brancato, 2020; southern sector: Castellana, 1982; Guzzone, 1994; La Torre & Toscano Raffa, 2016).

AMS and Radiocarbon Dating

Despite a longstanding methodological resistance to the wide use of ^{14}C radiocarbon dating in defining the chronological framework of prehistoric Sicily, the situation has been changing rapidly, with many projects adopting multidisciplinary approaches. A recent survey conducted by the *Calib_Sicily* project (Giannitrapani, 2023) listed 262 dates collected from 64 sites distributed throughout Sicily and its satellite islands (Fig. 3).

For the study area, we have a total of 108 AMS and radiocarbon dates obtained from 22 sites (4 for the northern sector, 10 for the central sector, 8 for the southern sector) (Supplementary Materials), covering the four sub-phases for which the start and end boundaries are defined by the Bayesian modelling of the relevant dates (Table 1). The Bayesian

[2] The data were gathered from the authors' private collections of papers, books, and documents from Regione Sicilia.

Fig. 3 Distribution map of the sites with AMS and radiometric chronology selected in the study area

model presented here poses a series of methodological criticalities, mainly due to the limited dataset available (Table 1). However, we employed the model without referencing the statistical and analytical complex processes involved in such an analysis to provide a general chronological framework for the four sub-phases. The model evidences some gaps in the sequence. However, the gaps between Phases A and B (about 180 years) and between Phase C and D (about 50 years) are false since in the general regional modelled framework, these overlap each other, thus suggesting a lack of sampling and dating for the study area. On the other hand, the gap between Phase B and C (about 850 years) is also clearly evidenced in the modelled dates for the Sicilian CA, as shown by the probability density curve that sums up all the dates available for the study area and confirmed by the modelled data for the entire region (Fig. 4).

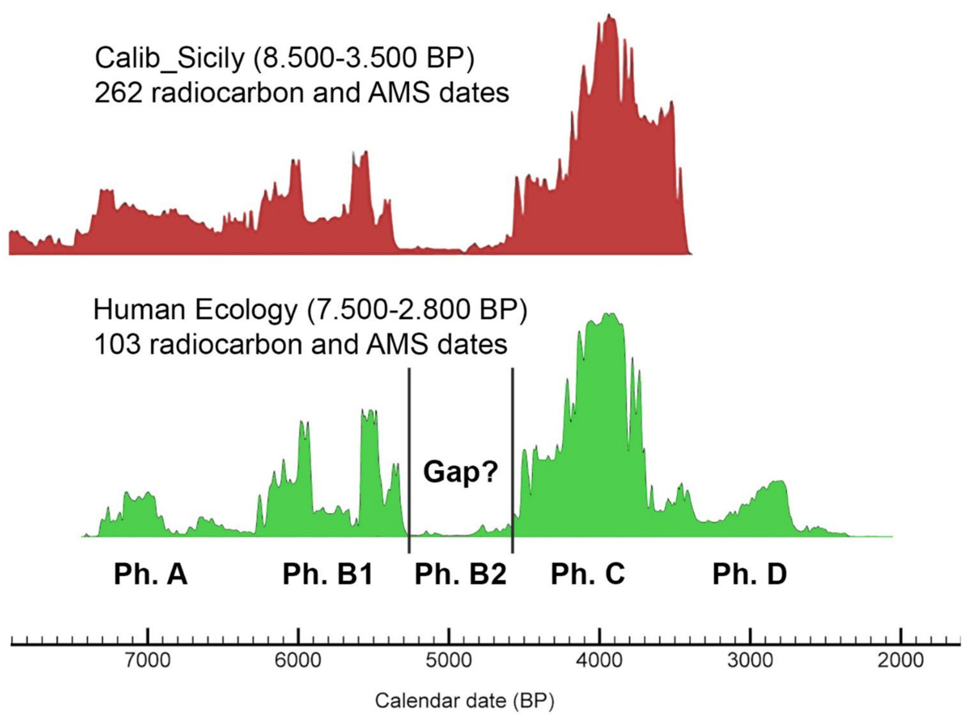


Fig. 4 Summed Probability Density curve for the AMS and radiocarbon dates from the study area (re-elaborated from Giannitrapani, 2023)

Table 1 Bayesian modelled yrs BP boundaries for the four phases discussed in the text

	Phase A	Phase B	Phase C	Phase D
Boundary Start	7350–7190	6235–6105	4490–4425	3590–3290
Boundary End	6660–6420	5420–5305	3685–3640	2790–2610

Archaeobotanical and Zooarchaeological Data

Archaeobotanical studies (plant macro- and micro-remains) from prehistoric contexts are scattered throughout the island. Some are more dispersed for the classical and medieval phases (Mercuri et al., 2015b, 2019b; Montecchi & Mercuri, 2018). Unfortunately, prehistoric analyses are centered on some "hotspots" such as North-Eastern Sicily for the BA, Western Sicily for the IA, and a reliable stratigraphic sequence from Mesolithic until LBA (Pasta & Speciale, 2021) (Fig. 5).

Only six sites in the study area have archaeobotanical analyses (Fig. 5; Table 2), covering from the MN to the LBA, but in very different ecological frameworks. Unfortunately, there is a big chronological gap between the early neolithization (Costantini & Costantini Biasini, 1997) and the widespread of domestic species during the CA (Speciale et al., 2020; Pasta & Speciale, 2021).

During the last 15 years, the use of stable isotopes allowed to increase the perspectives on local responses to environmental and climate changes. A series of AMS/IRMS analyses were conducted on plant remains from archaeological sites concomitant to carbon isotopic analyses, $\delta^{13}C$ (Ferrio et al., 2003). The Aeolian islands archaeobotanical dataset has been enriched with a series of AMS/IRMS analyses conducted on selected plant remains (Caracuta et al., 2012; Speciale et al., 2016). The most recent study of the isotope composition of seeds and wood charcoal remains from the site of Case Bastione gives a picture of the changes in aridity and manuring techniques (Speciale et al., 2020).

Sicily's zooarchaeological tradition is more consolidated, with a significant increase in studies since the 1990s. Data from Central Sicily are quite well represented, with 16 sites in total, six of which cover at least two chronological phases (Table 3); nevertheless, the applied sampling protocol is not always clearly reported, and data can be affected by different sampling methods adopted (see Prillo et al., in press).

Paleoenvironmental and Paleoclimatic Data

The estimation of the vegetation composition during the four time periods was calculated taking into account the pollen records referring to key species available in the northern, central, and southern sectors of the study area. The selected sites provide well-dated pollen records covering the last 7000 years (Table 4) and all the archaeological sites compared are located in similar environments and no more than 50 km distant from the site (see above). The four pollen sequences are in very different environments, from the mountainous areas of Madonie and Nebrodi in the northern sector, to the continental climate of internal Sicily down to the sandy coast of the southern sector. The north-easternmost sequence is Urio Quattrocchi, a perennial pond in the supra-Mediterranean belt (1044 m a.s.l.); despite its geographical position in the Nebrodi Mts., we treated it as a marked but controversial local indicator of climatic changes, especially for

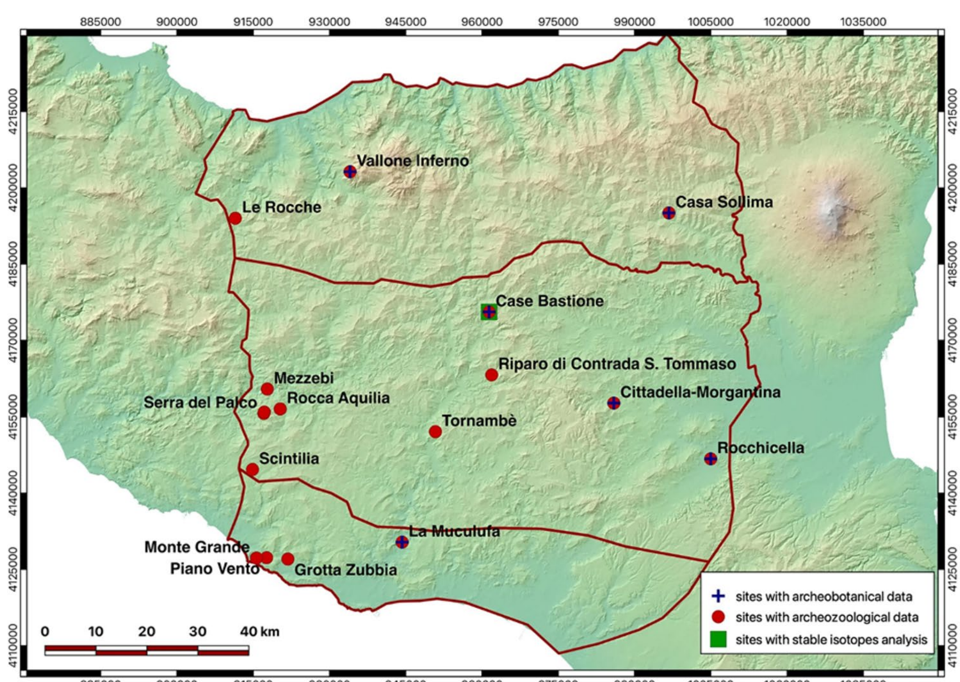


Fig. 5 Sites with published archaeoenvironmental data: zooarchaeological data (blue dots), zooarchaeological and archaeobotanical data (blue dots with a red cross), stable Carbon isotope analyses (green squares)

Table 2 List of the sites with archaeobotanical remains

Name	Rocchicella	Rocchicella	Rocchicella	C. Sollima	C. Bastione	V. Inferno	Rocchicella	Muculufa	Morgantina
Cultural Phase	**A - MN**	**B - ECA/MCA**	**B–C - MCA/LCA**	**B–C - MCA/LCA**	**C - LCA**	**C - EBA**	**C - EBA**	**C - EBA**	**D - LBA**
Arboreal plants									
Acer sp.						x			
Alnus sp.					x				
Carpinus sp.					x				
Erica arborea					x	x			
Ficus carica				x					
Fraxinus sp.		x				x			
Hedera helix						x			
Fabaceae			x			x			
Olea europaea	x	x	x	x		x	x		
Pistacia cf. *terebinthus*					x	x			
Populus/Salix		x							
Quercus sp.	x				x	x		x	x
Quercus type *cerris*									
Quercus type *ilex*	x	x	x		x	x			
Quercus type *robur*	x	x			x		x		
Rhamnus/Phillyrea					x	x			
Rosaceae/Maloideae					x	x			
Rosaceae/Prunoideae					x				
Ulmus sp.					x		x		
Pinus sp.								x	
Pinus type *silvestris/nigra*									
Seeds									
Cereals undiff	x	x			x				
Hordeum vulgare				x	x			x	
Triticum monococcum				x	x			x	
Triticum dicoccum		x			x			x	
Triticum cf. *spelta*					x				
Triticum aestivum (*compactum*)				x	x			x	
Triticum sp.		x			x	x			
Vicia faba				x				x	
Lens culinaris				x					
Pisum sp.				x				x	
Pisum cf. *sativum*	x	x							
Lathyrus sp.				x	x				

Table 2 (continued)

Name	Rocchicella	Rocchicella	Rocchicella	C. Sollima	C. Bastione	V. Inferno	Rocchicella	Muculufa	Morgantina
Cultural Phase	**A - MN**	**B - ECA/MCA**	**B–C - MCA/LCA**	**B–C - MCA/LCA**	**C - LCA**	**C - EBA**	**C - EBA**	**C - EBA**	**D - LBA**
Fabaceae > 0.5 cm					x				
Vitis vinifera				x				x	
cf. *Vitis vinifera*					x				
cf. *Ziziphus lotus*					x				
Olea europaea			x						
Lithospermum sp.								x	
Prunus sp.				x				x	
Avena sp.				x				x	
Anthemis sp.								x	
Calendula sp.								x	
Sinapis sp.								x	
Boraginaceae		x						x	
Brassicaceae					x				
Lamiaceae					x				
Fumaria officinalis-type						x			
Quercus sp.						x			
Rubus sp.				X		x			

Table 3 List of the sites with archaeozoological remains; the percentages are calculated on the NISP based on the data available in the publications; site number are related to Table S1

ID	Site	Phase	Chronology	*Ovis/Capra*	*Sus s.*	*Bos t.*	**Total Domestic**	Wild ruminants	Birds	Carnivora	Other	**Total Wild**	Reference
389	Serra del Palco I	A	Middle Neolithic	46.75%	19.57%	20.19%	**86.51%**	N/A	N/A	N/A	N/A	**11.72%**	Wilkens (1997)
200	Rocchicella	A	Middle Neolithic	9.8%	3.3%	8.2%	**21.3%**	76,2%	0	0	2.5%	**78.7%**	Di Patti and Lupo (2008)
486	Fiaccati/Le Rocche	A	Middle Neolithic	47%	21%	19%	**86.7%**	2%	2%	5%	4%	**5.41%**	Iannì et al. (2022)
407	Rocca Aquilia	B C	Copper Age	71.55%	6.03%	17.67%	**92.25%**	N/A	N/A	N/A	N/A	**3.44%**	Wilkens (1997)
200	Rocchicella	B C	Copper Age	51.9%	8.0%	25.9%	**85.8%**	12.6%	0.3%	0	1.3%	**14.2%**	Di Patti and Lupo (2008)
367	Scintilia	B	Early Copper Age	69.53%	8.15%	22.32%	**100.00%**	0	0	0	0	**0.00%**	Di Rosa (2014)
130	Casa Sollima	B	Early Copper Age	62.7%	11.5%	16.1%	**90.3%**	1.1%	0	0	8.6	**9.7%**	Ashley et al. (2007)
10	Case Bastione	C	Late Copper Age	56.6%	17.5%	8.4%	**82.5%**	15.5%	0	1.7%	0.3%	**17.5%**	Giannitrapani et al. (2014)
55	Tornambè	C	Late Copper Age	76.0%	6.8%	14.6%	**97.4%**	1,8%	0	0,2%	0,6%	**2.6%**	Giannitrapani and Iannì (2022)
275	La Muculufa, village	C	Late Copper Age	63.2%	13.9%	19.1%	**96.3%**	3.7%	0	0	0	**3.7%**	Bartosiewicz (2012)
404	Mezzebi	C	Late Copper Age	46.18%	18.83%	32.73%	**97.74%**	N/A	N/A	N/A	N/A	**2.24%**	Wilkens (1997)
10	Case Bastione	C	Early Bronze Age	80.2%	22.1%	8%	**90.1%**	8.3%	0	1.5%	0	**9.9%**	Giannitrapani et al. (2014), Di Simone et al. (2019)
274	La Muculufa, sanctuary	C	Early Bronze Age	84.4%	9.5%	5.7%	**99.6%**	0.4%	0	0	0	**0.4%**	Bartosiewicz (2012)
367	Scintilia	C	Early Bronze Age	77.59%	3.45%	18.97%	**100.00%**	0	0	0	0	**0.00%**	Di Rosa (2014)
298	Monte Grande	C	Early Bronze Age	41.40%	22.10%	32.60%	**96.10%**	N/A	N/A	N/A	N/A	**3.90%**	Bedini (1998)
482	Vallone Inferno	C	Middle Neolithic/ Early Bronze Age	71.00%	12.00%	5.00%	**88.00%**	2,60%	-	1,20%	8,20%	**12.00%**	Di Simone et al. (2019), Forgia et al. (2023)
390	Serra del Palco II	C	Early Bronze Age	48.10%	10.12%	32.34%	**90.56%**	0	0	0	0	**0.00%**	Wilkens (1997)
39	Riparo San Tommaso	C	Early Bronze Age	17.95%	23.30%	7.90%	**49.20%**	36.3%	3.8%	1.85%	8.7%	**50.80%**	Mannino et al. (2010)
390	Serra del Palco II	D	Middle Bronze Age	50.22%	26.07%	21.31%	**97.90%**	N/A	N/A	N/A	N/A	**1.58%**	Wilkens (1997)
39	Riparo San Tommaso	D	Late Bronze Age	12.75%	17.08%	0.00%	**29.83%**	10.1%	4.40%	0	55.8%	**70.33%**	Mannino et al. (2010)
390	Serra del Palco II	D	Late Bronze Age	46.06%	13.48%	37.07%	**96.61%**	N/A	N/A	N/A	N/A	**2.80%**	Wilkens (1997)
200	Rocchicella	D	Late Bronze Age	20.3%	16.5%	40.5%	**77.2%**	20.3%	0	0	2.5	**22.8%**	Di Patti and Lupo (2008)
91	Morgantina	D	Late Bronze Age	34.62%	8.0%	41.7%	**84.3%**	15.7%	0	0	0	**15.7%**	Bartosiewicz (2012)

Table 4 List of the pollen sequences

Site	Coordinates	Elevation (m a.s.l.)	Bioclimate	Mean annual precipitation	Mean annual temperature	Chronology	Relevant data	References
Urio Quattrocchi	37.901, 14.395	1038	Oro-Mediterranean	990 mm	12.5 °C	10 cal ka - 0 BP	Pollen, microcharcoals, fungal spores (*Sporormiella*)	Bisculm et al. (2012)
Urgo di Pietra Giordano	37.852, 14.127	1323	Oro-Mediterranean	870 mm	11.5 °C	6.6 cal ka – 0 BP	Pollen, microcharcoals, fungal spores (*Sporormiella*)	Tinner et al. (2016)
Lago di Pergusa	37.514, 14.305	667	Meso-Mediterranean	600 mm	13.4 °C	6.8 cal ka – 0 BP	Pollen, microcharcoals	Sadori et al. (2013), Sadori and Narcisi (2001)
Biviere di Gela	37.017, 14.345	7	Thermo-Mediterranean	409 mm	18.5 °C	7.2 cal ka – 0 BP	Pollen, microcharcoals, fungal spores (*Sporormiella*)	Noti et al. (2009)

some aridification trends during the Mid and Late Holocene (Bisculm et al., 2012). On the Madonie Massif, Urgo di Pietra Giordano (1323 m a.s.l.) (Tinner et al., 2016), a small mire with a chronology dating from 6.2 ka calBP, was considered. Lago di Pergusa, near Enna (667 m a.s.l), includes two core sequences useful for the the interpretation of the Mediterranean Holocene landscape. PG1 is a sequence with consistent results to this study (Sadori & Narcisi, 2001), and together with PG2 represents the main reference site for Central Sicily; not only pollen analyses, but also microcharcoals, stable isotopes of $\delta^{18}O$ and oscillations in lake level were considered as palaeoenvironmental indicators (Sadori et al., 2013). The last sequence, Biviere di Gela, is situated on the Southern coast providing both local and regional data starting from about the 7.3 ka calBP (Noti et al., 2009).

We collected pollen values of the four sequences as: API (Anthropogenic Pollen Indicators) (*Artemisia*, *Centaurea*, Cichorieae, *Plantago*, Cereals, *Urtica* and *Trifolium* type), following Mercuri et al. (2013a), AP – Arboreal Pollen and OJC – *Olea, Juglans, Castanea* following Mercuri et al. (2013b). The raw pollen data were obtained using the Neotoma Paleoecological Database, available by CC rights. When available, presence and density of microcharcoals and *Sporormiella* were used respectively to detect natural or anthropogenic fire activities, in some cases associated with lipid biomarkers (see Thienemann et al., 2017), and variation of husbandry practices (Etienne & Jouffroy-Bapicot, 2014). Further indicators of variations in lake levels of the Mediterranean area, like Lago Preola (Magny et al., 2011, 2013) and stable isotope curves of $\delta^{18}O$ (Sadori et al., 2008; Zanchetta et al., 2007) were used as paleoclimatic indicators.

Results

We considered a total of 524 sites, some of them with more than one chronological phase (Table S1, Fig. 6). The southern sector has an increasing relative contribution from the

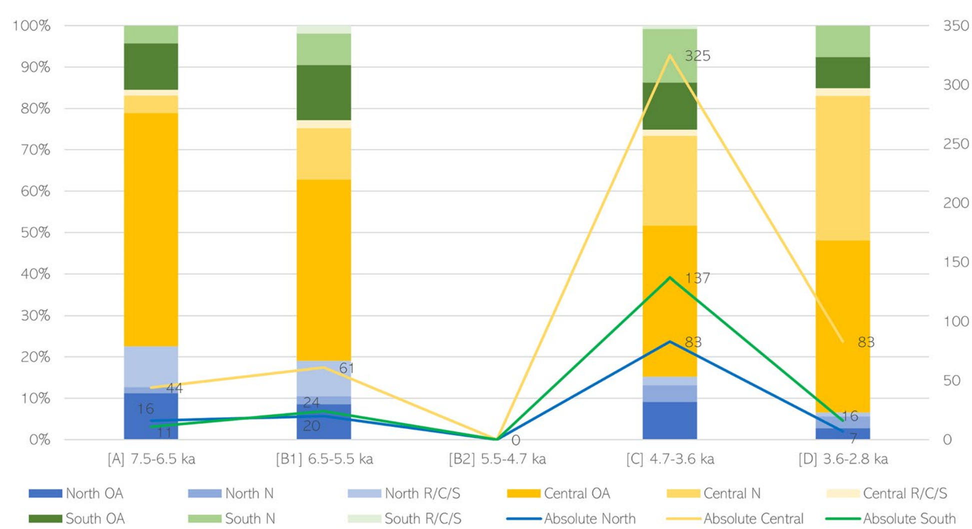


Fig. 6 Relative and absolute proportions of the sites per each phase; in the blue part of the columns, the relative contribution and blue line for the absolute contribution of the northern sector; in the yellow part of the columns, the relative contribution and yellow line for the absolute contribution of the Central Sector; in the green part of the columns, the relative contribution and green line for the absolute contribution of the Southern Sector. For the legend, please refer to Table S1 in ESM

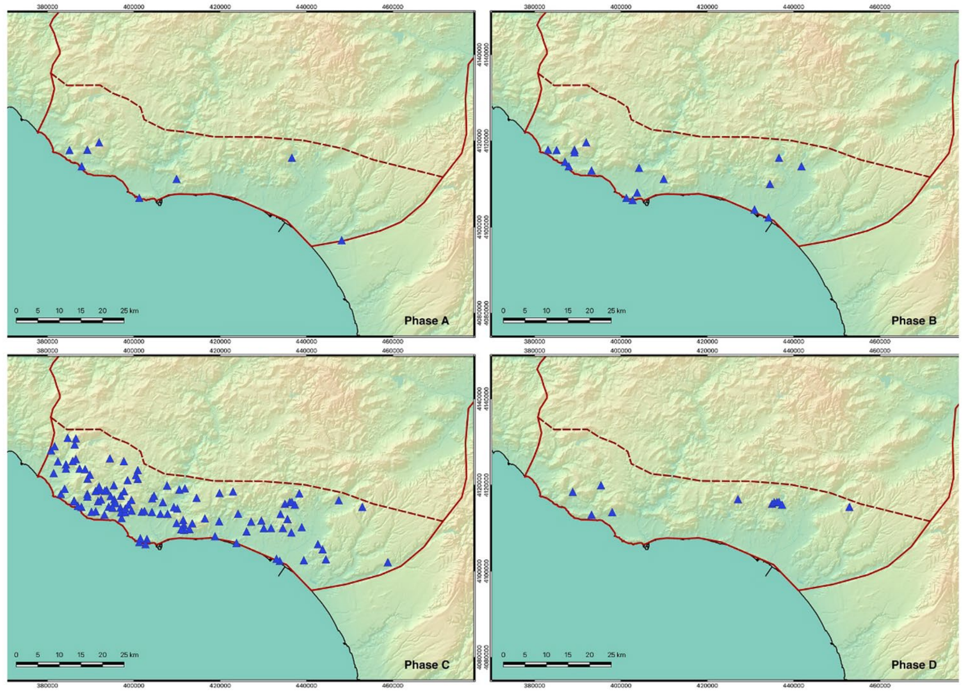


Fig. 7 Geographic distribution of the sites in the southern sector, in the four chronological phases selected in this study

Neolithic to the Middle Bronze Age (phases A-C), with a decrease both in absolute and relative contribution in the last phase D. The central sector shows an inverted trend of decrease of relative proportion from phase A to phase C, despite its absolute proportion is significantly higher in phase C. The northern sector shows a relative contribution that is higher in the Middle Neolithic and that slightly decreases until the end of the Bronze Age, with the highest absolute contribution in phase C, as the near sector (Fig. 6).

Southern Sector

The southernmost part of the study area is the hilly landscape of the coastal area of Agrigento and Caltanissetta

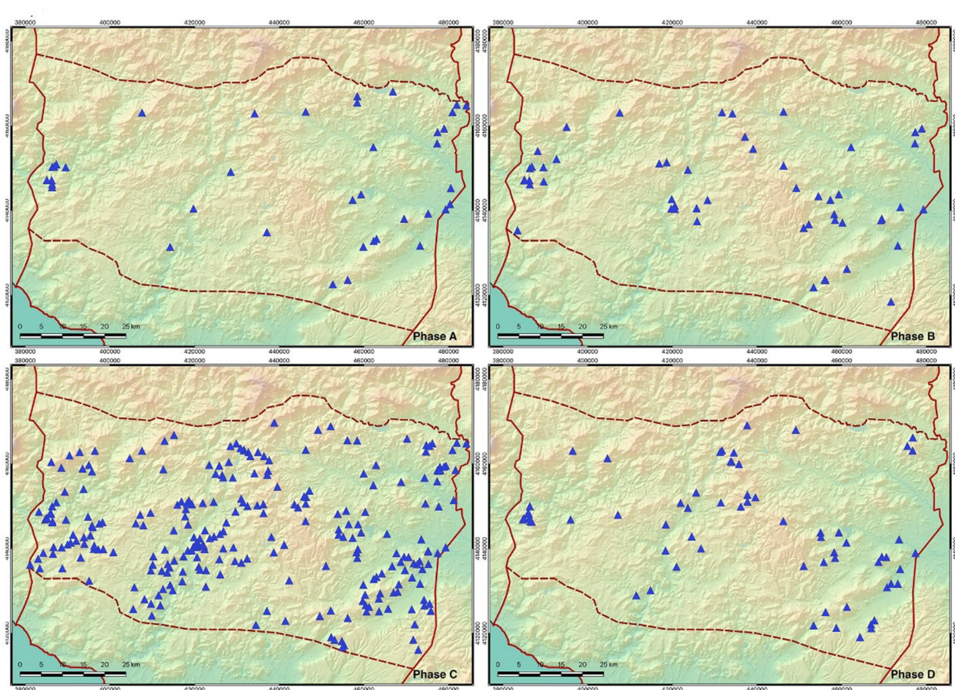


Fig. 8 Geographic distribution of the sites in the central sector, in the four chronological phases selected in this study

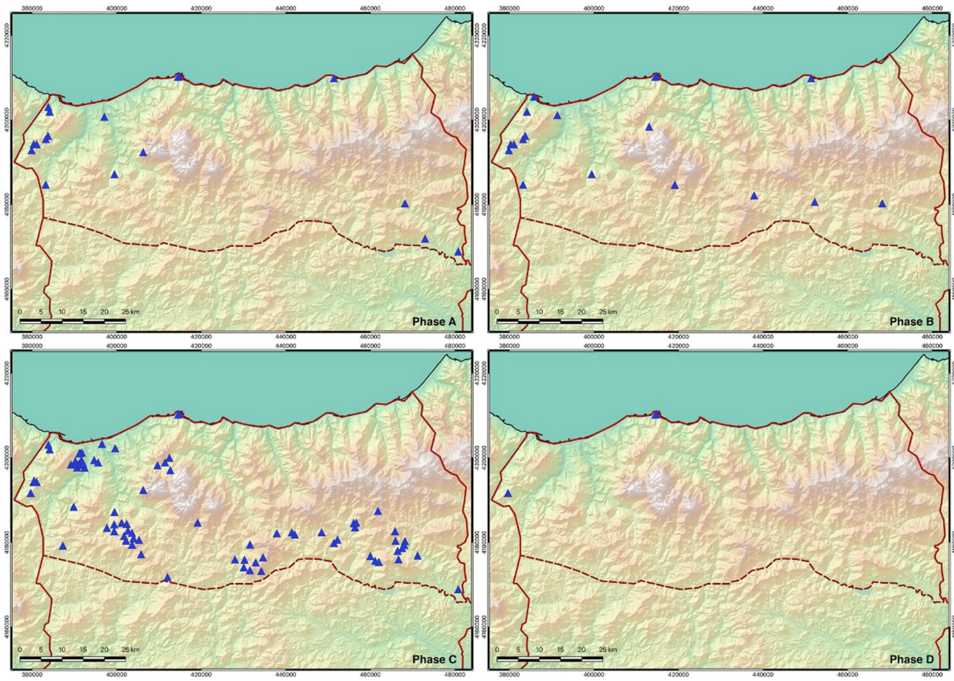


Fig. 9 Geographic distribution of the sites in the northern sector, in the four chronological phases selected in this study

provinces and hosts 153 archaeological sites (Fig. 7). The oldest phase registers 8 sites (five open-air sites and three open-air sites with necropolis); phase B1 has 18 sites (eight open-air sites, seven open-air sites with necropolis, two necropolis, one cave), while phase B2 has no archaeological sites definitively attributed. The area records the highest relative and absolute increase of the three sectors during phase C, with a presence of an absolute number of 113 both coastal and inland sites (three caves, one rock shelter, forty-seven necropolis, thirty-seven open-air settlements, and twenty-five open-air settlements with necropolises), mostly around the modern towns of Campobello di Mazara, Naro, Palma di Montechiaro, Licata, and Butera, along the river valleys of Naro, Palma, and southern part of Imera Meridionale. During phase D, the area is highly depopulated (11 sites, with eight necropolises with open-air sites and three open-air sites), with some remnants in the district of Butera.

In the site of La Muculufa, n. 274, archaeobotanical data revealed a spread consumption of domesticated cereals (*Hordeum vulgare*, *Triticum monococcum*, *Triticum dicoccum*, *Triticum aestivum*) and pulses (*Vicia faba, Pisum* sp.) during the EBA (phase C) in this area (Costantini, 1990). Faunal analyses are also available from the LCA/EBA phase of the site, showing a high percentage of domestic species (99.6%), similar to the ones from Monte Grande, n. 298 (96%) (Bedini, 1998).

Central Sector

The central part of the study area includes 49 sites (forty-one open-air settlements, seven necropolises, and one rock shelter dated to MN (phase A) located in the municipalities of Campofranco, Centuripe, Ramacca, and Mineo. Occupation slightly increases during phase B1, with the presence of 51 sites (thirty-two open-air settlements, two necropolises, fourteen open-air sites with necropolis, two caves) primarily concentrated in the municipalities of Mussomeli, Campofranco, Caltanissetta, Aidone, and Pietraperzia (Fig. 8); as for the other sectors, there are no sites unquestionably attributable to phase B2. The peak of the demographic spread of human communities in the central sector is during phase C, with 261 sites (three caves, three rock shelters, fifty-six necropolises, one hundred thirty-five open-air sites, sixty-three open-air sites, and necropolis, one open-air and ritual site, one ritual site), the highest presence since the Neolithic. Sites are mainly gathered along the river valleys, but the territory is densely occupied. During phase D, only a small part of the sites from phase C keeps being occupied (a total of 64 sites: one cave, one rock shelter, twenty-five open-air settlements, eighteen necropolises, nineteen open-air settlements and necropolis), so a huge decrease is registered.

The diachronic analysis of the exploitation of plant resources in Rocchicella, n. 200, shows that adopting the agrarian economy is established in the EBA, with the exploitation of olive trees since at least the CA (phases B-C) (Castiglioni, 2008). The almost exclusive presence of *Quercus pubescens* and the high presence of hygrophilous tree species in the macroremain record of Case Bastione, n. 10, underlines the presence of downy oak forests surrounding the prehistoric site and extensive cereal and legume croplands (phase C) (Speciale et al., 2020). Finally, data from

Morgantina, nn. 91–93, show the use of oaks in that area during the LBA (Ramsay, 2012).

Serra del Palco I, n. 389, presents a high percentage of domestic animals (more than 85%) in the MN (Wilkens, 1997); this is in line with the Neolithic of Southern Italy, as a similar proportion was found in Fiaccati/Le Rocche, n. 46, during phase A (Iannì et al., 2022). The case of Rocchicella, n. 200, is very interesting for the exploitation of wild ruminants during the Neolithic phase (78.7%) (A), which decreases markedly during the CA (14.2%)(B1) and increases again at the end of BA (22%) (phase D). In Scintilia, n. 367, unexpectedly, both in phase B1 and C, only domestic animals are represented (*Ovis/Capra*, *Bos taurus* and *Sus scrofa*), maybe due to the limited number of samples (Di Rosa, 2014).

In Tornambè, n.55, the zooarchaeological analyses indicate a great importance of goats and sheep, followed by cattle and pigs, with a very low incidence of wild animals, possibly related to the sedentary nature of the community that occupied the village. At Case Bastione, n.10, the faunal assemblage shows some substantial differences: while the prevalence of goats and sheep in the faunal complex and the importance of pigs is here confirmed, the lesser importance of cattle is observed. The latter site may have been at the centre of routes connected with the seasonal transhumance practices adopted by shepherds in this internal part of the island, where, however, particular importance was also given to hunting, considering the high percentages of deer remains. The substantial differences in the faunal complex of the two sites also take on a value for the definition of the different environmental and landscape characteristics in which these settlements are located: Tornambè is situated in the meso-Mediterranean band, between 150 and 450 m above sea level, with more open vegetation than the forested supra-Mediterranean area, between 450 and 700 m, where Case Bastione is located, and consequently more sensitive to climatic variations such as those highlighted in the pollen sequence of Pergusa (Sadori et al., 2013).

Northern Sector

During phase A (16 sites: seven open-air settlements, one open-air settlement with a necropolis, seven caves, one rock shelter), most areas located on the Madonie Mts. and near Termini Imerese (western part of the sector) register occupation, probably biased by the lack of extensive research in the Nebrodi area (Fig. 9). A slight increase occurs during phase B1 (19 sites: eight caves, two necropolis, and nine open-air settlements), a drop of sites is registered during phase B2 (0 sites) while during phase C, as in the other sectors, an increase on Madonie (municipalities of Caccamo and Gangi) and southern slopes of Nebrodi Mts. is recorded (78 sites: ten caves, one rockshelter, eleven open air settlements with necropolis, thirteen necropolis, fourty-three open air sites). Another significant drop is instead recorded for phase D (3 sites: two caves, one open-air site and necropolis).

Archaeobotanical data from Vallone Inferno, n. 482 (phase C), show the adoption of agricultural practices since the EBA on mountainous areas, with a high representation of naked wheat (*Triticum aestivum*). Probably due to the presence of several forested areas near the site, the percentage of wild fauna is high during phase C compared to the one of other sites (Forgia et al., 2012, 2023).

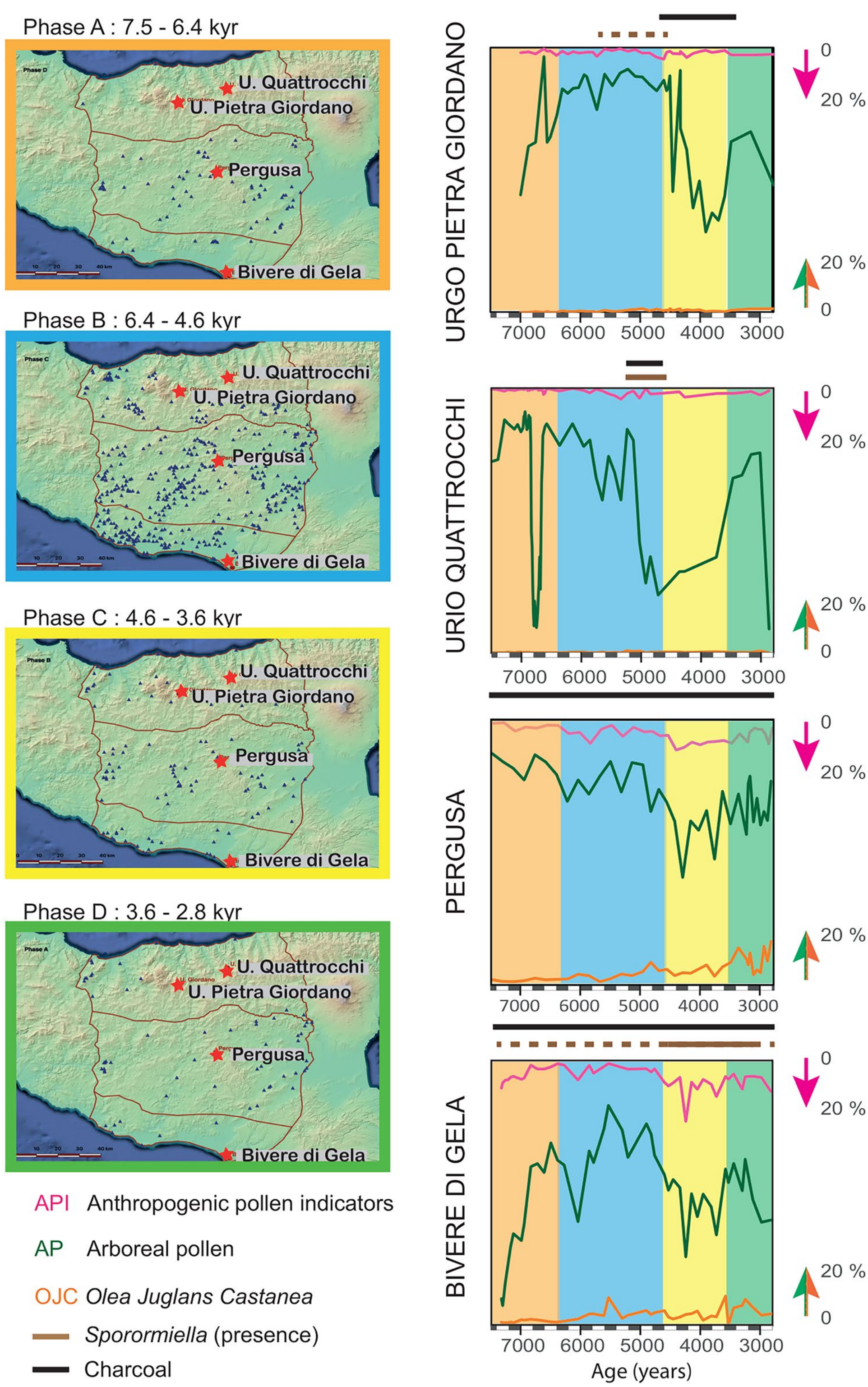
Discussion

Middle Neolithic (7.5–6.4 cal ka BP): The First Steps of the Farming Economy

The demographic and settlement patterns for this phase are still ambiguous in most of the three sectors, with little data for the northern sector. The central sector is populated primarily along the main eastern river valleys, possibly reflecting penetration routes from the Catania Plain, while in the southern sector, the few known Neolithic sites are concentrated along the coast, similarly to Eastern Sicily.

In general terms, the demographic trend for this period suggests a low-density occupation, followed by a slow increase of the occupied sites during the later phases, with a growth in cave sites and a decrease in open-air settlements. The relative contribution of the northern sector is nevertheless the highest of the whole chronological span (Fig. 6), and this could justify the unexpected drop of arboreal pollen, respectively at 6.8 and 6.6 cal ka BP in the natural sequence of U. P. Giordano (Fig. 11). At the same time, there is no apparent presence of indicators of pastoralism. Less clear is the interpretation for the sequence from the central part of the island from Pergusa. Here, the presence of API is relatively low, and no marked signal of agriculture or pastoralism is detected. In the southern sector, as in the whole sequence, the pollen sequence of Biviere Gela reveals an open environment, especially 7.4–7.0 cal ka BP, with a significant representation of API, mainly consisting of indicators of pastoral activities (Florenzano, 2019) (Fig. 10). These indicators decrease at the end of the phase. While not much can be said of crop cultivation from archaeobotanical remains, pollen sequences seem to point to a very low incidence of agricultural activities for these phases; the few data from faunal remains testify to the reliance on domestic species with

Fig. 10 On the left, synthesis of the four phases with the archaeological sites and the position of the four pollen sequence; on the right, pink line = API, Anthropogenic Pollen Indicators (e.g. *Cerealia*-type*, Rumex, Plantago lanceolata*); green line = AP, Arboreal Pollen; red line = OJC, *Olea-Juglans-Castanea* sum; black line upon the graphics is the microcharcoals incidence when indicated in the publication, brown line is the *Sporormiella* incidence when indicated in the publication



a still high percentage of wild species (Tables 2 and 3). Nevertheless, forest clearing during the Neolithic probably enhanced the effect of the natural trend of aridification that started earlier in Central Sicily and a little later in Northern Sicily (Frisia et al., 2006; Sadori et al., 2008; Sadori & Narcissi, 2001).

Late Neolithic – Middle Copper Age (6.4–4.6 cal ka BP): The Beginning of the Economic Transition and the Demographic Gap

The demographic and cultural change from the Neolithic to the E-MCA is also a largely unclear phase. According

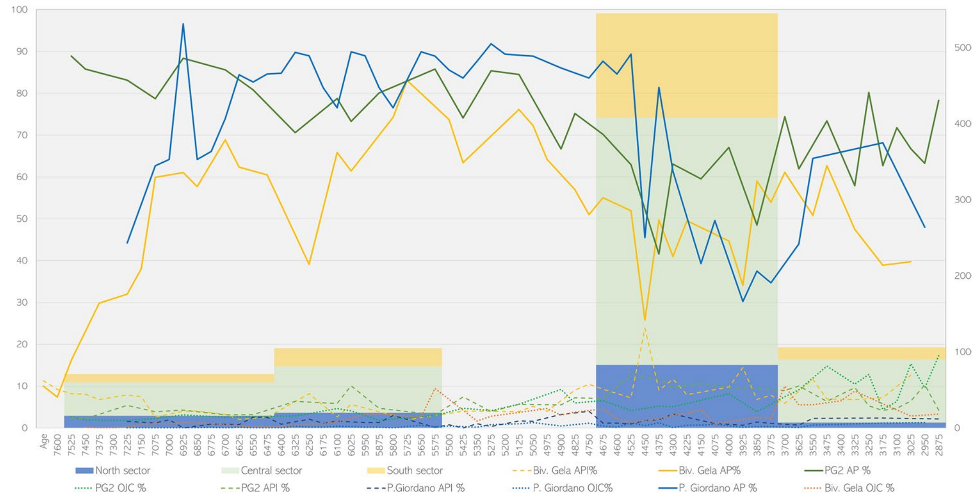


Fig. 11 Synthesis of demographic (columns in the background) and pollen data (lines); in yellow, southern sector; in green, central sector; in blue, northern sector; solid lines indicate the AP%; dotted lines show OJC %; broken lines show API %

to the available AMS dates, the cultural differences evidenced in the current literature between LN and ECA are blurred, possibly reflecting geographical patterns more than cultural ones (particularly *Diana* and *San Cono-Piano Notaro* cultural assemblages). In Central-Eastern Sicily, the persistence of the Neolithic way of life has been recently suggested (Giannitrapani, 2020). The change in pottery production and in the funerary and settlement patterns of Western Sicily needs to be more evident here, also with influences from the Aeolian islands and the Italian peninsula. During subphase B1, the incidence of the occupation of the central sector starts to increase both relatively and absolutely (Fig. 6), starting a general trend of major occupation of the inner areas. According to the pollen data (Fig. 10), the presence of API strikingly increases in the central and southern sectors. At the same time, starting from 6.0 cal ka BP, corresponding to a general dry period in the Mediterranean (Mercuri et al., 2011; Sadori et al., 2011), the northern sector records a trend of decrease in AP, and a major incidence of API. These changes must be related to the spread of the *Diana* cultural phase and the increased involvement of Northern Sicily in the international trade network of obsidian at the end of the Neolithic. Right after 5.5 cal ka BP, central and especially northern sectors were probably relying on agropastoral activities, affecting the forest vegetation, despite the demographic pattern still to define more clearly for the Nebrodi Mts.; during this phase, a significant presence of indicators of pastoralism (*Sporormiella*) is registered in the two northern sequences. The vegetation framework in the coastal southern sector seems only partially affected after 5.5 cal ka BP, despite the slight increase in human occupation related to the ECA (Fig. 11). Archaeobotanical and zooarchaeological data are almost absent from the investigated area, except Rocchicella site, which shows the prevalence of domestic animals (mostly caprines and cattle) and cultivation of wheat during these centuries; also, the exploitation of the oaks seems to decrease from the LN to the MCA phases, while the use of olive tree wood is registered, as in Casa Sollima (Tables 2 and 3). Data from the isotopic values of human bones in Scintilia (southern sector) confirm that their diet was prevalently based on agricultural products, something already detectable in the data from Piano Vento (Tykot et al., 2020).

The available AMS dates and the archaeological data suggest a possible demographic gap from 5.2 to 4.6 cal ka BP (phase B2)(MCA) (Giannitrapani, 2023); this finds a clear correlation in AP curves (both percentage and concentration) of Pergusa (AP dropped from 57% at ca. 5220 to 30% at 5080 cal BP to start recovering after 4800 with 49%) (Figs. 10 and 11) and corresponds to a period of general increased aridity in the Mediterranean, suggested also by drops in AP concentration in other sequences (Magny et al., 2013; Pérez-Obiol & Sadori, 2007); also in Urio Quattrocchi, right after 5.2 cal ka BP a sharp decrease in AP is detected, with a significant increase in microcharcoal concentration and *Sporormiella*. The negative deviation in demography, as already known in literature (Palmisano et al., 2021), follows a moment of increase between the end of the Neolithic and the beginning of the Copper Age all over the island (Parkinson et al., 2021). The explanation for this apparent gap is still unclear, although we argue a potential change of the economic system and a greater reliance on mobility and pastoral activities could have taken place, probably partially pushed by the increased aridity.

Late Copper Age – Early Bronze Age (4.6–3.6 cal ka BP): After the Gap, the Demographic Explosion

A sharp economic, social, and cultural change took place, particularly in central Sicily, during the LCA, as suggested by an abrupt demographic rise of population. In archaeological terms, this is pointed out by the appearance of substantial domestic architecture, complex funerary habits, and craft activities, supported by a primary economic system based on intensive agriculture and specialized pastoral activities. It is also possible that this demographic boom was supported by a more intensive exploitation of raw materials (sulphur, rock salt) available in the study area. Finally, the spread of metallurgical activities probably impacted the exploitation of wood resources (Giannitrapani & Iannì, 2020).

In terms of demography, the increase is quite marked in all three sectors, with an absolute increase higher for the central sector; the relative proportion of population from the central sector is nevertheless the same as in the previous phase (Fig. 6) while the EBA and Castelluccio cultural horizon mark everywhere the establishment of the agrarian landscape. API shows a slight decrease in the northern sector, a specific stability in the central one, and an increase in the southern one, while an opening in the landscape is registered in all the pollen records (Fig. 10). Differently from other Mediterranean regions (e.g., southern Greece (Weiberg et al., 2019); Central Italy (Stoddart et al., 2019)), the demographic increase develops along and through the 4.2 cal ka BP event (Bini et al., 2019). All the 3 sectors are involved in it, with a significant increase in the central sector (Fig. 11).

Regional climatic trends show that the island is only partially affected by this event: a gap in the Carburangeli sequence is due to the generally more arid conditions that had occurred since 6.0 ka BP (Zanchetta et al., 2022), while the persistence of *Fagus* in the northern Sicilian pollen sequences shows that humid conditions continued at higher elevations (Bisculm et al., 2012; Tinner et al., 2016). In fact, a rapid expansion of *Fagus* is known to have occurred since the early Holocene in southern and central Italy, and then its decrease just after around 5700 cal BP marked a trend towards increasing dryness (Magri et al., 2006; Mercuri et al., 2012).

Level in Lago Preola shows a quick decrease followed by an increase (Magny et al., 2011), and $\delta^{18}O$ of the sediments (calcareous muds and freshwater shells) in Pergusa records a slight water level increase in the general trend of aridification (Zanchetta et al., 2007). $\delta^{13}C$ values of archaeological seeds and wood charcoals from the Aeolian sequence show a discontinuous pattern of some drier conditions after the 4.2 cal ka BP that are nevertheless affecting the Capo Graziano economy (Speciale et al., 2016); other local responses, like the one from Case Bastione, show that slightly drier conditions corresponding to the 4.2 cal ka BP event, probably did not last very long and did not affect severely the local forest ecosystems or the agricultural activities (Speciale et al., 2020). Archaeobotanical and faunal remains show an established economy based on domestic species all over the island, with a possible preference for naked wheat in Central Sicily (Speciale et al., 2020), in comparison with the higher presence of barley in other areas such as Aeolian islands (Speciale, 2021). Data concerning diet preferences inferred by stable isotope analysis of human bones show a very heterogenous framework within the same communities (Varalli et al., 2022), nevertheless primarily based on agricultural products as shown also in a multiphase site as Grotta dell'Uzzo (Yu et al., 2022). Pastoral indicators like *Sporormiella* and API increase especially in the southern sector, but disappear in the northern sector, in favor of the sedentary socioeconomic system expected for this phase (Fig. 10). Reliance on hunting and wild animal species seems to be a feature of some specific sites. Carpological data from inner and southern Sicily (Case Bastione, Muculufa) indicate the spread of the most common crop species (glume and free-threshing wheats, barley, domestic pulses: *Hordeum vulgare*, *Triticum monococcum/dicoccum*, *T.* cf. *spelta*, *T. aestivum*, *Vicia* sp.) (Table 2) differently from mountainous areas like the Madonie mountains where it was probably not one of the main subsistence activities (Forgia et al., 2023). Forest clearance was enhanced by increasing grazing and burning disturbance as elsewhere in the Mediterranean (Vannière et al., 2011; Mercuri et al., 2019c; Pasta et al., 2022).

Middle Bronze Age-Late Bronze Age (3.6–2.8 cal ka BP): The Human Demographic Drop

The selected time window ends at about 2.8 ka cal. BP, i.e., at the end of the LBA with the arrival of Greek colonists. This phase is characterized by the setup of an extended network with the Mycenean societies, a larger use of metals and the transformation of settlements that reduce their number but generally increase their size and complexity (Knapp & van Dommelen, 2014). A general demographic drop is recorded in Central Sicily after 3.6 cal ka BP, with a relative proportion for the central sector significant compared to the coastal areas of the study region (Fig. 6). Local environmental conditions in Aeolian Islands show a short trend towards moister conditions (Speciale et al., 2016); the same positive moisture trend is registered in Carburangeli cave at the beginning of the MBA (Frisia et al., 2006), as well as at Lago Preola and Lago di Pergusa (Curry et al., 2016). All the four sequences show an increase in the AP since around 3.6 ka BP and a decrease of AP at 3.2 cal ka BP or right after; this probably corresponds to a peak in aridity soon before the prolonged increase of wetness lasting until 2.8 cal ka BP in the PG2 isotope record of Pergusa, that matches an increase in wood cover (Zanchetta et al., 2022). API is almost absent in the pollen sequences of the northern sector. In contrast, human imprint on the central and southern sector is more evident, together with some recovery of woodlands, primarily oaks (Fig. 10). Some of the AMS-based demographic analyses show short positive deviations (Palmisano et al., 2021), while others record a slower and continuous decrease (Parkinson et al., 2021). The combination of natural and anthropogenic factors seems to have marked quite irreversibly the central sector, probably starting those profound processes of environmental disturbance of inner and Southern Sicily until today (Henne et al., 2015). Data on the economic subsistence systems are quite poorly represented for this phase, despite the fact that the available faunal remains show similar percentages as the one of phase C. Still unclear is the exploitation of fruit tree species, probably not significant in Sicily in this phase compared to other parts of Southern Italy, with the exception of figs. Nevertheless, interestingly, in Pergusa there is an increase in OJC-*Olea*, *Juglans* and *Castanea* cultivation that clearly indicates the establishment of an agricultural and arboricultural landscape and an exploitation of woodland since around 3.2 cal ka BP, mainly olive trees. Wild olive (*Olea europaea* var. *sylvestris*) is autochthonous in Sicily, it requires a Mediterranean climate characterized by summer aridity and is typical of the coastal zone in Sicily and of the warmest areas of Mediterranean (Langgut et al., 2019). The cultivated olive tree (*O. europaea*) is now found in the whole area colonized by the evergreen oak forests. In this perspective, more than 20% of olive pollen at Pergusa can hardly be interpreted as "natural" as discussed in Sadori et al. (2013), also considering the modern pollen production in olive groves (meanly 13%, Florenzano et al., 2017). Such high values are in fact found only in coastal pollen records of Sicily, where wild olives are widespread (Tinner et al., 2009; Calò et al., 2012). Even if we lean towards an explanation of cultivation for olives, we must also consider that the climate at that time would have been arid and warm enough to allow the growing of olive groves outside their natural distribution area.

Disentangling human and natural factors in the human decrease during these phases is extremely difficult. Beyond the climatic constraints and the potential overexploitation of some areas (Molloy, 2022), the significant increase in Mediterranean conflicts could have played an essential role in establishing the demographic pattern at the end of the BA (Fernandes et al., 2020).

Conclusions

Our research covers the most recent data on the demography of late prehistoric Sicily, which we interpret from a diachronic perspective, aiming to reconstruct the changes in landscape of Central Sicily and comparing demographic with archaeobotanical and archaeozoological datasets and pollen sequences. Thanks to the density and accuracy of paleoenvironmental analyses, Sicily stands out in the wider framework of Central Mediterranean Holocene climate reconstruction. But even with detailed paleoclimatic datasets, the "worse" or "better" climatic conditions, mostly defined on "dry" or "moist" conditions, cannot always be positively correlated with demographic trends. Rather, specifically in a region such Sicily, prehistoric demography and climate amelioration apparently show an opposite trend during many phases. The phase post-4.2 ka BP event is one of the most significant in this sense, as increase of population occurred during increasing dryness, and only cultural interpretation and economic adaptation can help to find some answers.

Despite not being analytically presented, Early Neolithic data in Sicily record the introduction of domesticated plants at least around 9.0 ka cal BP, as testified by the archaeobotanical dataset of Grotta dell'Uzzo (Costantini & Costantini Biasini, 1997), but less clear for the rest of the region (Speciale, 2023). During Middle Neolithic (7.5–6.4 cal ka BP), Sicily has a low-density demography, even if mountainous areas (Madonie massif and Nebrodi Mts.) are quite well represented; as shown by the pollen sequences, the whole island experiences some human impact due to the spread of the Neolithic economy and the exploitation of part of the central and northern areas for pastoral activities. An opening of the landscape is registered especially in the northern sector. Nevertheless, analyzing the API, the incidence of the agricultural activities still seems quite low. In the southern sector, the indicators of pastoralism are higher than in the other sectors.

Between the end of the Neolithic and the beginning of the Copper Age (6.4–5.2 cal ka BP), there is a slight increase in demography in all the sectors. API is more detectable in all the sequences and the indicators point to a diffused agro-pastoral economy. The few archaeobotanical and zooarchaeological data, together with the isotopes of human diet, support this increase in the reliance on domestic species. The demographic drop right after, during the so-called Middle Copper Age (5.2–4.6 cal ka BP), could be the result of a combination of environmental and anthropogenic factors and a partial switch to a less permanent settlement system. As a matter of fact, the lowest tree cover percentage recorded at Pergusa and Urgo di Pietra Giordano in the considered period (7.0–2.8 cal ka BP) is found in the correspondence of the start of the demographic gap evidenced by Giannitrapani (2023); so, in this case, a phase of potential increased aridity is correlated to a decrease in human demography, despite the API had an increase in all the sequences. Probably, the anthropogenic pollen indicators mark pastoral activity as the most common land-use, which greatly favoured synanthropic plants.

It is only in the following phases, at the end of the Copper Age (4.6–4.2 cal ka BP), that human impacts become evident and relevant. The demographic boom after the Late Copper Age in Sicily seems strictly dependent on regional conditions that allowed human communities to populate notably the inner areas and establish a capillary spread all over the island, more intensely than in other regions of Central Mediterranean. Perhaps the Sicilian environment was less affected by the 4.2 ka BP event, ratherby the general aridification trend that had started, according to some authors, at the beginning of the Neolithic (Sadori & Narcisi, 2001). The striking demographic increase between the Late Copper Age and Early Bronze Age (4.6–3.6 cal ka BP) is characterized by the first establishment of a structured agricultural landscape. This is quite clear from API evidence of Biviere Gela and Pergusa, while in the northern sector API does not account for significant changes. Archaeobotanical and zooarchaeological data point to the establishment of a structured agropastoral economy, that persists in the following phase.

The demographic increase of this last phase is followed by a decrease during the Middle Bronze Age (3.6–3.3 cal ka BP), probably enhanced by a change in the settlement system, as known also in other regions of the Italian peninsula. This demographic decrease seems counterintuitive in view of the conditions of increased humidity indicated in palaeoclimatic data; also, a significant recovery of the wood cover is detectable in all the sequences, possibly also as result of the lowered human presence. Between the end of the Middle Bronze Age and the Late Bronze Age (ca. 3.3–2.8 cal ka BP) the decrease in demography becomes more evident. The causes are probably, once again, a synergy of natural and human dynamics, following what has been defined as climatic crisis of 3.2 cal ka BP event (Molloy, 2022; Zanchetta et al., 2022). The depopulation of this central sector of the island, despite the slight increase in humidity at the beginning of the Late Bronze Age, is probably due to changes in the local economic and cultural assets, which at the present state of our investigation cannot be linked just to the overexploitation of local natural resources. The central sector is the only one characterized by a significant presence of API and OJC, recording a clear structuring of an agricultural and arboricultural landscape with olive tree exploitation, which is almost nonexistent in the southern sector. In sum, despite the early arrival of domestic species on the island, the spread and adoption of an intensive agricultural system seems to have occurred only during the Late Copper Age.

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Declarations

Conflict of Interest The authors declare no conflict of interests.

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