



# Radiocarbon Dated Trends and Central Mediterranean Prehistory

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## Abstract

This paper reviews the evidence for long term trends in anthropogenic activity and population dynamics across the Holocene in the central Mediterranean and the chronology of cultural events. The evidence for this has been constituted in a database of 4608 radiocarbon dates (of which 4515 were retained for analysis following initial screening) from 1195 archaeological sites in southern France, Italy and Malta, spanning the Mesolithic to Early Iron Age periods, c. 8000 to 500 BC. We provide an overview of the settlement record for central Mediterranean prehistory and add to this an assessment of the available archaeological radiocarbon evidence in order to review the traditional narratives on the prehistory of the region. This new chronology has enabled us to identify the most significant points in time where activity levels, population dynamics and cultural change have together caused strong temporal patterning in the archaeological record. Some of these episodes were localized to one region, whereas others were part of pan-regional trends and cultural trajectories that took many centuries to play out fully, revealing prehistoric societies subject to collapse, recovery, and continuing instability over the long-term. Using the radiocarbon evidence, we model growth rates in the various regions so that the tempo of change at certain points in space and time can be identified, compared, and discussed in the context of demographic change. Using other published databases of radiocarbon data, we have drawn comparisons across the central Mediterranean to wider prehistoric Europe, and northern Africa. Finally, we include a brief response to the synchronously published but independently developed paper (Palmisano et al. in *J World Prehist* 34(3), 2021). While there are differences in our respective approaches, we share the general conclusions that large-scale trends can be identified through meta-analyses of the archaeological record, and these offer new perspectives on how society functioned.

**Keywords** Italy · France · Malta · Mediterranean · Mesolithic · Neolithic · Copper age · Bronze age · Radiocarbon dating · Palaeodemography

## Riassunto

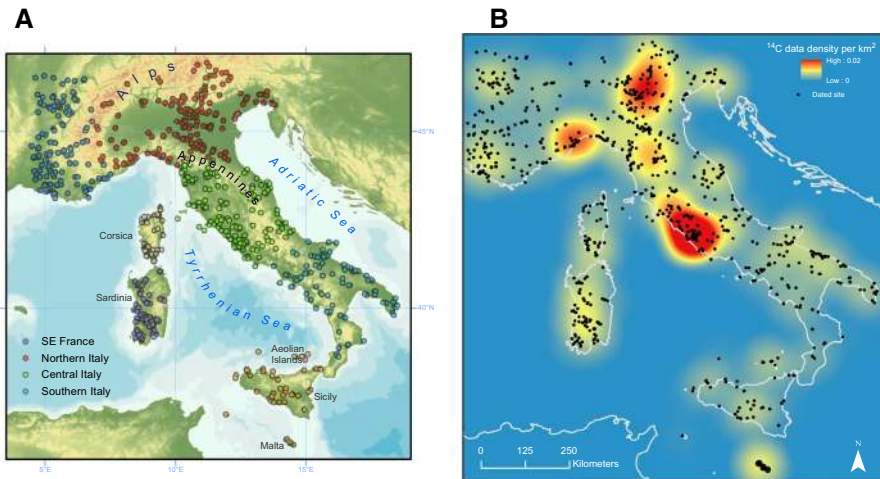
Il presente contributo esamina la presenza di trends nei livelli di attività antropiche e nelle dinamiche popolazionistiche del Mediterraneo centrale durante l'Olocene. I dati

consistono in un database di 4608 datazioni al radiocarbonio provenienti da 1195 siti archeologici dalla Francia meridionale, dall'Italia e da Malta, che coprono un arco cronologico che va dal Mesolitico all'Età del Ferro (8000–500 a.C. circa). A seguito di uno screening iniziale, 4515 datazioni al radiocarbonio sono state selezionate per l'analisi finale. Si fornisce una panoramica generale sulla preistoria del Mediterraneo centrale assieme a una valutazione delle datazioni archeologiche al radiocarbonio al fine di rivalutare le interpretazioni tradizionali sulla preistoria dell'area analizzata. Questo approccio ha consentito di identificare i momenti più significativi nei quali i livelli di attività antropica, le dinamiche popolazionistiche e i cambiamenti culturali hanno congiuntamente causato forti patterns temporali nel record archeologico. Alcuni di questi fenomeni sono circoscritti a una singola regione, mentre altri fanno parte di tendenze pan-regionali e traiettorie culturali che hanno richiesto molti secoli per essere pienamente realizzate, mostrando società preistoriche soggette a collasso, ripresa e continua instabilità nel lungo periodo. Utilizzando le datazioni al radiocarbonio, il presente contributo propone modelli sui tassi di crescita delle diverse regioni in modo da identificare nello spazio e nel tempo momenti di cambiamento, comparandoli e discutendoli alla luce della fluttuazione demografica. L'articolo propone inoltre un confronto tra il Mediterraneo centrale, l'Europa preistorica e l'Africa settentrionale attraverso l'utilizzo di altre datazioni al radiocarbonio disponibili in letteratura. Infine, si presenta una breve risposta all'articolo sviluppato contemporaneamente ma in maniera indipendente da Palmisano et al. (2021). Anche se i due contributi presentano evidenti differenze nei rispettivi approcci, questi condividono le conclusioni generali secondo cui la meta-analisi del record archeologico può identificare tendenze su larga scala e offrire nuove prospettive sulle società antiche.

## Introduction

The use of large databases of radiocarbon dates to explore past levels of anthropogenic activity and settlement patterns is an approach to archaeology that has recently gathered much momentum. Estimates have been made of past human activity and demographic fluctuations by assuming a relationship between levels of human activity or population size and the frequency with which datable material enters the archaeological record (Haynes, 1969; Rick, 1987). In this paper, we review the radiocarbon and settlement evidence for the prehistory of the central Mediterranean region, identify trends in prehistoric activity levels and settlement patterns, and discuss their potential causes in terms of demography, migration and the response to environmental change, with detailed reference to relevant archaeological context.

The prehistoric central Mediterranean (Fig. 1) comprises a rich and varied archaeological record of pronounced cultural developments within an extremely diverse physical landscape. The study of prehistory in the central Mediterranean has stood somewhat apart from wider continental traditions, with the region having been historically divided into distinctive sub-regional academic traditions split between the natural sciences and more humanities-leaning approaches (Guidi, 2010). As a consequence of these localized research traditions, the application of archaeological science has been far more widespread in the central-northern Italian peninsula



**Fig. 1** Maps showing: **a** the topography of the central Mediterranean region and the location of archaeological sites included in this study; and **b** spatial density of radiocarbon dates in the study

than in southern Italy and the surrounding islands. Chronology building in the central Mediterranean has traditionally been focused on developing typo-chronologies of ceramic styles and artefacts, resulting in an extremely refined relative chronology. However, whilst traditional typo-chronologies have both practical and ontological uses, they often confuse and hamper broader regional syntheses and offer little insight into the timing and tempo of cultural change in prehistory. In contrast, radiocarbon evidence offers an independent opportunity to identify the absolute chronology and explore the dynamics within past human societies.

One barrier to achieving this synthesis is that the available radiocarbon evidence for the prehistoric central Mediterranean is limited in contrast to other areas of continental Europe. Although the situation has rapidly improved in recent years, the paucity of radiocarbon evidence has long been recognized as particularly problematic in Mediterranean island contexts such as Malta, Sicily and Sardinia (Burleigh, 1984). Whilst there were early attempts to draw together the radiocarbon evidence for discrete periods of central Mediterranean prehistory (Renfrew, 1971; Whitehouse & Renfrew, 1974), a surge of research on Italian prehistory by Italian and Anglo-American researchers throughout the 1990s led to the first attempts to gather together systematically the available radiocarbon evidence for the central Mediterranean (Bagolini & Biagi, 1990; Pluciennik, 1994; Skeates, 1994, 1996; Skeates & Whitehouse, 1994b; Trump, 1996). The most significant contribution of all was Skeates and Whitehouse's (1994a, 1994b) volume *Radiocarbon Dating and Italian Prehistory*, which provided the first exhaustive list of radiocarbon dates for prehistoric Italy and serves as the foundation for our study. In recent years, a renewed focus on evaluating the radiocarbon evidence for the central Mediterranean Mesolithic (Lo Vetro & Martini, 2016), Neolithic (Binder et al., 2017; Lugliè, 2018; Natali & Forgia, 2018; Pearce, 2013; Skeates, 2013; Starnini et al., 2018), Copper Age (Cocchi Genick, 2013), Bronze Age (Alberti, 2013b; Capuzzo, 2014; Capuzzo

et al., 2014) and, to a lesser extent, Iron Age (van der Plicht et al., 2009) periods has provided a strong basis on which to explore long-term regional trends in radiocarbon data. Recent studies by Palmisano et al. (2017) and Stoddart et al. (2019) have utilized a multi-proxy approach combining archaeological surveys, sites and summed probability distributions of radiocarbon dates to explore long-term demographic trends in central Italy, demonstrating the effectiveness of radiocarbon evidence as an estimate of past demography and human activity in a central Mediterranean context. Similar studies analysing large bodies of radiocarbon dates have been undertaken for elsewhere in Italy (Martínez-Grau et al., 2020; Parkinson & McLaughlin, 2020) and the wider Mediterranean region (McLaughlin et al., 2020a; Broodbank and Lucarini, 2020; Fernández-López de Pablo, 2019; Welberg et al., 2019; Berger et al., 2019; Palmisano et al., 2019), underscoring the value of such approaches.

A further challenge in constructing regional syntheses that extend beyond modern political boundaries is terminology. Overall, a broad division of Mesolithic, Neolithic, Bronze and Iron Age applies across all the regions considered here, but the terminology related to sub-periods varies considerably between Italy, France and the Maltese Islands. This situation is further compounded by the complicated typochronologies that exist for some time periods. For example, there has been some debate over the phasing of the Italian Neolithic (see Whitehouse, 2013), with Tinè (1983) proposing a tripartite division consisting of an Early, Middle and Late phase, although including 11 sub-divisions. This was subsequently revised by Whitehouse (1986), who reshuffled the boundaries of the tripartite scheme and added a fourth Final Neolithic phase that coincided with Tinè's (1983) Late Neolithic. Whilst the initial tripartite scheme remains in use among Italian scholars (Pessina & Tinè, 2018), the two schemes are still used interchangeably, but with a general preference among Anglo-American scholars towards Whitehouse's (1986) revision. The picture gets muddled further when we consider other, closely related, cultural sequences in the region, such as the Maltese Islands where the Early Neolithic defined by Trump (1966b) falls within the southern Italian Middle to Final Neolithic cultural setting as designated by Tinè (1983) and Whitehouse (1986). In the later Neolithic, further regional variation in terminology confuses synthesis. Most notable is the definition of the Late Neolithic and Copper Age which differs between Italy and France: where mid fourth millennium BC introduces the Copper Age, or Eneolithic, in Italy, the term 'Late Neolithic' continues in use within French literature, lasting into the third millennium BC until the onset of the Bronze Age (see Pearce, 2019 for a historical perspective on the term 'Copper Age' and the impact of regional terminologies).

The division of the central Mediterranean Bronze Age is primarily based on pottery typology and in Italy is separated into Early, Middle, Recent and Final phases, each with numeric sub-phases. On the Maltese Islands, the Bronze Age is divided into Early, Middle and Late phases, and in France into Early, Middle and Final phases. Here we aim to use the relevant regional terminologies specific to whichever region is being discussed, although by virtue of Italy's geographical dominance in the central Mediterranean, there is a general reliance on Italian chronological frameworks. A summary of the main terminologies used and a chrono-typological sequence for the central Mediterranean is offered in Fig. 2. This scheme does not, however, include numeric sub-phases (e.g. Middle Bronze Age I, Middle Bronze

Date (cal. BC)	Phase	Southern Italy	Central Italy	Northern Italy	Southeast France (Provence)	Corsica	Sardinia	Sicily	Aeolian Islands	Maltese Islands
8000	Mesolithic									
7500		Castelnovian Mesolithic	Castelnovian Mesolithic	Castelnovian Mesolithic	Castelnovian Mesolithic	Undifferentiated Mesolithic	Undifferentiated Mesolithic	Castelnovian Mesolithic		
7000										
6500										
6000										
5500		Archaic Impressed wares		Ligurian Impressed	Impressed ware	Cardial-Impressed wares	Cardial-Impressed wares	Archaic Impressed ware		
5000		Evolved Impressed wares/Painted wares	Impressed wares	Impressed: Fianzano/Vho/Gabavi/Fantozzi etc. in east	Epicardial	Epicardial	Epicardial/Filestru	Evolved Impressed wares/	Impressed/	Ghar Dalam
4500		Serra d'Alto/Trichrome wares	Ripoli	VBO		Curasien	Bonu Ighinu	Stentello/Serra d'Alto	Stentello	Skoeba
4000		Diana	Diana-Chassey	Chassey-Lagozza	Chassen	Presa	San Ciriaco	Diana-Bellavista	Diana-Bellavista	?
3500		Taurasi		Remedello I		Bassien	Ozieri	San Coco-Piano Notara-Coma d'Oro	Spatirella	Zebbug-Mgarr
3000		Gaulo	Gaulo	Remedello II/Civate Group/Spilimbergo Group	Dolines Megalithic group/ Ferrères-Courmenin		Sub-Ozieri	Serrafellicchio	Piano Conte	Ggantija
2500		Laterza	Laterza		Rhône-Ouvéze/Fontbouisse					Tarxien
2000		Ortucchio	Ortucchio	Bell Beaker	Bell Beaker	Terrisien	Filigossa d'Albeolu/Bell Beaker/Monte Claro	Malpasso-Sant'Ipollito	Piano Quataro	Thermi
1500		Palma Campana/Ceccaniti (Calabria)	Belverde-Mezzano	Polada	Early Bronze Age	Proto-Torran	Bonamaro A	Castelluccio I/Rodi-Tindari-Vallèlunga	Capo Graziano I	
1000		Protoapennine/Messina-Riadi (Calabria)	Protoapennine	Taranata/Viverone/Castelferi (Friuli)	Middle Bronze Age	Torran	Bonamaro B	Castelluccio II/Rodi-Tindari-Vallèlunga	Capo Graziano II	Tarxien Cemetery
600		Apennine/Sub-Apennine	Apennine							
		Proto-Villanovan	Proto-Villanovan	Proto-Villanovan	Final Bronze Age		Nuragic	Thapsos	Milazese	Borg in-Nadur
		Villanovan/Pyrgos/Greek	Villanovan/Latini/Umbri/Piceni/Sabin/Samni	Villanovan/Palcosivelli/Gellicca	Iron Age	Iron Age	Punic	Paralica I & II	Ausonian I & II	Bahja
								Sicili/Sicani/Elimi/Greek/Punic	Greek	Punic

Fig. 2 Simplified relative chronology for the central Mediterranean 8000–600 cal. BC. Sub-phases not included

Age II). Ultimately, attempts to formulate such schematic views of cultural change in prehistory are fraught with challenges and will inevitably have shortcomings, but Fig. 2 is intended to provide a context for the archaeological background and radiocarbon trends discussed here.

Although Italy’s landmass dominates much of the central Mediterranean—and therefore prehistoric studies in the region—the importance of considering non-Italian islands has also long been recognized (Malone, 2003; Robb, 2007; Tykot, 1994). Following Skeates’ (1994) initial synthesis of radiocarbon dates for the Italian Palaeolithic to Iron Age periods, calls were made for a broader overview of the central Mediterranean that included the Maltese Islands (Skeates & Whitehouse, 1994a; Trump, 1995), with subsequent date lists aimed at addressing this issue (Skeates, 2000a; Trump, 1996). Only in studies documenting the spread of the Neolithic across the central Mediterranean has specific attention been paid to non-Italian territories, rightly highlighting the close relationships between Sardinia and Corsica (Lugliè, 2018), Liguria and south-east France (Binder et al., 2017; Maggi et al., 2020; Pearce, 2013) and the Adriatic coast of the Italian peninsula and Dalmatia (Conati Barbaro, 2019, pp. 79–83; Forenbaher & Miracle, 2005; Pearce, 2013, pp. 85–159) during the transition to agriculture. Such approaches have yet to be widely applied to later time periods, in particular the Bronze and Iron Ages, which are instead defined by long standing regional scholarly traditions.

## Methodological Context

The availability of large datasets and methodological developments have together transformed our ability to extract meaningful time series from aggregated radiocarbon data. Pioneering, continental-scale studies (Hinz et al., 2012; Peros et al., 2010; Shennan & Edinborough, 2007) summed the radiocarbon dates from a region to construct a model of human activity, settlement dynamics or population levels through time. A full description of the methods, their robusticity and interpretation, is provided in the Methods section of the paper and more detail is given in the online Supporting Information. Although this approach to the archaeological record has incurred some criticism (Attenbrow & Hiscock, 2015; Carleton & Groucutt, 2021; Contreras & Meadows, 2014; Torfing, 2015), further developments in simulation and bootstrapping have introduced methods that deal with calibration noise and enable identification of points in time where activity levels significantly deviate from null models of uniform or exponential growth (Carleton & Groucutt, 2021; Timpson et al., 2014). More recently, methods for formally testing the difference in activity and dynamics at various co-ordinates in time or space have been published (Crema et al., 2017; Edinborough et al., 2017) and, as discussed below, kernel density estimation (KDE) is a useful alternative to summed probability modelling for archaeological data (Bronk Ramsey, 2017; Brown, 2017; McLaughlin, 2019).

Recently published case-studies dealing with large-scale meta-analysis of radiocarbon data are now moving beyond methodological development, and instead seek to frame cultural evolution and population history within specific questions of, for example, continuity (Morin et al., 2018), oral traditions (Edinborough et al., 2017), climate and landscape change (Jørgensen, 2018), and economic history (McLaughlin, 2019). These studies, combined with discussions about what aggregated radiocarbon data actually mean in terms of past activity (Freeman et al., 2018), represent a considerable theoretical movement within archaeology, but a timely one given the renewed interest in past demography engendered by studies of ancient DNA. Irrespective of its methodological and theoretical approach, the current study is an expansion of work already completed for prehistoric central Italy (Palmisano et al., 2017, 2018), south-eastern France (Berger et al., 2019) and central-southern Europe in the Bronze Age (Capuzzo et al., 2018), and has been undertaken in the wider context of a burgeoning number of detailed, time-series-based syntheses of the archaeological record from macro-regions as diverse as Korea (Oh et al., 2017), Peru (Riris, 2018), North America (Zahid et al., 2016), and the British and Irish Isles (Bevan et al., 2017). We aim to contribute to this larger effort of systematically organizing archaeological information and uncovering new insights into large-scale patterns in world history.



## Archaeological Context

### The Mesolithic

The evidence for human activity during the Mesolithic period in the central Mediterranean (c. 9700 to 6000 BC) varies by sub-region. On the Italian peninsula, Mesolithic settlement largely occurred in caves and rock-shelters and is broadly characterized by the earlier ‘Sauvetterrian’, and later ‘Castelnovian’ lithic industries (or the ‘first’ and ‘second’ Mesolithic in French literature), whilst the surrounding islands are associated with undifferentiated lithic traditions (see Lo Vetro & Martini, 2016). Northern Italy has a particularly well-documented Mesolithic, and settlement evidence demonstrates use of both lowland and upland or mountainous territories (see Fontana & Visentin, 2016), with sites known in the Trieste Karst, Adige Valley, Tuscan-Emilian and eastern Ligurian Apennines, and Po Plain (Biagi et al., 1988; Franco, 2016; Kompatscher et al., 2016; Scoz et al., 2015; Visentin & Carrer, 2017; Visentin et al., 2014, 2016). In central and southern Italy, local terrestrial and marine resources appear to have been exploited in a pattern consistent with the seasonal utilization of coastal caves and rock-shelters (Lo Vetro & Martini, 2016). In general, however, earlier Mesolithic settlement in the south shows particular focus on coastal areas, as on the Salento peninsula in Puglia, in contrast to greater exploitation of inland areas in central (Pluciennik, 2008) and northern Italy (Fontana et al., 2013).

Among the islands of the central Mediterranean, Sicily has some of the most important Mesolithic sites. A cluster of well-studied cave sites with Mesolithic occupation and burial is known in north-west Sicily (D’Amore et al., 2010a, 2010b; Lo Vetro & Martini, 2016; Lo Vetro et al., 2016; Tagliacozzo, 1994), whereas in southern Sicily the comparative dearth of Mesolithic activity (Martini et al., 2007) resembles the situation in the Maltese Islands, which have no evidence for Mesolithic occupation (Bonanno, 2000). In Sardinia and Corsica, the Mesolithic period is similar to that of peninsular Italy, although marked differences that stem from the natural isolation of the two islands are reflected in the archaeological record. Settlement of the Tyrrhenian islands is defined by short-term and discontinuous occupation of small coastal rock-shelters (Costa et al., 2003; Lugliè, 2009a), although Mesolithic presence in larger caves is documented in Sardinia (Lugliè, 2009a, 2018). The Mesolithic economy of Sardinia and Corsica reflects exploitation of local terrestrial and marine resources, with a significant reliance on the endemic small mammal *Prolagus sardus* (Vigne, 1998). It has been suggested that, taken together, the evidence indicates short-term seasonal visits to the islands by small sea-faring groups from the Italian mainland (Costa et al., 2003).

The end of the Mesolithic was also regionally varied. In southern and central Italy, there appears to be a clearer chronological gap between the last Mesolithic hunter-gatherers and the arrival of the first Neolithic farmers (Perrin & Manen, 2021; Pluciennik, 1997), while the situation is considerably more varied in the north. Along the northern coast of the Tyrrhenian Sea, an area without any late

Mesolithic sites spanning western Liguria and eastern Provence lies between the Rhône valley and the eastern Ligurian Apennines where later Mesolithic sites are documented (Battentier, 2018; Biagi et al., 1988; Maggi et al., 2020). This distinctive pattern of late Mesolithic activity appears to have had a major bearing on the settlement pattern of northern Italy's earliest Neolithic pioneers, who spread along coastal routes, favouring areas without Mesolithic hunter-gatherers (see below). In the rest of northern Italy, along the Po and northern Apennines, the available radiocarbon data reveal a much murkier picture, and it is difficult to prise apart the relationship—and potential interactions—between the earliest farmers and last hunter-gatherers in the region (Martínez-Grau et al., 2020; Pearce, 2013, pp. 159, 204–207; Perrin & Manen, 2021).

## The Neolithic

The transition to agriculture in the central Mediterranean in the run-up to the sixth millennium BC brought with it technological innovations, new belief systems, domesticated animals and traditional 'Neolithic package' crops (Guilaine et al., 2019; Malone, 2003; Uccesu et al., 2017). The earliest Neolithic settlements in Italy associated with impressed-ware ceramics have been found along the lowland coastal areas of south-east Italy on the Salento peninsula and Tavoliere of Apulia (Brown & Alexander, 2013; Natali & Forgia, 2018). The region is perhaps best known for its many large ditch-enclosed settlements (*villaggi trincerati*) (Delano Smith, 1978; Jones, 1987), and with some 774 such sites of varying size documented on the Tavoliere alone (Whitehouse and Hamilton, 2020, p. 163), the Neolithic of southern Italy marks a point of major population increase and settlement density. The majority of ditched villages consisted of small groups of ditch-enclosed farmsteads set within larger perimeter ditches spanning areas of 4–7 hectares, but megasites such as Passo di Corvo reached up to 130 ha (Tinè, 1983; Trump, 1987, pp. 118–129). The Neolithic then rapidly spread westward into Calabria (Morter, 2010) and Sicily (Leighton, 1999, pp. 66–74; Natali & Forgia, 2018). In Sicily, Neolithic settlement was contained within caves and in open-air ditched village sites along the northern and southern coasts. Most of the known Sicilian open-air villages were excavated in the late nineteenth and early twentieth century along the south-eastern coast of the island (Orsi, 1899, 1921) and have received little attention since. Only a few later village sites located further west, such as at Stretto-Partanna and Piano Vento, have undergone more systematic investigation (Castellena, 1985; Martínez Sánchez et al., 2016). Most of our understanding of the Early Neolithic in Sicily therefore stems from two cave sites in western Sicily—Grotta dell'Uzzo and Grotta d'Oriente—where transitional Neolithic–Mesolithic stratigraphy has been identified (Tagliacozzo, 1994; Lo Vetro and Martini, 2016).

The spread of the Neolithic to central and northern Italy can be viewed as a series of parallel maritime expansions along the Adriatic and Tyrrhenian coastlines, including Sardinia and Corsica (for detailed discussion see Pearce, 2013, pp. 21–158). The speed at which agriculture spread northwards is demonstrated by the extremely early introduction of the Neolithic to western Liguria and eastern



Provence by as early as 5900 cal. BC (Binder et al., 2017; Maggi et al., 2020). In Adriatic central and northern Italy, where the spread of agriculture was intertwined with its spread along the adjacent eastern Adriatic coasts of Albania, Montenegro and Croatia (Conati Barbaro, 2019, pp. 71–83; Ferrari et al., 2018; Forenbaher & Miracle, 2005), the Neolithic arrived several centuries later (Martínez-Grau et al., 2020). This combination of routeways for the spread of the Neolithic into northern Italy resulted in the development of regionally distinct cultural traditions that can be divided between the north-western Italian Ligurian Impressed wares, and the Vhò, Fiorano, Gaban and Fagnigola groups to the east across the Po and Alpine valleys (Starnini et al., 2018). In central Italy, Early Neolithic settlements are found in subcoastal areas and lowlands on terraces overlooking rivers and lakes (Conati Barbaro, 2019, p. 13; Fugazzola Delpino et al., 2003a, pp. 94–99; Radi et al., 2018; Malone et al., 1992), whereas the settlement pattern in the north is one of cave and rock-shelters in the west and open-air villages in the east (Bagolini, 1980; Pessina & Tinè, 2018), further echoing the west–east differentiation in cultural traditions for the North Italian Neolithic.

In Sardinia, the arrival of the Neolithic around 5800–5600 cal. BC also saw complete genetic and cultural discontinuity with the preceding Mesolithic, as attested by stratigraphic information from Grotta Su Coloru (Lugliè, 2009b, 2018), radiocarbon data (Perrin et al., 2021), and aDNA studies (Modi et al., 2017). Together with the suggestion that Mesolithic activity on Sardinia and Corsica may have been restricted to occasional visits by groups from the Italian mainland (see above), this may therefore indicate that the Tyrrhenian islands were largely—if not entirely—depopulated by the time the earliest Neolithic settlers arrived. Following an initial Neolithic pioneer phase, the Neolithic in Sardinia signalled a period of significant settlement expansion, as indicated by the number of archaeological sites especially on the west coast, whilst, by contrast, Early Neolithic expansion in Corsica was more muted (Lugliè, 2009b, 2018).

Narratives of the Middle and Late Neolithic describe how gradual economic diversification and pastoralism occurred in increasingly dispersed and varied settlement contexts (Barker, 1999, pp. 13–14; Dolfini, 2020, p. 515; Malone, 2003, p. 299). Whereas areas of previous intense human occupation in southern Italy and Sicily—namely the Tavoliere and Catania plains—declined (Leighton, 1999, pp. 53–54; Fiorentino et al., 2013; Skeates, 2015; Whitehouse, 2013), there was expansion into a variety of upland and lowland areas, but also into small islands. The Maltese archipelago was settled by 5500 cal. BC, with occupation in both caves (Despott, 1917) and open-air settlements (Brogan et al., 2020; McLaughlin et al., 2020b, pp. 154–155; Trump, 1966b, 2015). In the larger islands of Sardinia and Corsica, Middle and Later Neolithic human occupation spread into a range of inland and coastal lagoon areas (Dyson & Rowland, 2007, pp. 36–37). Within central Italy, Middle and Late Neolithic settlement continued in subcoastal areas but also penetrated further inland to the Apennine valleys and wetland areas (Fugazzola Delpino et al., 2003a, pp. 97–99; Malone, 1994, 1994a, 1994b, pp. 67–80). A similar situation occurred further north, with open-air settlement expansion into wetland zones and into the upland Alpine and Apennine areas (Mottes et al., 2009; Skeates, 2013, p. 8; Visentini, 2006).

## The Final Neolithic and Copper Age

The fourth and third millennia BC broadly correspond to the Copper Age in the central Mediterranean (Final or Late Neolithic in French and Maltese literature) and are defined as a period of social and economic transformations which developed out of the later Neolithic. The settlement record for the Italian Final Neolithic and Copper Age is spotty at best, but in general the period saw a movement away from nucleated villages towards more dispersed settlement into a wider variety of landscape settings (Dolfini, 2015, pp. 30–33, 2020, p. 517) and continued expansion into upland zones—where the latter narrative has been driven further by the discovery of the Tyrolean Iceman in the Ötztal Alps (Barfield, 1994b; Spindler, 2000). Traditionally, the lack of open-air settlement for Copper Age Italy was explained within the mid-twentieth-century culture-historical framework as evidence that the period was characterised by nomadic ‘warrior pastoralists’ who migrated into the central Mediterranean and introduced metal working into the region (Trump, 1966a, pp. 79–80; see Robb, 2007, p. 288; Dolfini, 2020, p. 524). Barker (1981a) was the first to argue against the ‘warrior pastoralist’ narrative, and discoveries of numerous settlements over the last 20 years (largely thanks to developer-led archaeology) further refute the long-held view that Copper Age settlement was ephemeral and suggest that the role of transhumant pastoralism during the period has been over-emphasized (Cardarelli, 2015, pp. 154–156). Settlement evidence for the central Mediterranean Copper Age has changed drastically, particularly in the central-southern Italian peninsula (Anzidei et al., 2007; Baioni & Poggiani-Keller, 2013; Giola et al., 2007; Tunzi et al., 2013), and several substantial domestic sites indicate that larger stable settlements endured throughout the Copper Age (Anzidei et al., 2016; Bernabò Brea et al., 2011; Fugazzola Delpino et al., 2003b; Manfredini, 2014; Salerno and Marino, 2011). Many Italian sites also show continuity from the Late Neolithic to the Early Bronze Age (Baioni & Poggiani-Keller, 2013; Fugazzolo Delpino et al., 2003a, p. 101; Ingravallo, 1980; Silvestrini & Pignocchi, 1997; Talamo, 2006), suggesting relative homogeneity in settlement patterns throughout the fourth and third millennia BC.

The north Italian Copper Age was traditionally associated with the Remedello culture that extended across the Po Valley (Barfield, 1971). As is the case with much of the central Mediterranean, systematic research in recent decades has shown that the archaeological record is in actual fact considerably more nuanced (De Marinis, 1997). To the south of the Po River, inhumation cemeteries and settlements are found associated with the Spilamberto Group (Bagolini, 1981; Miari, 2014; Miari & Benazzi, 2018; Miari et al., 2017) and to the north the Civate Group is known from burial in caves and statue menhirs in the Alpine regions (Barfield, 1983). Copper Age settlement in northern Italy appears on fluvial terraces and on the slopes of the pre-Alps, where multi-stratified sites demonstrate long occupation histories spanning the duration of the Copper Age (e.g. Lovere-Colle del Lazzaretto and Monte Covolo in Lombardy: Baioni & Poggiani-Keller, 2013). Similarly long occupation spans also occur in the inner Alpine valleys, as at Latsch, Vinschgau (Festi et al., 2011), which are exploited from the Late Neolithic onwards (Putzer et al., 2016). Copper Age settlements also occurred on the southern Po Plain, with some focus on

the margin of the Apennines in Emilia-Romagna (Bernabò Brea et al., 2011; Berni et al., 2011; Miari, 2014).

The Rinaldone culture traditionally defined the central Italian Copper Age (Trump, 1966a, pp. 72–80), although recent research has shown the complex spatial and temporal relationship between Italy's traditional Copper Age 'cultures' in central and southern Italy (see Fig. 2). Areas such as the 'core' Rinaldone zone on the Tuscany–Latium border still lack definitive settlement evidence (Fugazzola Delpino et al., 2003a, pp. 100–101), but a large number of sizeable cemetery sites suggests considerable population increase during this period (Negroni Catacchio, 2006; Negroni Catacchio et al., 2016). Some of the most important developments have occurred in the area south of Rome, where excavations have uncovered extensive evidence for Copper Age settlement in the area between the Tiber river and the Colli Albani and redefined the entire Copper Age sequence for central-southern Italy (Anzidei et al., 2007, 2012, 2016; Carboni & Anzidei, 2013; see Anzidei & Carboni, 2020) by revealing the complicated spatial and temporal relationships between the Rinaldone, Gaudio, Laterza and Ortucchio ceramic styles (Fig. 2). The Roma-Colli Albani sites indicate dense and stable settlement in southern Rome from the mid fourth to late third millennia BC, alongside continuity in economy and burial traditions across the entire Late Neolithic and Copper Age sequence. On the Adriatic coast of central Italy, Copper Age activity is known in Marche along the narrow coastal plains surrounding Ancona and into the Apennines, with funerary sites situated towards the coast and settlement located inland (Fugazzola Delpino et al., 2003a, p. 101; Manfredini et al., 2009; Skeates, 1997). Large open-air villages are also known in Marche at Conelle di Arcevia (Cazzella & Moscoloni, 1999; Cazzella & Recchia, 2014) and Maddalena di Muccia at Macerata (Manfredini, 2014) and attest to the existence of substantial and stable Copper Age settlement here too.

The southern Italian Copper Age was until recently known solely from large rock-cut tomb cemeteries associated with the Gaudio culture in Campania and the Laterza culture in Apulia (Biancofiore, 1967; Whitehouse & Renfrew, 1974, pp. 349–357). The Roma-Colli Albani sites mentioned above have highlighted the complexities of the Copper Age in southern Italy too, extending the distribution of Gaudio and Laterza ceramic styles to central Italy, and as actually reflecting chronologically discrete cultural horizons—Gaudio representing the middle Copper Age and Laterza representing the recent Copper Age (Carboni, 2020a, p. 89, 2020b; Carboni & Anzidei, 2013, pp. 149–161; Fig. 2). The recent introduction of a new earlier Taurasi phase associated with cremation cemeteries in Campania (Passariello et al., 2010), Apulia and Basilicata (Aprile et al., 2013; Quarta et al., 2014), further demonstrates the true complexity of the south Italian Copper Age. In Campania, Middle Copper Age settlements from the early third millennium BC are situated on the fertile coastal plain north of Naples (Aurino, 2013). At the settlement of Caivano, two successive phases of occupation associated with the Gaudio culture were separated by the Agnano 3 eruption horizon (Passariello et al., 2010), demonstrating a rapid reoccupation of the area following the event. The settlement record for later prehistory in Campania also shows general consistency from the Late Neolithic to Early Bronze Age, with settlements known in both lowland and upland areas, with those in the highlands appearing to relate to the control of natural route ways (Talamo, 2006). In Apulia, Copper

Age activity on the Tavoliere was minimal, and Final Neolithic–Copper Age settlements are found on the Murge plateau (Fiorentino et al., 2013), the Salento peninsula and Basilicata (Pacciarelli et al., 2015). The picture for the Late Neolithic and Copper Age of Apulia has started to improve in recent years, and the recent excavation of a settlement at Tegole represents a rare and important Copper Age presence on the western margin of the Tavoliere (Tunzi et al., 2013, 2017).

Turning to the islands, the Sicilian ‘proto-Eneolithic’ during the late fifth to early fourth millennia BC is largely associated with the development of rock-cut tomb cemeteries in the south related to the San Cono–Piano Notaro culture, such as Piano Vento (Castellana, 1995) and Scintilia (Gulli, 2014), and with the Conca d’Oro culture in the north (Tinè, 1960). Copper Age settlement sites in Sicily show utilization of a variety of landscape locations, and like adjacent areas of peninsular Italy, there was continuity with Late Neolithic and Early Bronze Age patterns (Leighton, 1999, p. 100). The period is characterized in general by an expansion into the uplands (Leighton, 2005), apparent in both the earlier Copper Age (Cazzella & Moscoloni, 2012, pp. 59–62) and middle and later Serrafelicchio and later Malpasso cultural contexts (Giannitrapani et al., 2014; Malone et al., 2003). In southeast Sicily, areas of dense Early Neolithic settlement on the coastal plains surrounding Syracuse and Catania remained largely unused during the Copper Age (Leighton, 1999, pp. 89, 100), but use of cave sites for habitation, burial and cult purposes continued in the coastal areas of Agrigento in southwest Sicily (Gulli, 2011).

In the Sardinian Copper Age, it appears that Early Copper Age Sub-Ozieri and Middle Copper Age Abealzu and Filigosa settlement shows general continuity with the Late Neolithic Ozieri phase (Melis, 2000, p. 141; Melis, 2009), which is also reflected in continuity in funerary traditions (Melis, 2014). Interpretation of the details of Copper Age settlement patterns in Sardinia should, however, proceed with some caution, given the stylistic similarities in material culture across the Late Neolithic and earlier Copper Age and the fact that most sites are known from either surface features or find scatters (Webster & Webster, 2017, p. 57). The chronology of the Sardinian Copper Age has received much-needed attention in recent years (Melis, 2013; Melis et al., 2017), but many questions remain over the spatial and temporal interplay between cultural phases in the third millennium BC. More recently, Pearce’s (2017) updated chronology (see Fig. 2) has expanded the Ozieri phase to 4200–3400 cal. BC and Sub-Ozieri to 3600–2800 cal. BC. By the early third millennium BC, the Filigosa and Abealzu phases emerged alongside the distinctive Monte Claro phase, which spanned the majority of the third millennium BC and overlapped with the Sardinian Bell Beakers (Melis, 2013, pp. 206–207). Marked differences in settlement and material culture are more apparent in Monte Claro phase contexts (Melis, 2000, p. 144), with the emergence of large villages in some cases consisting of up to 60 huts, as at Monte Pranu (Manunza et al., 2014). In general terms, Monte Claro phase settlements were primarily located on lowlands in the south and hills to the north, in contrast to the coastal settings of earlier periods (Lai, 2008, p. 102).

Finally, the fourth and third millennia BC on the Maltese Islands saw the rise of a complex culture characterized by elaborate and sophisticated megalithic ‘temples’, art and ritual processes that expressed a strong local identity (Bonanno et al.,

1990). The sharp cultural discontinuity between the Early Neolithic (Għar Dalam and Skorba phases) and the Late Neolithic ‘Temple Period’ has been the focus of much discussion (Trump, 2002, pp. 238–241), establishing a theoretical framework that suggested cycles of relative isolation and insularity over time (Stoddart et al., 1993; Trump, 1961); this has since been challenged (Grima, 2002; Robb, 2001), and then reiterated in both cultural and biological detail (Malone & Stoddart, 2004; Ariano et al. in press). Domestic evidence for the Temple Period on the Maltese Islands is extremely scant (Malone et al., 2009), in contrast to a wealth of ritual architecture (Trump, 2002). Aside from unconvincing arguments that subsidiary structures at megalithic sites represent huts (Sagona, 2015, pp. 55,78), only two Temple Period domestic structures have been excavated in the archipelago, both on the smaller island of Gozo (Malone et al., 1988, 2020a).

## The Bronze Age

The Italian Bronze Age has been divided into four phases, Early, Middle, Recent and Final. Traditions of scholarship dictate that the Bronze Age of northern Italy has been studied in the context of its close ties with broader continental Europe (Barfield, 1994a). The north Italian Early Bronze Age is represented by the Polada culture, noted for numerous lake settlements distributed along the southern Alps, particularly along Lake Garda, and limited settlement on the Po Plain (Barfield, 1994a; Capuzzo, 2014; Nicolis, 2013). This settlement pattern changed greatly throughout the mid second millennium BC in the Middle Bronze Age, which was marked by the rise of the Terramare system. The Terramare was accompanied by a dense settlement shift to the central-southern Po Plain and considerable population increase (Bernabò Brea et al., 2018; Vanzetti, 2013), which reached a peak at the turn of Middle Bronze Age and Recent Bronze Age (Cardarelli, 2009, p. 468). The Terramare settlements were essentially planned villages of pile-built houses that were serviced with drainage and enclosed within quadrangular banks (Pearce, 1998). By the Recent Bronze Age, the Terramare settlements had become more complex, showing greater monumentality in their earthworks, which implies a necessity for defence, alongside technological advancements in metallurgy and agriculture (Bernabò Brea et al., 1997; Blake, 2014).

A subsequent decline of the Terramare system led to an eventual collapse at the end of the Recent Bronze Age (Cardarelli, 2009, p. 485); however, this collapse was not universal, since some Terramare north of the Po River continued into the Final Bronze Age (Cupitò et al., 2015). The decline of the Terramare is associated with a large-scale demographic collapse (Cardarelli, 2009; Rondelli, 2008), caused by a variety of factors, including environmental decline and climatic deterioration (Cremaschi et al., 2006, 2016; Whitehouse, 2001) or social and political instability (Cardarelli, 2009, p. 471). Overall, the region inhabited by the Terramare group has limited evidence for much of the Final Bronze Age and Early Iron Age (Barfield, 1994a), with the exception of the Valli Grandi Veronesi sites (Cardarelli, 2009, p. 506). A similar abandonment of Recent Bronze Age settlements is attested in other areas of the Peninsula, such as the Romagna plain (Von Eles & Pacciarelli,

2018) and a substantial part of the Marche region (Cardarelli, 2009, p. 507). Recent authors (Pearce, 2020; Stoddart, 2020c; Zamboni, 2021) have also sought to consider the extent to which the Terramare actually reflected a form of ‘fragile’ proto-urbanism in the later Bronze Age that deviated from the typical model of Mediterranean urbanisation, which revolved around long established centres.

Central Italy is an example of this ‘typical’ process, where the Bronze Age is defined by gradual development in social and political complexity that ultimately led to state development in the Iron Age (Bietti Sestieri, 2010, pp. 356–358; Pacciarelli, 2000; Stoddart, 2020a, 2020b). Although interpretation must proceed with caution because of the methodological and geographical biases implicit in the data (Stoddart, 2020a, pp. 13–22), central Italy is nonetheless the best-resolved Italian region. Most of the work has been concentrated on South Etruria (Northern Lazio) (Barbaro, 2010; Di Gennaro, 1986; di Gennaro & Pacciarelli, 1992), Latium vetus (Southern Lazio), the area close to Rome (Cardarelli, 2018), and the Marche on the Adriatic coast (Cardarelli et al., 2017), although notable exceptions such as Gubbio, in Umbria, have some of the highest densities of pottery in the region (Malone and Stoddart, 1994).

The social and political transformations of the Bronze Age were clearly accompanied by an increase in archaeological sites and population (Barker, 1999; Barker & Stoddart, 1994), which has been corroborated by the available radiocarbon evidence (Palmisano et al., 2017). Settlement patterns for the Early and Middle Bronze Age of central Italy show occupation of both upland and lowland areas as part of a mixed economy (Barker, 1981b, 1999, 2005). The Recent Bronze Age in Italy corresponds to a period of profound social and political change, and it has been argued that it is under-represented in the archaeological record, especially through surface survey (Barker & Stoddart, 1994). This pattern of demographic growth continued to develop into the Final Bronze and is associated with a general increase in sites, in contrast to northern Italy. Increased density of settlements and associated cemeteries in South Etruria during the Final Bronze Age has also been interpreted as evidence for increasing social hierarchy (Barbaro, 2010; di Gennaro & Barbaro, 2008) and cultural homogeneity, recognized as Proto-Villanovan material culture and latter attested in a significant part of the Italian peninsula (Negroni Catacchio, 2010). A further profound change took place at the transition to the Iron Age in Etruria, when settlement concentrated on larger plateaux or alternatively neighbouring hills with a significant extension of 125–180 ha or 40–90 ha in case of smaller centres (Pacciarelli, 2000, p. 279); in some cases (e.g., Tarquinia) these were already occupied from the last phase of the Final Bronze Age (Bietti Sestieri, 2010). There has been much discussion regarding the politics of how this process was accomplished, with interpretations ranging from collective action to the authority of a restricted leadership (see Stoddart, 2010; Stoddart et al., 2020).

For the southern part of the central Mediterranean, the picture of the Bronze Age is one of considerable regional diversity. Early Bronze Age Campania villages in the south of the peninsula show varied use of settlement locations, including coastal and riverine areas, lowlands sites and mountain camps (Di Vito et al., 2019; Talamo, 1996), indicative of small societies engaged in mixed agriculture and small-scale pastoralism (Albore Livadie, 2007; Di Vito et al., 2019). Evidence from the



exceptionally well-preserved settlement of Nola-Croce del Papa in Campania shows a reliance on ovicaprines, pig and cattle, alongside active food storage (Albore Livadie & D'Amore, 1980; Albore Livadie and Vecchio, 2020). Traditionally, Early Bronze Age occupation of Campania was thought to have been severely impacted by the Avellino Pumice eruption of c. 1935 to 1880 cal. BC (Albore Livadie et al., 1998; Passariello et al., 2009), with some sites showing delayed reoccupation only in the Middle Bronze Age (Di Lorenzo et al., 2013; Di Vito et al., 2019), although recent research has also demonstrated considerable continuity and rapid resettlement of the area following the eruption (Albore Livadie et al., 2019).

Major sites such as Toppo Daguzzo (Basilicata) and La Starza (Campania), located between environmental zones on communication routes, seem positioned as important or central places (Malone et al., 1994a, 1994b). Excavations at Poggiomarino, Campania, have revealed a significant wetland site that was established during the Middle–Late Bronze Age and persisted into the Iron Age (Albore Livadie et al., 2010; Price, 2013), showing the presence of large and complex settlements in southern Italy during the second millennium BC, echoing the pattern known from further north. During the Middle Bronze Age, settlement is variable throughout southern Italy although there is significant use of cave sites and shelters for ritual, funerary and seasonal purposes, one of the most significant being the Grotta Cardini di Praia (Bietti Sestieri, 1997). Sites on the coast are also widespread, particularly in the Adriatic and Ionic regions, whilst fortified sites in Apulia, such as Roca Vecchia and Coppa Nevigata (Alberti, 2013b), and Broglio di Trebisacce in the Sibaritide (Peroni and Trucco, 1994), may have been connected with increased maritime trade at the time. In the Late Bronze Age, a pattern similar to that of central Italy occurred, in that the numbers of sites increased, and focus shifted to sites in naturally defensible locations (Malone et al., 1994a, 1994b).

The Sicilian Early Bronze Age is represented by the Castelluccio phase when settlement expanded to defended sites located inland, associated with increasing pastoralism, and some coastal settlements (Malone et al., 1994a, 1994b; Leighton, 1999, p. 114, 2005). On the Aeolian Islands, as the Early Bronze Age Capo Graziano phase progressed, there was a shift to settlement on higher ground (Alberti, 2013a; Leighton, 1999). On Malta and Gozo, the transition from the Temple Period to the Bronze Age now appears to be characterised by the appearance of an intermediate 'Thermi ware' phase and a subsequent hiatus before the start of the Early Bronze Age Tarxien Cemetery phase (McLaughlin et al., 2020a, 2020b, p. 33), when levels of activity on the islands are much reduced. For Sardinia, the defining feature of the Bronze Age is the Nuragic period (Lilliu, 1963; Webster, 2015), which saw a massive population increase and settlement expansion across the island. The Nuragic period is defined by its eponymous architectural feature, the *nuraghe*, consisting of a large conical tower, with later nuraghi featuring multiple towers and a large number of subsidiary structures. Early Nuragic sites, or proto-nuraghi, tend to be distributed in western-central Sardinia, north of Cabras (Demurtas & Demurtas, 1992), before the tradition expanded across the entire island. As the Nuragic period developed during the Middle to Recent Bronze Age, settlements increased in number, size, and elaboration, culminating in complex nuraghi (Depalmas, 2009a, 2009b, 2009c; Melis, 2017), such as at Su-Nuraxi/Barumini. With an estimated 7000 nuraghi found across Sardinia (Klob, 2005), the Bronze Age in Sardinia is seen as a period of considerable population increase, similar to northern

Italy. Although nowhere else hosts such elaborate sites in such high densities, parallel traditions to the nuraghi occur in other western Mediterranean islands, such as the Torre of southern Corsica (Peche-Quilichini & Cesari, 2017), Sesi in Pantelleria (Orsi, 1899) and Talayots on the Balearic Islands (Gili Surlinach et al., 2006). In the Maltese Islands, villages associated with the Middle Bronze Age Borg in-Nadur phase were located within large walled enclosures that also recall this wider tradition (Evans, 1971; Tanasi and Vella, 2011).

## The Iron Age and the End of Prehistory

The end of the prehistoric period in the central Mediterranean was a complex set of transformations brought about by the indigenous development of pre-Roman Iron Age states in central Italy (Pacciarelli, 2000; Perego & Scopacasa, 2016; Peroni, 2000; Stoddart, 2020a, 2020b, 2020c), increasing presence of Phoenician and Greek colonies in southern Italy, Sicily, Sardinia and the Maltese Islands, and Italic and, later, Gallic settlement of the northern parts of the central Mediterranean region. The cultural homogeneity that characterized the Final Bronze Age then dissolved, giving way to distinct regional cultural groupings (Riva, 2010). This regional diversity, generated by special chains of networks and relationships (Bietti Sestieri, 2012; Blake, 2014; Di Gennaro, 1996), and increasing entanglement in wider worlds, also saw economic transformation and significant changes in patterns of agriculture, land use and settlement. The archaeological evidence for this period takes many forms and is not easily summarized; but in general terms there was a greater degree of long-distance trade, centralized authority, nucleated settlement and technological sophistication than in any preceding period. From this patchwork of independent, and sometimes competing social units, Rome in the eighth Century BC rose to dominate first central Italy, then the entire central Mediterranean region, culminating in a civilization that spanned much of Europe, North Africa and the Middle East. Rome's political and cultural legacies were so pervasive that they are still strongly felt throughout the world today.

## Methods

This study comprises the Italian peninsula, Sicily, Sardinia, the Maltese Islands, Corsica and southeast France spanning the Mesolithic to Early Iron Age. To investigate regional trends, we divided the Italian peninsula into separate northern, central and southern areas using modern regional borders. Whilst the use of modern administrative and political borders may not seem ideal in a prehistoric context, they do broadly correspond to landscape features across the Italian peninsula and therefore have useful heuristic value.

A database of radiocarbon dates for prehistoric Italy was compiled through the aggregation of existing databases (McLaughlin et al., 2020a; Palmisano, et al., 2017; Pearce, 2013; Pinhasi et al., 2005; Skeates & Whitehouse, 1996; Skeates, 1994,

**Table 1** The number of archaeological sites and radiocarbon dates retained for analysis for the present study, and their spatial density

Region	No. sites	No. dates	Area, km <sup>2</sup>	Sites/100 km <sup>2</sup>	Dates/100 km <sup>2</sup>
SE France	264	565	94,000	0.28	0.60
Northern Italy	350	1566	120,000	0.29	1.31
Central Italy	266	1047	60,000	0.44	1.75
Southern Italy	133	501	123,000	0.10	0.41
Corsica	47	185	8680	0.54	2.13
Sardinia	79	263	24,090	0.33	1.09
Sicily	47	233	25,711	0.18	0.90
Malta	9	155	316	2.85	49.10
Total	1195	4515	455,797	0.26	0.99

The most sparsely dated region is Southern Italy

**Table 2** Numbers of radiocarbon dates from the various categories of sample per region

Region	A	B	C	D	H	R	O	S	Sc	U	W
SE France	6	91	324	4	12	0	10	1	9	8	97
N. Italy	52	54	670	1	298	0	8	14	41	242	186
C. Italy	23	36	353	0	244	10	17	22	19	182	141
S. Italy	25	49	186	0	57	0	2	11	36	130	5
Corsica	0	12	105	0	2	0	1	0	0	65	0
Sardinia	11	56	59	0	22	0	0	2	1	110	2
Sicily	18	8	124	0	6	0	0	2	9	65	1
Malta	8	0	10	0	25	0	0	0	53	0	0
Totals	143	306	1831	5	666	10	52	38	168	802	432

The codes used are (A) animal bone, (B) undetermined bone, (C) charcoal, (D) bulk deposit, (H) human bone, (M) marine (a different <sup>14</sup>C reservoir), (R) mortar, (O) other, (S) short-lived plant, (Sc) domesticated cereal grain, (U) unknown, (W) wood. Marine samples (6 from Southern Italy, 4 from Central Italy, 3 from Northern Italy, 1 from Sardinia, 11 from SE France, and 16 from Sicily have been excluded from the analysis but their details are provided in the Supplementary Information, available online)

1998, 2000a, 2003; Trump, 1996), and a literature review (see supplementary data). The database was imported into various Geographical Information Systems (ArcGIS 10.5, QGIS 3.4, GRASS 4.1 and mapprools 0.9) for visualization and analysis. Spatial density was computed using a two-dimensional kernel density estimator with a search radius of 100 km.

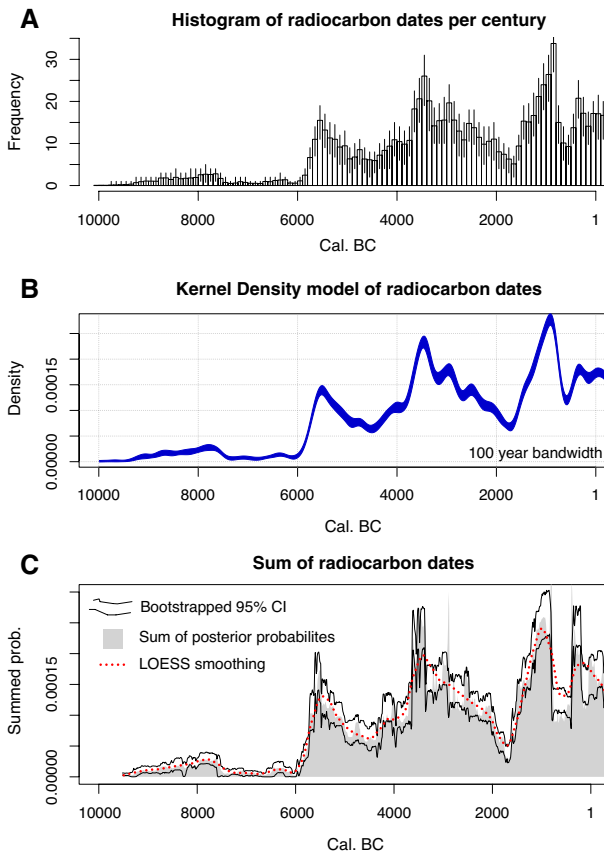
Each entry in the database consisted of a radiocarbon age determination (<sup>14</sup>C yrs ± standard deviation), geographic attributes, some contextual information and details of the material that constituted the sample. The total number of dates from each region is given in Table 1 and each sample type in Table 2. These data were audited, pruning from the database 128 measurements with excessive error terms (> 400 <sup>14</sup>C years) or dates that could not be unequivocally identified with human activity, such as samples of bulk sediment. Hierarchical cluster analysis was

performed in order to identify individual unique site phases (Bevan & Crema, 2020, see Supporting Information document p. 2), enabling the analysis to be undertaken using only one date from each site phase, thus avoiding overrepresentation of any one site (i.e. a particularly well-dated site) in the KDE models.

To process these data and develop density models on a calendar time scale, we used kernel density estimation (KDE) (Bronk Ramsey, 2017; Brown, 2017; McLaughlin, 2019). This method calculated the probability density of radiocarbon activity in each region with a fixed bandwidth of 75 years—the bandwidth being a smoothing parameter intended as a model of sampling error. For detailed study of rapid changes in the density models, we re-calculated them using a bandwidth of 30 years. By bootstrapping thousands of individual KDE models built from repeated ‘Monte Carlo’ random samples drawn from the posterior probability densities of each calibrated radiocarbon date, we were able to express in the KDE models uncertainty introduced by the radiocarbon calibration process. A relevant advantage to this approach is that radiocarbon dates with large error terms, such as the dates obtained during pioneering work in the 1960s and 1970s, can be included in the density models in a meaningful way, in contrast to summed probability approaches where the posterior probabilities of such dates are so low that they are lost among noise in the calibration curve (Brown, 2017). We repeated the density modelling process using multiple permutations of the dataset and with a sample of 50% of the dates in the database across multiple sampling runs (see Supporting Information document pp. 9–11). This process expressed a further uncertainty interval caused by the stochasticity of the data. This inherent variability, caused by archaeological factors such as site density and the average number of radiocarbon dates per site, was checked through random sampling of the data that ensures that no one site or regional research effort has undue influence over the overall results. The atmospheric or marine IntCal20 (Reimer et al., 2020) calibration datasets were used to calculate as appropriate, using *rowcal* (McLaughlin, 2019); for convenience in most cases the marine samples were simply excluded from the analysis, as they are so few in number (Table 2). We also performed some modelling using simulated ensembles of ‘back-calibrated’ radiocarbon dates to see how various modelled scenarios are represented in the radiocarbon KDE.

### Interpreting Kernel Density Estimation (KDE) Models

The method used here for calculating radiocarbon kernel density models is one of a range of similar approaches that aggregate radiocarbon data and visualise their inherent trends. A KDE model can be interpreted much like a histogram representing the number of dates falling within a time slice or ‘bin’, which is analogous to the bandwidth of the KDE. Whilst a histogram consists of counts of dates within fixed breakpoints, the KDE is a continuous function that creates a smoothing effect that is naturally better at resolving sudden changes (Fig. 3) and is therefore our preferred means of visualising these data. Furthermore, because each calibrated date has a large range of uncertainty, bootstrapping techniques must also be employed to develop a confidence envelope for the counts of each histogram bar. As Fig. 3



**Fig. 3** A comparison of a histogram, KDE, and summed probability distribution of the same set of radiocarbon dates (in this case, the central Italian data discussed below). The confidence interval of the summed probability distribution has been calculated using the method of Fernández-López de Pablo et al. (2019)

demonstrates, not only is the uncertainty of the histogram greater, but subtleties in the data are also more difficult to identify.

A closely-related alternative is the use of summed probability distributions, which are very often used to summarize sets of radiocarbon dates. The summing approach can be criticized on the grounds that spurious artefacts are introduced into the sums via the idiosyncrasies of the calibration curve. However, the latest refinements in smoothing and bootstrapping have moved towards addressing these issues. Compared with the KDE or histogram (Fig. 3), the summed probability distributions contain more calibration noise, and although this can be removed with locally-estimated scatterplot smoothing algorithms (LOESS modelling), we prefer the KDE approach as the underlying assumptions in the smoothing model are easier to relate to real-world conditions.

The KDEs were numerically differentiated in order to calculate annual average growth rates (see Supporting Information document pp. 21–22). The radiocarbon database, and the R code used to undertake the analysis are included in this paper as electronic supplementary information, which also contains some supplementary analysis and alternative projections of the data.

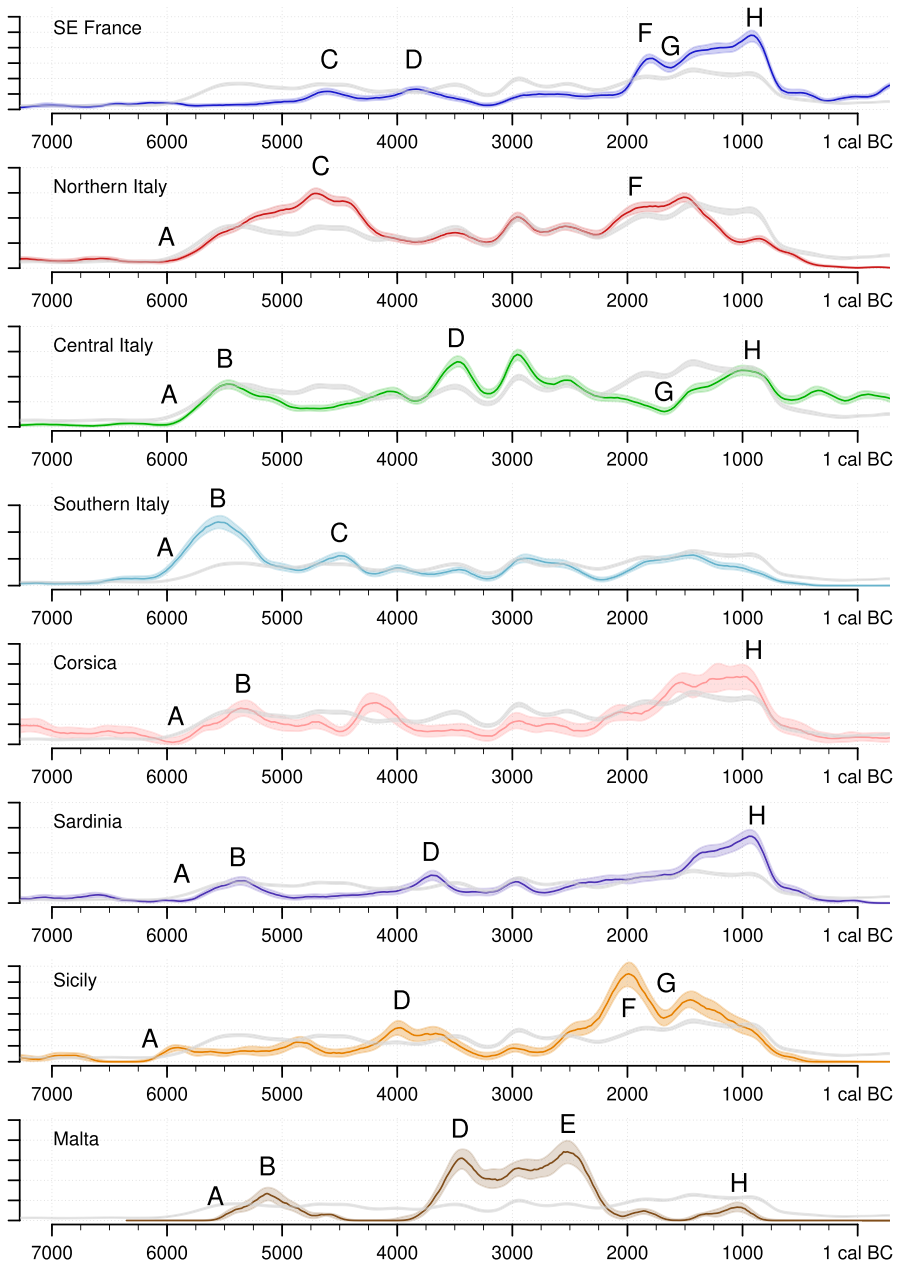
## Results

The KDE activity models for each region in the study are plotted in Fig. 4 and animated maps showing spatio-temporal patterning of the data are included as supplementary material. The results of the KDE analysis are described in overview here, and in general show fluctuating patterns in human activity levels, with multiple periods of increase and decline in anthropogenic activity. Turning first to the Mesolithic period, represented by approximately 500 dates, the models show a constant low level of activity across the central Mediterranean (Fig. 4; see Supplementary Figure S1). The Neolithic transition, which occurred during the onset of the sixth millennium BC, signals a period of significantly higher activity throughout the region. The beginnings of this phenomenon around 6200 cal. BC in southern Italy are associated with the initial introduction of the Neolithic into the wider central and western Mediterranean (Fig. 4, point A). This led to a pronounced apogee in activity in around the mid sixth millennium BC in southern Italy, central Italy, Sardinia, Corsica and the Maltese Islands (Fig. 4, point B). In contrast, the apex of Neolithic activity occurs later in southeast France and northern Italy during the mid fourth millennium BC (Fig. 4, point C).

The early–mid fourth millennium BC sees a modular pattern of activity across the entire central Mediterranean area at the interface between the Neolithic and Copper Age, with significant spikes occurring in both mainland areas and the islands (Fig. 4, point D). Where southern Italy and Corsica exhibit low levels of activity, the KDE models show a sharp increase in activity in Sicily, central Italy, Sardinia and southeast France during the early–mid fourth millennium BC, whilst northern Italy sees only a modest non-significant rise. In all regions, the later fourth millennium BC and majority of the third millennium BC is a period of long-term low-level stability, with the exception of the Maltese Islands, which seem to flourish at this time (Fig. 4, point D). A pronounced drop around 3000 cal. BC punctures intense anthropogenic activity in the Maltese archipelago, which is the setting for another significant peak of activity in the mid third millennium BC (Fig. 4, point E) at a time of continued subdued activity across the entire central Mediterranean. The mid third millennium BC increase observed on the Maltese Islands gradually declines and a coeval increase occurs in neighbouring Sicily, associated with the Early Bronze Age (Fig. 4, point F). Only in southeast France and northern Italy does a similar increase occur with the inception of the Early Bronze Age (Fig. 4, point F), with central and southern Italy and the Tyrrhenian islands showing no such pattern.

The development of the Bronze Age in southeast France, central Italy, Sardinia and Sicily is interrupted by a significant drop in the KDE models (Fig. 4, point G),

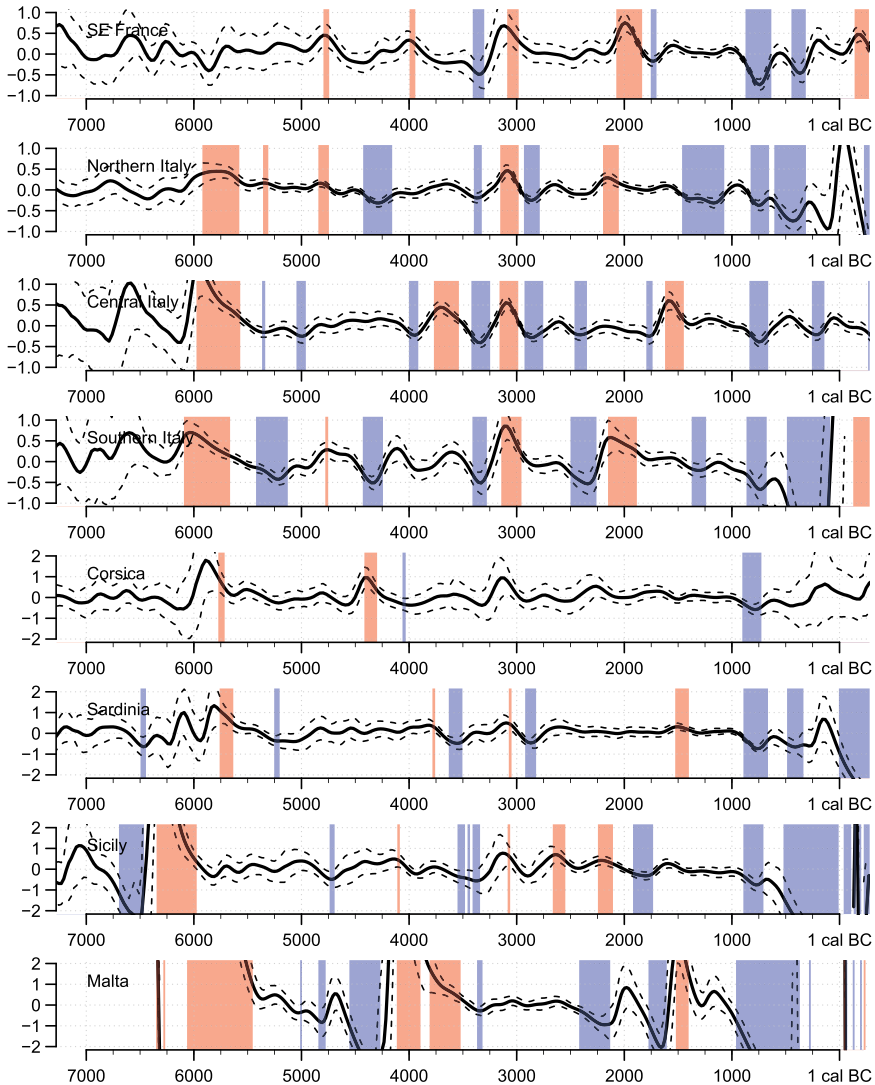




**Fig. 4** KDE models (75 year bandwidth) of past human activity for each region. Letters denote the main points of discussion throughout the article. The faint grey ribbon is the KDE for the entire 4515 dates from all regions

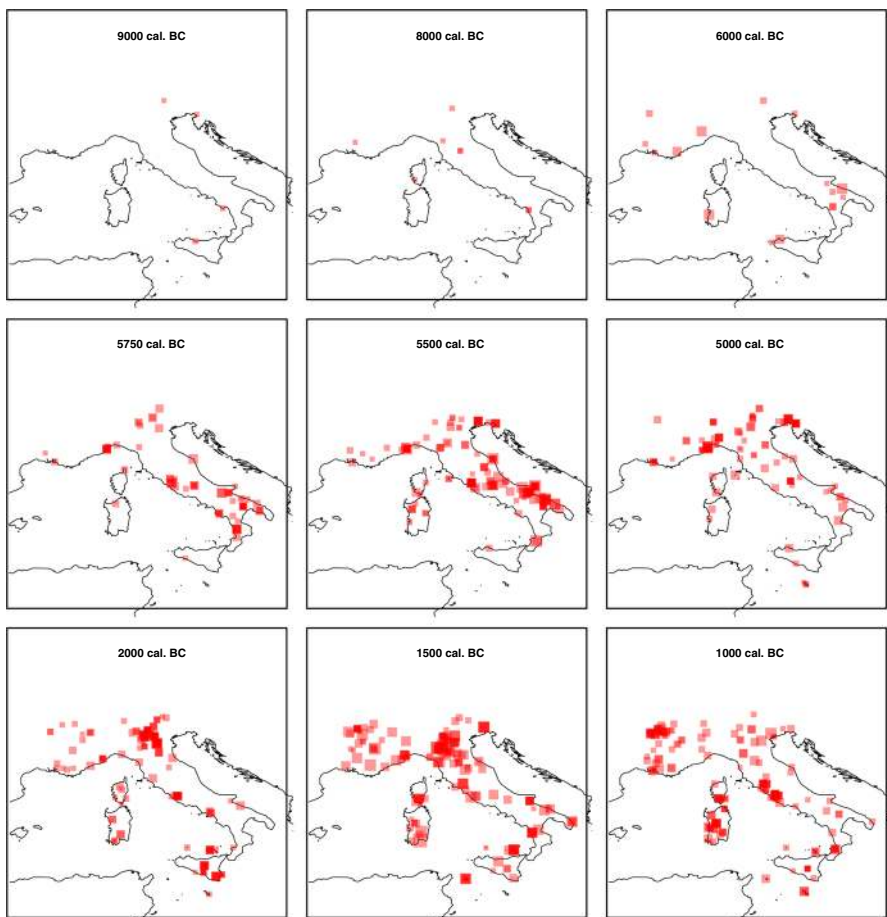
although weak traces of this trend can be observed across almost all of the central Mediterranean. A later collapse is then seen in the early first millennium BC, occurring earlier in the islands of Malta, Sardinia and Corsica, and slightly later in central Italy (Fig. 4, point H).

It is also possible to visualize these trends as an animation by drawing a map for each calendar year and plotting the position of each radiocarbon sample as a point that is size-scaled to the posterior probability of the sample dating to that year



**Fig. 5** Average annual growth rates (%) for central Mediterranean (Table 4) (see Supporting Information document pp. 21–22)

(McLaughlin et al., 2016). This analysis highlights a number of interesting spatio-temporal patterns in settlement and anthropogenic activity, especially in the Early Neolithic and Bronze Age of the Italian peninsula. In particular, the animated maps display very clearly the sparse activity throughout the region during the Mesolithic, and subsequent dense settlement in southern Italy following introduction of the Neolithic. After 6000 cal. BC, the animated maps effectively visualize the rapid maritime spread of agriculture along the Adriatic and Tyrrhenian coasts (Fig. 5) in a pattern that reflects the ‘wave-of-advance’ model (Ammerman & Cavalli-Sforza, 1979) that was proposed for the introduction of agriculture into the central Mediterranean, and similar to that reported for wider Europe by Pinhasi et al. (2005). The animated maps also document the decline of intensive settlement following the initial introduction of agriculture, which is particularly noticeable on the Apulian Tavoliere in



**Fig. 6** Individual frames from the animated radiocarbon map included as electronic supplementary data, indicating (top) the sparse Mesolithic settlement of the region; (middle) Neolithic expansion from south to north; and (bottom) a Bronze Age shift in settlement, in the central part of the Po Plain especially

southern Italy where activity is muted for much of the later sixth and fifth millennia BC. Changing settlement patterns over the course of the north Italian Bronze Age are also visualised, charting the marked shift in settlement from the sub-Alpine lake dwellings of the Early Bronze Age Polada culture in the late second millennium BC, to the dense settlement of the central Po Plain with the rise of the Terramare system in the mid second millennium BC (Fig. 6). As with the Neolithic however, the eventual decline of activity on the Po Plain at the end of the Bronze Age and Early Iron Age is readily apparent, and contrasts with the situation in central Italy and south-eastern France, which appears more sustained.

In addition to analysing spatio-temporal trends in the archaeological record, the results highlight regional biases in coverage of radiocarbon dates (Fig. 1, Table 1). Northern and central Italy have a longer tradition of widespread and systematic application of radiocarbon dating, in contrast to the south of Italy and the islands of Sicily and Sardinia. Where northern Italy is represented by 1566 radiocarbon dates, and central Italy by 1047 radiocarbon dates, the south of Italy has just 501, representing the lowest density of radiocarbon dated sites in the central Mediterranean. Sicily and Sardinia are similarly problematic, with 233 and 263 radiocarbon dates respectively. The density of radiocarbon dates is slightly better on Corsica (185 dates), and on the Maltese Islands (155 dates) when their smaller size is taken into consideration (Table 1). In essence, these regional biases in the radiocarbon record reflect long standing scholarly traditions that divide the study of prehistory in Italy (Guidi, 2010), and have seen the application of scientific methodologies in northern-central Italy more frequently than in southern Italy and the islands (Burleigh, 1984; Malone, 2003, p. 236; Tykot, 1994). Even within regions with good coverage there is a degree of unevenness in research (Fig. 1b), with significant clusters of well-dated sites in the vicinity of Rome, on the northern fringes of the Po Valley in Veneto, in northern Tuscany, and in Liguria.

The phases of growth and decline that mark the beginning and end of defined cultural phases can also be detected in the KDE models. Most regions demonstrate marked change in activity levels during most episodes of cultural change, although the observed patterns are not universal and differ in both timing and region (Table 3). To supplement the visual comparison provided in Fig. 4, we have calculated the average growth rate for each of these events in terms of percentage change per year (Table 4) and present modern and historic population growth rates (Table 5). This is especially useful for the interpretation of the KDE models as a potential proxy for population (Haynes, 1969; Rick, 1987; Shennan et al., 2013), as annual growth rate is a well-documented statistic available for modern and historical populations. As discussed below, there are issues with interpreting radiocarbon data as a proxy for population levels, but such comparisons remain instructive and enable a further exploration of the trends we see in prehistory.

**Table 3** Timing of changes in the KDE density models associated with episodes of cultural change

	SE France	Northern Italy	Central Italy	Southern Italy	Corsica	Sardinia	Sicily	Malta
Early Neolithic growth	5000 to 4600 BC	6000 to 4800 BC	5900 to 5450 BC	6100 to 5500 BC	5700 to 5350 BC	5700 to 5350 BC	6100 to 5900 BC	5600 to 5100 BC
Neolithic decline	3800 to 3100 BC	4400 to 3800 BC	5450 to 4900 BC	5500 to 5100 BC	5300 to 4500 BC	5300 to 5000 BC	NA	5050 to 4800 BC
Copper Age growth	3000 to 2750 BC	3800 to 3350 BC	3800 to 3400 BC	Pulse at 3200 to 3000 BC	Insuff. data	4000 to 3600 BC	4300 to 4000 BC	3800 to 3450 BC
Copper Age decline	NA	NA	3400 to 2000 BC	2900 to 2250 BC	Insuff. data	3000 to 2650 BC	3700 to 3200 BC	2500 to 2100 BC
Bronze Age growth	2000 to 1800 BC	2250 to 1950 BC	1800 to 820 BC	2100 to 1500 BC	Insuff. data	1600 to 900 BC	2600 to 2150 BC	Insuff. data
Iron Age	900 to 650 BC	1500 to 1100 BC	850 to 650 BC	Insuff. data	850 to 550 BC	850 to 550 BC	1300 to 750 BC	Insuff. data

**Table 4** Average annual growth rates (%) at critical times of cultural change, computed by differentiating the bootstrapped KDE models for the various regions for the date spans given in Table 3

	SE France	Northern Italy	Central Italy	Southern Italy	Corsica	Sardinia	Sicily	Malta
Early Neolithic growth	$0.4 \pm 0.3$	$0.4 \pm 0.2$	$1.5 \pm 0.5$	$0.7 \pm 0.2$	$1.0 \pm 0.8$	$1.0 \pm 0.6$	$> 2.0$	$> 2.0$
Neolithic decline	$-0.5 \pm 0.5$	$-0.3 \pm 0.1$	$-0.2 \pm 0.1$	$-0.3 \pm 0.1$	$-0.3 \pm 0.3$	$-0.4 \pm 0.3$	NA	$-0.8 \pm 0.6$
Copper Age growth	$0.7 \pm 0.4$	$0.4 \pm 0.2$	$0.4 \pm 0.1$	$0.8 \pm 0.3$	$1.0 \pm 0.5$	$0.4 \pm 0.2$	$0.4 \pm 0.3$	$> 2.0$
Copper Age decline	NA	NA	$-0.4 \pm 0.1$	$-0.5 \pm 0.2$	Insuff. data	$-0.5 \pm 0.2$	NA	$-0.9 \pm 0.4$
Bronze Age growth	$0.7 \pm 0.3$	$0.3 \pm 0.1$	$0.5 \pm 0.2$	$0.5 \pm 0.3$	$1.0 \pm 0.8$	$0.2 \pm 0.1$	$0.3 \pm 0.2$	Insuff. data
Iron Age decline	$-0.7 \pm 0.2$	$-0.6 \pm 0.2$	$-0.4 \pm 0.1$	Insuff. data	$-0.5 \pm 0.2$	$-0.7 \pm 0.1$	$-0.6 \pm 0.3$	Insuff. data



**Table 5** A selection of modern and historic population growth rates, for comparison with Table 4

Context	Annual growth rate (%)	References
Modern Japan	−0.23	UN (2015)
Modern Italy	−0.13	UN (2015)
Modern USA	0.71	UN (2015)
Modern India	1.1	UN (2015)
Modern Nigeria	2.58	UN (2015)
Global average 2015–2020	1.09	UN (2015)
Europe, fourteenth century	−1.6	Russell (1958)
USA, 1950 ‘baby boom’	2.0	US Census Bureau
Ireland, late nineteenth century ‘potato famine’	−3.4	Cullen (1974–5)
Late Mesolithic (palaeoanthropological <sup>a</sup> )	0.05	Bocquet-Appel (2002)
Early Neolithic (palaeoanthropological <sup>a</sup> )	1.24	Bocquet-Appel (2002)

<sup>a</sup>Derived from the proportion of immature skeletons in relatively large burial assemblages; population growth rate tends to correlate with the relative frequency of child and young adult remains in a given context

## Discussion

In the following sections we discuss the main features of the KDE models in chronological order within the framework of their cultural setting. It is important, however, to acknowledge the methodological challenges that are inherent in studies of this kind. The most significant limitation of this study is that we, as archaeologists, are always constrained by the available data and by the nature of the archaeological record and the research traditions that shape it. We have attempted to gather together as many data as possible for the Italian peninsula, Sardinia, Sicily and the Maltese Islands, but acknowledge that the pressure of research has been less for Corsica and south-eastern France; similarly, our chronological focus has been the period before c. 700 cal. BC. Practical reasons have prevented us from conducting an exhaustive study of the radiocarbon evidence of the Iron Age civilizations of central Italy and the intertwined Phoenician and Greek colonization of other areas. We suspect, however, that our data constitute a robust and representative sample of the limited data available in total for the later first millennium BC. But despite the even research pressure we have applied to the Italian peninsula, some regions (the south in particular) have much less data density than others (see Table 1). Thus, a different kind of trend—the behaviour of archaeologists towards radiocarbon dating—has a powerful effect on the observed patterns, although this is extremely difficult to quantify. There may or may not be *a priori* biases in research interests for scholars *within* a given cultural context, but there are almost certain to be different research traditions, attitudes and funding priorities affecting work when different cultural contexts are compared. For this reason, it is not appropriate to compare, for example, Neolithic and Iron Age activity levels on absolute terms, although on-going work is already redressing this imbalance by engaging more with scientific dating, and comparison

of radiocarbon evidence to other quantitative proxy measures of human activity and demography, such as surface survey (Stoddart et al., 2020, 2020a; Stoddart et al., 2020b, 2020c) and aDNA. We do, however, argue that relative changes in activity over the shorter term, or coeval comparisons of activity between neighbouring regions, remain valid because there can be no point in time when such biases suddenly take hold.

The imprecise nature of fieldwork, heterogeneous preservation of sites, and the preference for certain kinds of radiocarbon samples can, in theory, influence the results. These are essentially stochastic, or random, variables that will, according to the central limit theorem in statistics, tend to self-cancel if (and only if) a large enough dataset is under analysis. It is difficult to guess at how many dates are ‘enough’, and although the numbers of dates analysed here comfortably exceed the heuristic minima suggested by Williams (2012), at sub-regional levels there are very few dates for some discrete points in time or even occasional gaps in the record. We have therefore chosen an analytical scale where the KDE process produces models that evince long-term trends, sometimes operating over millennia or spanning different archaeological cultures (effectively dampening such biases), and occasionally manifesting as simultaneous peaks and troughs in different regions. Such patterns therefore simply must be independent of research and taphonomic bias. And so, although it is important to bear these various methodological limitations in mind, they do not dominate or obscure the signals we can detect. Instead these signals are being driven by events in the distant past, and we predict they will continue to improve in strength and quality as research accumulates.

We also contextualize the results of this study within the archaeology of wider Mediterranean and European regions. This too is hampered by the availability of data; if we have tended to look towards other Western European regions it is because these areas have been so well researched. Other meaningful comparisons must be left to future work, especially the archaeology of North Africa and the Balkans. We have included a preliminary comparison with North Africa in this paper, but because the spatial density of excavated and dated sites in Europe and Africa is so very different, we are simply not comparing like with like.

## The Mesolithic

The KDE models suggest that there was little overall variation in the level of Mesolithic human activity in the central Mediterranean as a whole, other than a very gradual increase over time. Activity models for mainland Italian regions, Sardinia and Sicily for the period 10,000 to 6000 cal. BC are given in the Supporting Information document (pp. 6–7). These models indicate a degree of fluctuation in most regions, and occasionally significant differences from the overall picture, but given the relatively small sample sizes, these patterns could also be the product of differential preservation and other sources of bias. A weakly significant spike in activity in Sicily around 7700 cal. BC is due to a tradition of burial in caves and long-term occupation that is both archaeologically visible and well researched at a number of

sites in the northwest of the island (D'Amore et al., 2010a, 2010b; Lo Vetro & Martini, 2016; Lo Vetro et al., 2016). This could, on some level, reflect the underlying demography but further investigation of this phenomenon is something we leave for future work. It would be possible to extract all open-air settlement sites from the database and analyse them separately, for example, to see whether they conform to a similar trend, although reducing the size of the dataset reduces its statistical power. Similarly, decreasing levels of activity in the mid eighth millennium BC in central Italy are interesting, especially since the climate and landscape were still in a state of post-glacial flux, transitioning from the Boreal to Atlantic phases of the Holocene.

In general, however, any features and trends in the radiocarbon record of the central Mediterranean before c. 6000 cal. BC are quite weak and reflect an archaeological record that is for the most part defined by short-term occupation in rock-shelters and caves across the central-southern peninsula (Lo Vetro & Martini, 2016; Plucienik, 1994, 2008) and the surrounding islands (Costa et al., 2003; Lugliè, 2009a). The notable steady state of the density models for much of the Mesolithic period does not show the long-term increase in activity that would be expected under a model of stationary growth coupled with the underrepresentation of older sites due to taphonomic bias (Surovell et al., 2009). In the case of the central Mediterranean, this trend is most likely due to the predominance of cave sites, which are not subject to the same taphonomic processes as open-air sites.

### **The Neolithic 'Boom and Bust'**

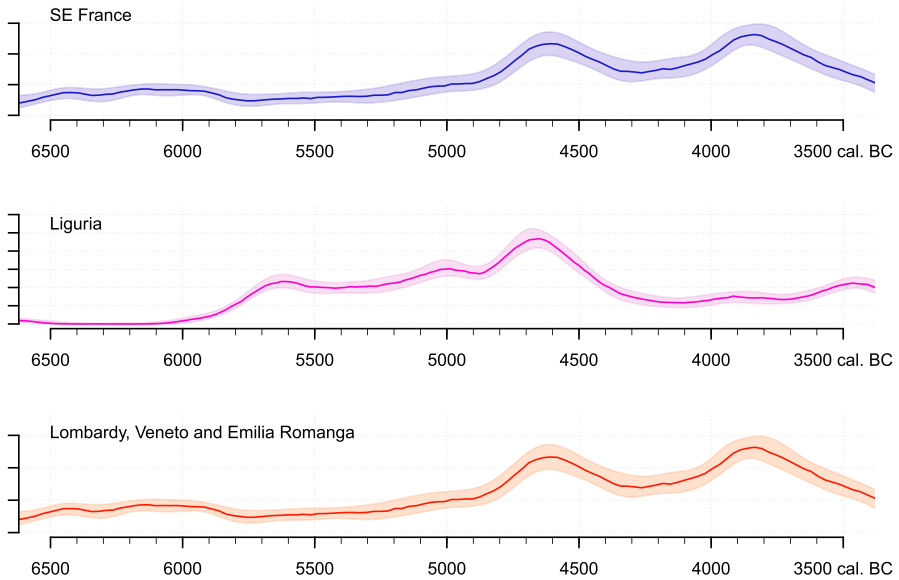
The transition to agriculture is clearly visible as a sharp increase in the gradient of the KDE density models (marked 'A' in Fig. 4), reflecting the rapid population growth and settlement density that is associated with the European Neolithic. This process did not occur simultaneously across the central Mediterranean, but once it became manifest, a similar trajectory of gradually rising then declining activity played out. In southern Italy and Sicily, the transition is first signalled in the KDE models around 6200 cal. BC, but in central Italy, southern France and the Tyrrhenian Islands it occurred later, between 5900 and 5800 cal. BC. The Neolithic reached the Maltese archipelago around 5500 cal. BC; however, activity on the islands declined around 5200 cal. BC and soon faded away entirely. New multi-proxy evidence from Malta and Gozo suggests either abandonment of the islands during this time, or a low population size and substantial landscape reorganization that left a limited trace on the island's landscape (Grima et al., 2020, p. 228; McLaughlin et al., 2020a, p. 31). Although aDNA studies have been lacking for the region until recently, current evidence from central Italy (Antonio et al., 2019), Sicily (Fernandes et al., 2020) and Sardinia (Modi et al., 2017) shows that central Mediterranean Neolithic groups conform to wider European trends by showing typical Anatolian farmer ancestry, indicating that the transition to agriculture in the region was indeed characterised by the movement of people who introduced the Neolithic way of life. The peaks in the KDE models and their timing likely reflect the demographic signature of a 'travelling wave' as suggested by Silva and Vander Linden (2017) for the European

Neolithic, with a ‘boom’ in emigrants followed by a ‘bust’ in immigrants (see below for discussion on wider Neolithic Europe).

In most regions, the pronounced increase in Early Neolithic activity reaches a peak several centuries after the introduction of farming (identified ‘B’ in Fig. 4). In central and southern Italy, this occurred at 5500 cal. BC, 5300 cal. BC in Corsica and Sardinia, and 5200 cal. BC in the Maltese Islands. The staggered dates for this high point of activity in Corsica, Sardinia and Malta match the pattern of later introduction of the Neolithic to these islands and suggest that the Neolithic cultural phenomenon followed a similar trajectory in these places, but at different times, further exemplifying the ‘boom and bust’ characteristic of the Early Neolithic in Europe (Shennan et al., 2013). Nowhere is this more pronounced than in southern Italy, where the signal of intensification and subsequent decline is primarily driven by sites on the Tavoliere plain in Apulia.

The ditched villages of the Apulian Tavoliere have traditionally defined the Neolithic of southern Italy (Delano Smith, 1978; Pessina & Tinè, 2018). Whilst it is clear that the ditched villages were not all occupied at once, the Tavoliere represents the densest area of settlement anywhere in Neolithic Europe (Brown, 2003), which peaked in the mid sixth millennium BC (Fiorentino et al., 2013; Parkinson & McLaughlin, 2020), representing a major demographic event in an area with no Mesolithic presence in the preceding centuries (Perrin et al., 2021). This archaeological evidence for population increase and dense settlement activity is clearly reflected in the KDE models (Fig. 4) and animated maps (see Supplementary Information). Comparisons between historic or modern population growth rates and those derived from the radiocarbon data therefore provide a particularly useful benchmark against which the results can be interpreted (see Supporting Information, pp. 21–22). In the case of southern Italy, growth associated with the Early Neolithic started around 6200 cal. BC and increased by approximately  $0.7 \pm 0.2\%$  per year, which is less than the current global population growth rate of 1.09% and estimations for the wider European Neolithic, but similar to modern growth rates in the USA (Table 5). Our results indicate that the peak of the southern Italian Neolithic occurred between 5700 and 5450 cal. BC and signals a major demographic event, before the region entered a phase of slow decline akin to population decline rates in modern Japan (Table 5). According to Skeates (2000b), the following 5500 to 5250 cal. BC period is considered a phase of continuity among the ditched villages of the Apulian Tavoliere, with the radiocarbon evidence suggesting a general back-drop of declining activity levels and settlement intensity. In central Italy, an Early Neolithic peak occurred at 5500 cal. BC, and although this was followed by a reduction in activity, the decline was much more gradual than it was in the south.

The eventual abandonment of the Tavoliere, so visibly apparent in the KDE models for southern Italy and animated maps, has been hypothesized to be the result of possible land exhaustion and overpopulation that led to settlement expansion into nearby valleys (Malone, 2003, pp. 252–253; Whitehouse, 2013). Fiorentino et al. (2013) identified a wet period that occurred on the Tavoliere between 6200 and 5500 cal. BC, which was followed by a dry period, coinciding directly with the growth and subsequent decline observed in the KDE analysis presented here. This may suggest that favourable climatic factors played a major role in shaping the



**Fig. 7** Regional differences between the Neolithic in southeast France, northwest Italy (Liguria) and regions in central-northeast Italy (Lombardy, Veneto and Emilia-Romagna) (see Supporting Information document pp. 8–9)

southern Italian Neolithic, and that a mixture of overpopulation, land exhaustion and climate probably triggered a decline in human activity and settlement in the area. This observation is corroborated by a second spike in the KDE model for southern Italy during the later Neolithic at around 4500 cal. BC (Fig. 4, point C), which corresponds with a second brief wet period recorded on the Tavoliere by Fiorentino et al. (2013).

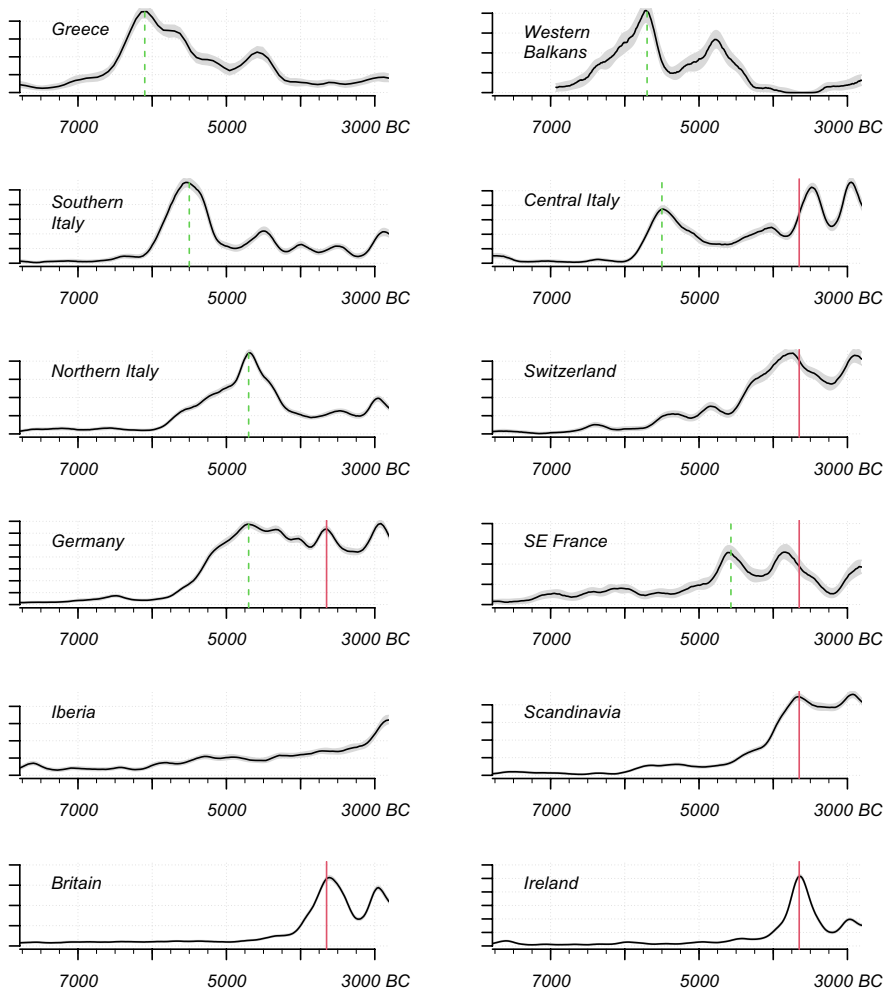
In northern Italy, our results show how the transition to agriculture played out in a markedly different way, characterised by an initial period of relatively rapid growth which slowed at 5500 cal. BC before finally peaking around 4800 cal. BC. However, when viewed at a sub-regional level, the results illustrate the stark differences between north-western and north-eastern Italy during the Early Neolithic (Fig. 7). The early arrival of the Neolithic in the north-western region of Liguria is apparent in Fig. 7 (Binder et al., 2017; Maggi et al., 2020) and contrasts with the much more muted introduction of agriculture towards the north-east on the Po Plain. These regional differences have long been acknowledged in the cultural setting of the Early Neolithic of northern Italy, which is characterized by a variety of regional ceramic traditions (Malone, 2003, p. 251) including the Ligurian impressed wares—which display a visible influence from southern Italy—and, to the north-east, the Isolino, Fiorano, Vhò, Gaban and Fagnigola groups on the Po and in the Alpine valleys, which so clearly stand apart from the broader central-western Mediterranean context. Rather than directly relating to the broader Impressed-Cardial complex that characterises the Early Neolithic of the central-western Mediterranean, the ceramic traditions of north-eastern Italy have been argued to be influenced by Adriatic or

central Italian traditions (Biagi et al., 2020, pp. 194–195; Pearce, 2013, p. 204). The evidence for continued Mesolithic presence in parts of northern and central Italy has also been cited as a factor in how the Neolithic played out in this part of Italy and its timing (for discussions see Binder, 2000; Pearce, 2013, pp. 206–207), but overlaps between Mesolithic groups and Neolithic groups now seem less likely (Martínez-Grau et al., 2020). In terms of settlement, the record for the Early Neolithic of the Po Plain area is scant, in strong contrast to the south, with much of the evidence stemming from the so-called *fondi di capanna*, large storage pits previously considered to be hut foundations (Biagi et al., 2020), and the results of the KDE and animated map seem to illustrate this general picture. There are therefore still significant issues pertaining to the mechanisms behind the introduction and subsequent trajectory of the Neolithic into the central/north-eastern areas of Italy, the timing of which was perhaps additionally influenced by climatic factors and differences in physical



**Fig. 8** Locations of comparative  $^{14}\text{C}$  samples analysed in this paper, including those drawn from Bevan et al.'s (2017) data, and the BANADORA, RADON and RADON-B databases. These data are used in Figs. 9 and 12 in a comparison with the central Mediterranean





**Fig. 9** Early Neolithic KDE prehistoric activity models (75-year bandwidth) for peninsular Italy and other European regions, with the Early Neolithic ‘boom’ highlighted with a dashed line and 3700 BC highlighted with a solid line. Data sources: Italy, this paper; Britain and Ireland, Bevan et al. (2017); France, the BANADORA database (<http://www.arar.mom.fr/banadora/>); and other regions, the RADON database (<http://radon.ufg.uni-kiel.de>)

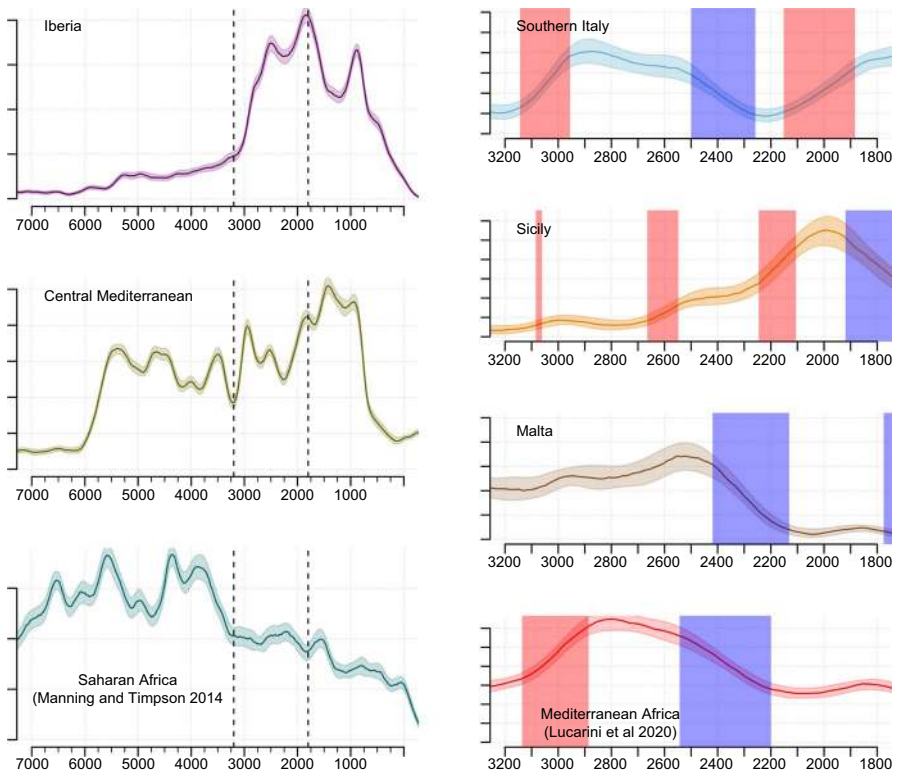
landscape. Ultimately, these can only be resolved by future research and targeted radiocarbon dating in the Adriatic area, as well as further consideration of the eastern shore of the Adriatic, which is vital to this story, and is currently the topic of further research by the authors.

The availability of databases of radiocarbon dates for neighbouring regions (RADON and BANADORA) also allows for comparisons to be drawn between the central Mediterranean and other European regions (Figs. 8 and 9). Although there are obvious differences in timing, the comparison demonstrates that southern Italian

settlement patterns in the Early Neolithic were very similar to those on the opposite side of the Adriatic. Likewise, there are commonalities between subsets of these European regions throughout time. For example, the northern Italian apogee of 4500 cal. BC was also manifested less prominently, but still significantly in southern Italy (Fig. 4, point ‘C’), and is also apparent in the records from south-eastern France, Iberia and Germany. The German case was associated with the final phases of LBK culture and the conclusion of 600 years of growth. In northern Italy, the increase at 4800 cal. BC is related to the widespread distribution of Middle Neolithic VBQ/Square-Mouthed Pottery sites across the region (Mottes et al., 2009; Visentini, 2006), which are well documented in the Ligurian caves, but also by a density of sites on the central Po Plain. Later, a widespread spike in activity early in the fourth millennium BC can be detected in central Italy, Switzerland, Germany, France, Scandinavia, Britain and Ireland. There are differences in the timing of this spike, which again allow us to visualise the ‘boom and bust’ and ‘travelling wave’ characteristics of the European Neolithic at the continental level (Shennan et al., 2013; Silva & Vander Linden, 2017). That said, almost everywhere saw a downturn in the mid fourth millennium BC.

Comparisons with North Africa (north of 13°N) can be made using the archaeological radiocarbon dataset published by Manning and Timpson (2014). This dataset captures the continental-scale demographic transformations brought about by the start and end of the African Humid Period (8500 to 3500 cal. BC) and, importantly, a temporary decline in activity spanning 5600 and 4700 cal. BC. In addition, the more detailed database published by Lucarini et al. (2020) of African sites in Mediterranean regions can be used to compare regional European patterns with those in Africa (Fig. 10). Whilst the sparse nature of the African data precludes a detailed spatial analysis, the overall signals of activity from North Africa and the European central Mediterranean share many characteristics. In particular, the Early Neolithic lull at 5100 cal. BC is common to both continents, although the fluctuations in activity that followed over the subsequent millennia were rather different. As discussed by Manning and Timpson (2014), such trends in the combination of archaeological data over a huge area suggest that human activity in prehistory was strongly influenced by climatic forces, even though the human response to these environmental challenges was different in each region and time period.

The mid fourth millennium BC is associated with the start of the Copper Age in the central Mediterranean, which brought with it marked regional diversity in the archaeological record, particularly in the island contexts of Sicily, Sardinia and the Maltese archipelago—as illustrated in the density models (Fig. 4, point ‘D’). Peninsular Italian Copper Age groups show genetic continuity from the Neolithic, in contrast to later Bronze Age groups (D’Amore et al., 2010a, 2010b; Saupe et al., 2021), indicating apparent population stability during the period. In central Italy, a gradual increase in activity occurred from 3800 cal. BC, peaking at 3500 cal. BC. Settlement evidence for the central Italian Copper Age is fairly patchy, although the occurrence of densely clustered cemeteries in areas lacking definitive settlement evidence (e.g. the Tuscany–Latium border), as well as a growing body of stable settlement evidence in areas of Marche and central Latium (Anzidei & Carboni, 2020; Caz-zella, & Moscoloni, 1999; Manfredini, 2014) paints a picture of population increase



**Fig. 10** KDEs for Iberia (RADON database) and central Mediterranean Europe (this paper) and North Africa (Lucarini et al., 2020; Manning & Timpson, 2014) for 7000 BC onwards (left panels) and a selection of results from the Copper Age and Early Bronze Age (right panels), with periods of significant positive or negative growth shaded

during the earlier Copper Age in this region of Italy, and seems to be reflected in the KDE model. These results are similar to those reported for the fourth millennium BC by Palmisano et al., (2017, 2018); however, in discussing their results they incorrectly state the beginning of the Copper Age in central Italy as 3000 cal. BC, when it is widely acknowledged as starting at approximately 3600 cal. BC (Dolfini, 2010, 2013; Cocchi Genick, 2013). Thus, the discussion by Palmisano et al. (2017, 2018) of trends across the fourth millennium BC is not framed within the appropriate cultural context, underscoring the importance of acknowledging local chronologies within larger syntheses so that they remain relevant to the traditions of research in the region.

In contrast to central Italy, activity in southern Italy remained low, reflecting the scarce evidence for Copper Age settlement in regions such as Apulia, and only a slight rise can be observed for northern Italy. In Sicily, a significant upturn in activity at 4000 cal. BC corresponds to the beginning of the ‘proto-Eneolithic’, where an increase in the number of archaeological sites is associated with the San Cono–Piano

Notaro and Conca d'Oro cultures. Unlike on the mainland, in Sicily the peak steadily decreased throughout the first half of the fourth millennium BC (Fig. 4, point 'D'). By this time, activity in the Maltese Islands underwent a significant increase, with growth rates above 2% per annum, from 3800 cal. BC until a peak at 3400 cal. BC. This is associated with the Żebbuġ and Ġgantija phases, which saw the development of megalithic architecture, which proliferated throughout the 'Temple Period' then briefly declined during the transition to the third millennium BC. The close parallels between Sicilian San Cono–Piano Notaro and Maltese Żebbuġ material culture (Leighton, 1999, p. 93; Speciale, 2011), and evidence for direct exchange of material culture (Barone et al., 2010), clearly demonstrate contact between the two islands at a time of fluctuating activity levels. While we should be cautious about stretching our interpretations of the data too far, the sustained phase of growth in the activity model for the Maltese Islands could be interpreted as a response to demographic pressures in Sicily, and may reaffirm that the unique 'Temple Period' cultures of Malta and Gozo had an antecedent in Sicily around 4000 cal. BC.

In Sardinia and southeast France, significant peaks occurred early in the fourth millennium BC. These points represent relatively short-term flares of activity and only in northern Italy does a modest mid-fourth-millennium BC increase appear more sustained, as it was during the Neolithic. The fourth millennium BC in the central Mediterranean shows asynchronous developments in anthropogenic activity, most of which occur in what are Late/Final Neolithic cultural contexts (Sardinia, Sicily, SE France, Maltese Islands) rather than in the Copper Age as in central Italy. This not only highlights the gradual nature of the transformations from the Neolithic and Copper Age in the central Mediterranean, but also suggests that the driving features of these trends were probably the social and economic developments that characterize the fourth millennium BC, rather than the impact of technological developments related to metal working and resource exploitation.

### **The Apogee of the Temple Period on the Maltese Islands (Fig. 4, Point E)**

Whilst the density models suggest lower but stable levels of human activity across much of the central Mediterranean in the third millennium BC, there is a distinctive apogee in the KDE models at 2500 cal. BC in the Maltese Islands (Fig. 4, point 'E'; see also Fig. 10). The mid-third-millennium BC peak followed a downturn around 3000 cal. BC, and possibly reflects a period of population recovery and eventual flourishing of ritual activity on the islands after an apparently difficult few centuries. Current evidence indicates that the soil cover of the Maltese Islands became progressively denuded over the course of the Temple Period, and that soil amendment processes were undertaken possibly as early as the early–mid third millennium BC (French et al., 2018). This may suggest that land management practices played a part in averting total collapse of the Temple Period around 3000 cal. BC, and instead triggered a rebound. It has long been suggested that agriculture intensified towards the end of the Temple Period, during the concluding Tarxien phase, under a more controlled system for which megalithic sites formed a focus, and possibly in response to increasing economic and environmental instability (Stoddart et al.,

1993; Trump, 1980). Recent work has significantly added to this picture by arguing that the Maltese megalithic sites played an important economic role in facilitating the display, consumption and organisation of resources within the restricted environment of the islands (Barratt et al., 2020; Malone et al., 2020b, p. 477). Archaeological evidence from excavated sites shows evidence for increased ritual activity at 2500 cal. BC (McLaughlin et al., 2020a; Thompson et al., 2020), and whilst the phasing of the Maltese temples remains difficult (Grima, 2008), it has been suggested that the present form of most megalithic sites on the islands reflects a final episode of restructuring and ritual elaboration at a crucial point towards the end of the Temple Period (Malone, 2007). Episodes of crisis management have been noted in monument-building societies elsewhere, as in the Sardinian Bronze Age (Ialongo, 2018), although in the case of the Maltese Islands the recovery was short lived. Activity on the islands appears to have tipped into decline after 2500 cal. BC, during a period that is associated with declining population health, the eventual end of monument building and significant environmental change driven by increasing aridity (French et al., 2020, p. 320).

This localized trend embodies the singularity of the Maltese archipelago's archaeological course during the fourth and third millennia BC. Elsewhere in the central Mediterranean, it is only on neighbouring Sicily that a significant increase in activity is initiated at around 2800 cal. BC (Fig. 4, point 'F'; Fig. 10), as part of a gradual intensification leading into the Early Bronze Age (see following section for discussion). Whilst the gradual growth in Sicily seems somewhat concurrent with the decline on the Maltese Islands at 2500 cal. BC, the growth in Sicily is initiated some three hundred years earlier. It has been proposed that the end of the Maltese Temple Period prompted an exodus out of the islands into neighbouring areas, most likely Sicily (Bonanno, 1993), and archaeological evidence points towards increasing ties between the two regions in the later third millennium BC (Procelli, 1996; Leighton, 1999, p. 137; Tanasi, 2014). The results of the KDE, therefore, do not appear to support this directly, and recent research has instead shown that the end of the Maltese Temple Period was defined by a gradual transition into the Early Bronze Age with a transitional 'Thermi' ware phase in the mid-late third millennium BC (McLaughlin et al., 2020a, p. 33).

### **Early Bronze Age Intensification and Middle Bronze Age Dynamics (Fig. 4, Points F and G)**

The decline in activity levels at the close of the third millennium BC in the Maltese Islands is also mirrored by the KDE models from southern Italy and Mediterranean Africa (Fig. 10). As the Early Bronze Age emerged, only in southeast France, northern Italy, and Sicily was a significant increase in activity observed (Fig. 4, point 'F'). Northern Italy enjoyed stability during the first half of the second millennium BC, in contrast to the adjacent areas of southeast France and central Italy, where a pronounced drop in activity appears to have occurred (Fig. 4, point 'G'). In Sicily, this pattern is also apparent, as the end of the Copper Age and Early Bronze Age signalled a 500-year period of sustained growth

that reached its peak at 2000 cal BC (Fig. 4, point ‘F’), followed by a significant decrease in activity around 1700 cal. BC in the lead-up to the Middle Bronze Age (Fig. 4, point ‘G’).

The Early Bronze Age of Sicily is traditionally recognized as a period of considerable settlement expansion and population increase (Malone et al., 1994a, 1994b), but Leighton (2005) has argued that a lack of landscape survey data for Sicily may mean that this narrative has been historically overemphasized (Leighton, 2005). The density models seem to support the former interpretation, although understanding the decline around 1700 cal. BC is more problematic. Leighton (2005) further suggested that contraction and discontinuity in settlement patterns occurred between the Early and Middle Bronze Ages in Sicily, whilst the Aeolian Islands show similar contraction of settlement into nucleated villages located on naturally defended higher ground as the Early Bronze Age progressed (Alberti, 2013a; Bietti Sestieri, 2013b). In central Sicily, site counts also suggest a sharp increase in Late Copper Age and Early Bronze Age settlement, followed by a considerable drop in the Middle Bronze Age (Giannitrapani, 2016), mirroring the trends in our density model. The results of the KDE analysis (Fig. 4, point ‘G’) may therefore corroborate the evidence for settlement nucleation and a punctuated transition between the Sicilian Early and Middle Bronze Ages—although the decline observed at 1700 cal. BC does appear to have been a synchronous phenomenon across the wider central Mediterranean. Interestingly, the dynamics of human activity in Sicily, as suggested by the KDE and observed in the archaeological record, also appear to correspond loosely with episodes of demographic change on the island, namely the arrival of Steppe ancestry by 2200 cal BC and possible Aegean ancestry between 1800 and 1500 cal. BC (Fernandes et al., 2020).

The density models and animated map are particularly illustrative of events in Early and Middle Bronze Age northern Italy, where the radiocarbon dates derive largely from Polada pile dwellings along the southern fringe of the Alps, and the Terramare system on the central Po Plain. The rapid demographic development and settlement density that is associated with the Polada culture (Barfield, 1994a; Nicolis, 2013) is clearly reflected in the KDE models (Fig. 4, point ‘F’) and the subsequent rise of the Terramare system sees further development of this trend. The demographic increase associated with the Terramare was accompanied by a general increase in site size over time (Cardarelli, 2009; Vanzetti, 2013), with the largest sites estimated to have accommodated up to a thousand people (Nicolis, 2013), and with population estimates for the entire system as high as 150,000 people (Cardarelli, 2018). With the exception of an insignificant decrease around 1700 cal. BC, the density models show consistent activity levels between the Early and Middle Bronze Age in northern Italy. This trend is unsurprising, given that both periods are associated with increased population levels, with the major change across the Early Bronze Age–Middle Bronze Age transition being a marked spatial shift in settlement from the southern fringe of the Alps to the Po Plain. The shift towards extremely high settlement density on the Po Plain and continuing demographic expansion is therefore better visualized in the animated radiocarbon maps from 2200 to 1450 cal. BC (Fig. 5; see supplementary data). The consistency in the KDE models does, however, indicate some degree of continuity between the two periods, and may in

some way contribute to the remaining debate as to whether the Terramare developed out of the earlier Polada pile dwellings (Nicolis, 2013; Vanzetti, 2013).

At the end of the Terramare, the gradual decline documented in the density models spanning approximately 1500 and 1100 cal. BC (approximately 0.9% per annum) does not reflect the collapse that is traditionally associated with the north Italian Recent Bronze Age between 1350 and 1150 BC (Cardarelli, 2009; Vanzetti, 2013). Whilst Terramare sites suffered decline in the southern Po Plain towards the end of the second millennium BC, several well-studied larger villages in the Grandi Valli Veronesi north of the Po River continued to thrive into the Final Bronze Age (Cupitò et al., 2015), and were engaged in broader continental and eastern Mediterranean trade networks as well as a high degree of intergroup mobility between settlements (Cavazutti et al., 2019). However, it is still a matter of debate whether the sites were suddenly abandoned at exactly the same time throughout the territory or whether the abandonment occurred over a prolonged period of crisis (Cardarelli, 2009, p. 485). Whilst the KDE models reflect the general timing of the Terramare collapse, the precise dynamics of the Recent and Final Bronze Age in northern Italy are perhaps better visualised in the animated maps where the activity associated with the Grandi Valli Veronesi sites is apparent (see supplementary data).

The results of the KDE models from 1100 cal. BC, following the decline of the Terramare, reflect the reduced levels of human activity on the Po Plain during the Final Bronze Age and Early Iron Age (Barfield, 1994a), in comparison with neighbouring areas of southeast France and central Italy which saw sustained and gradual growth (Fig. 4) (cf. Mathers and Stoddart, 1994 who registered these unaligned cycles of expansion and decline). The extent to which this trend may relate to demographic shifts is difficult to assess and touches upon a controversial theme that dominated research on the Terramare until the mid twentieth century (see Pearce, 1998). However, this period in southeast France is associated with north Italian influences on material culture (Mordant, 2013), also seen to a lesser extent in central Italy (Cardarelli, 2009; Manfredini et al., 2009). By contrast, southern Italy remained very quiet at this time, as reflected in the archaeological record (Bietti Sestieri, 2013a), but the impact of negative research bias must be emphasized, as the south of the Italian peninsula has on the whole fewer dated sites to represent later periods.

### Early First Millennium BC Collapse (Fig. 4, Point H)

A significant and rather sudden decline in the KDE models occurs in central Italy, Corsica and Sardinia in the early first millennium BC (Fig. 4, point 'H'). This is most pronounced in the record from Sardinia associated with the end of the Nuragic civilization. From 1500 cal. BC activity on the island gradually increased year-on-year, reaching its most intense level at a point between 980 and 820 BC, which was apparently succeeded by sudden collapse. Using simulation and back-calibration we have modelled different scenarios for this process (Fig. 9, see Supporting Information pp. 18–20); the models most consistent with the data feature an abrupt drop in activity around 800 cal. BC (Fig. 9, simulations 1 and 2). Although it is important to acknowledge that this approach does not 'prove' the mathematical correctness of the

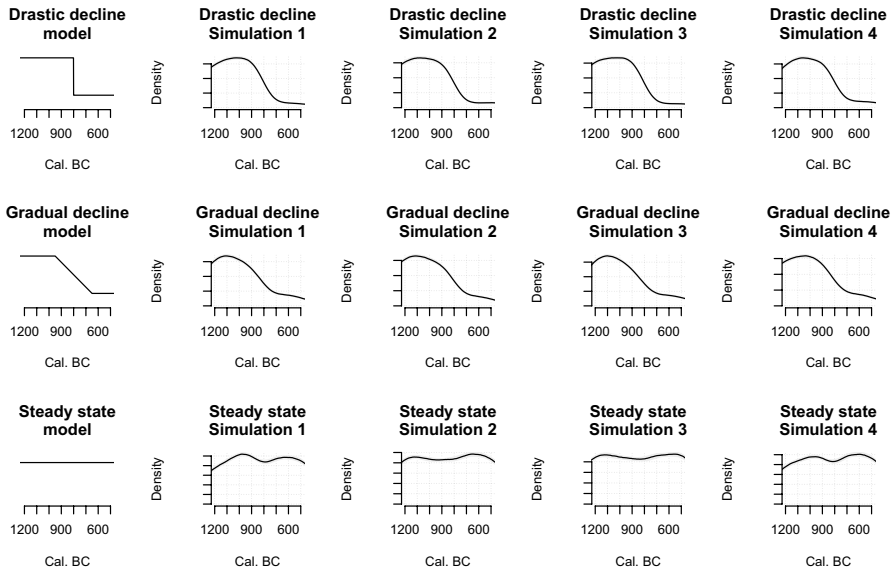


model, it nonetheless provides a plausible explanation for patterning of the radiocarbon data. The density models suggest that there was between a four- and 13-fold reduction in activity in Sardinia over a 150–175 year period, beginning between 980 and 820 BC. Whilst these results could reflect an edge effect as a result of negative research biases, clear regional differences across Sardinia during the Final Bronze Age (Lo Schiavo, 2013), and the apparent weakening and restructuring of the political structure of Nuragic civilization in the face of increasing foreign contact (Blake, 2015), are important factors that led to the decline of the nuraghi at the onset of the Iron Age. The first millennium BC in Sardinia also appears to signal a period of significant genomic transformation on the island (Marcus et al., 2020), with post-Nuragic period Iron Age individuals showing less evidence for pre-Bronze Age indigenous ancestry (Fernandes et al., 2020), altering the previously-held view that Sardinia was isolated from substantial genetic admixture and population migrations since the Neolithic (see Chang et al., 2018 for overview).

The same period in central Italy saw a similar, but less dramatic, reduction, which by virtue of a better-resolved record, can be more precisely dated to between 900 and 820 BC. In central Italy, the decline was a two- to three-fold reduction over the course of about 175 years. Significantly, in central Italy the reduction in activity recovered and by 600 cal. BC activity was once again intensifying, now associated with the emergence of city states (Barker & Stoddart, 1994). It will be important to concentrate research and future dating projects on this period between 900 and 600 BC, in conjunction with use of Bayesian statistics on relevant stratigraphies at the beginning of the Hallstatt plateau to investigate this significant phase of central Italian state formation and whether nucleation was accompanied by demographic pressures. Some important stratigraphies in the powerful places of Etruria cross this boundary (e.g. Tarquinia) and could be employed to test alternative interpretations and the validity of the demographic changes. In Sardinia, however, the recovery never came following the endemic collapse of 900 cal. BC (Fig. 4, point H), after which settlement and burial activity declined (Tronchetti, 2015), with most Nuragic sites abandoned and the nuraghe itself being reduced to an almost totemic symbol of Sardinian identity (Blake, 1997; Minoja and Usai, 2015).

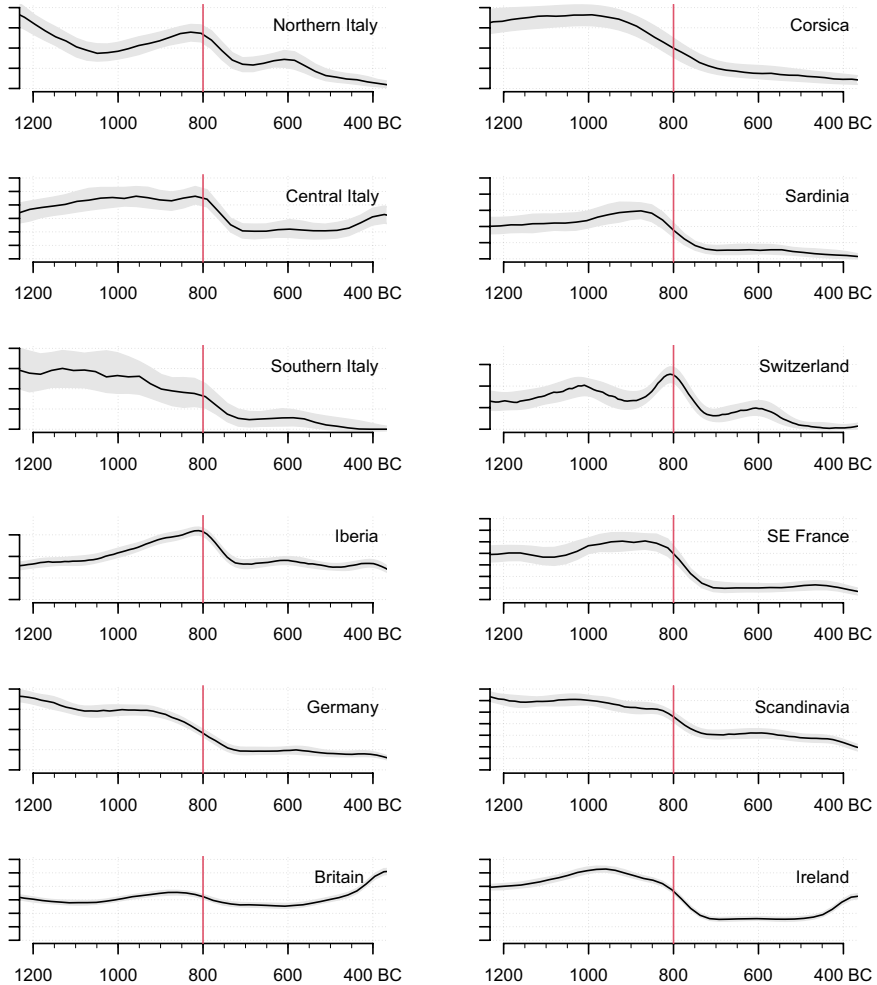
The question of whether this decline was sudden or gradual is therefore an important one. Although radiocarbon data are not well suited to reflecting rapid change due to the uncertainties involved, simulation modelling can be used to build hypothetical models of activity, and via a stochastic ‘Monte Carlo’ process, calculate how this pattern would be reflected in archaeological radiocarbon data. Such exercises also exclude the possibility that plateaux in the calibration curve influence the kernel density estimates. Testing three alternative scenarios in this way (Fig. 11), we can see that the Nuragic decline more closely corresponds to a sudden and drastic reduction in activity, rather than a gradual one.

It is possible to draw further parallels between the significant trends of central Italy, Sardinia and Corsica with events occurring elsewhere, using data from the RADON-B database. The downturn of 900–820 BC seen in the radiocarbon record from central Italy is mirrored, somewhat surprisingly, by events much further north in Scandinavia and Ireland (Fig. 12). In all three cases the density model plummets to lower values that are then sustained from c. 700 cal. BC. The pattern is also weakly



**Fig. 11** Density models for multiple simulated sets of radiocarbon dates consisting of a list of 1000 ‘back calibrated’ dates whose distribution in calendar time conforms to the three models presented on the left. Note that whilst KDE models are unable to articulate sudden change, they produce stable patterns that recover the underlying models without the noise inherent to the alternative SPD technique

represented by perturbations in the activity models from southern Italy, France and Britain. Switzerland experiences decline at this point, but no recovery from 700 cal. BC; instead the falling activity levels are sustained into the Iron Age. In Iberia, a similar pattern of intensification and subsequent decline also occurred, although slightly earlier than elsewhere. In their wider European context, Sardinia and Corsica present cases that mirror the rapid downturn seen in central Italy, Scandinavia and Ireland, but the timing of the collapse in the Mediterranean seems slightly earlier. The hypothetical model of drastic decline presented in Fig. 11 is consistent with real archaeological data from a great variety of locations and together they indicate a major mid-ninth-century BC event that impacted human activity across Europe. In some regions this manifests as a decline, in others as an apparent collapse. If real, this is a pattern that must have had a major bearing on the many cultural transitions that were occurring during this period, for example by causing abandonment of some localities and nucleation in others. In the case of central Italy, the period c. 950–800 BC was a period of centralisation into fewer settlements and our data are compatible with multiple ways of modelling this process. Nucleation may have been a response to demographic decline, and a collective solution to the problem of weakening social connections in an otherwise more dispersed settlement system. Alternatively, it may simply reflect a situation where fewer sites are represented by fewer dates. Our resolution of these processes is obviously hampered by the fact that there have been fewer attempts to apply radiocarbon dating to Iron Age, Phoenician and Classical contexts, and the subsequent ‘Hallstatt’ plateau in the calibration curve. We, however, contend that the pattern observed here for the early first millennium



**Fig. 12** KDE activity models (30-year bandwidth) for selected European regions at the interface between the Bronze and Iron Ages with 800 BC highlighted. Data sources: Italy, this paper; Britain and Ireland, Bevan et al. (2017); France, the BANADORA database (<http://www.arar.mom.fr/banadora/>); and other regions, the RADON-B database (<http://radon.ufg.uni-kiel.de>)

BC is broadly valid, given its occurrence in certain independent and extremely well-resolved radiocarbon datasets (such as Ireland, which is unaffected by such research biases), and highlights both an urgent need to undertake assessments of alternative proxies for activity (such as frequency of pottery finds), and the utility of extending studies of prehistoric demography beyond their usual 750 BC cut-off date.

## Conclusion

This study presents the first attempt at exploring long-term radiocarbon dated trends, settlement activity and population dynamics across the entire central Mediterranean region. The database used in this study comprises 4608 dates from Italy, France and the Maltese Islands ranging from the Mesolithic to Early Iron Age, which in itself represents an important step towards synthesizing central Mediterranean prehistory. The analysis presented here has shown that whilst some trends were local or regional in character, other events were shared with pan-European phenomena. We have tried to contextualise our results through reference to the archaeological record, palaeoenvironmental studies, and by acknowledging research biases, as well as the picture emerging from recent aDNA studies in the region. Our work has incorporated pre-existing databases of radiocarbon data for comparative purposes because the cost of their analysis has been greatly reduced by the time and effort already invested in them by others. In a similar vein, we offer our central Mediterranean database to the public domain in the hope that it will be useful to future researchers undertaking pan-regional studies in world prehistory.

The low level of human activity during the central Mediterranean Mesolithic acts as a prelude to the beginning of the Neolithic, where the comparative density models for wider Europe (Fig. 4) illustrate similar, but asynchronous, patterns of rising and falling activity. These results suggest an endogenous, historically-determined regimen of local resource exploitation that was a common feature of the wider European Neolithic (cf. Shennan et al., 2013; Timpson et al., 2014). However, the signals also carry evidence for certain events that occurred synchronously in radically different cultural, environmental, and geographical contexts, and in these cases it is difficult to frame an explanation for the observed trends without invoking a climatic cause; our discussion on the apparent influence of climatic factors on erratic fluctuations in anthropogenic activity across the Neolithic in southern Italy stands out here.

In particular, evidence from the south of the Italian peninsula seems to suggest that settlement on the Apulian Tavoliere was so dense and rapid, reaching a level not seen in central or northern Italy, that the growth was simply unsustainable. The results, coupled with the lack of intensive use of the Tavoliere for the remainder of prehistory, may support the suggestion that land exhaustion was a driving factor in this decline, and if anything, emphasize the need to undertake more palaeoenvironmental research on this important landscape.

Taking a broader view, an interesting characteristic of the Neolithic ‘boom and bust’ pattern in the central Mediterranean is that regions where initial growth was rapid, such as the Tavoliere and the island settings of Malta and Corsica, also declined more quickly once the Early Neolithic peak passed (see Table 3). The pronounced ‘boom’ in these settings can be best explained by the processes of neolithization, namely sustained migration *en masse* coupled with strong natural population growth. The correlation between relatively rapid growth and decline in the same regional settings indicates that, as a general rule, rapid growth led to equally rapid decline, which has been interpreted elsewhere for Early Neolithic Europe as the signal of a ‘travelling wave’ (Silva & Vander Linden, 2017). A similar symmetry

in growth and decline occurred during the Late Neolithic ‘Temple Period’ of the Maltese Islands. We therefore propose a model for the Neolithic whereby rapid prehistoric decline was caused, at least in part, by an unsustainable upward cultural trajectory initiated centuries beforehand.

By contrast, the Copper Age in central and northern Italy was a time of sustained activity levels. Although such models of stationary growth may not contain the intriguing oscillations in activity seen in earlier and later contexts, they are nonetheless interesting as they hint at a world where the economy and population—and by extension rates of food production, fertility and mortality—were held in balance. The reasons for this are probably rooted in social and political conditions that made manifest a pattern of stability and resilience in the face of the many risks common to prehistoric societies everywhere.

Through time, there seems to have been an inverse correlation between activity levels on the Maltese Islands and Sicily, with a decrease on one island signalling an increase on the other. Whilst this can be explained by expansion of people and ideas at given moments, as demonstrated by the spread of the Neolithic, the reciprocal relationship between the Maltese Islands and Sicily after 4000 cal. BC is harder to explain. It may be tempting to hypothesise that these patterns indicate population shifts that occurred between the two (see Bonanno, 1993), but the overlaps in the development and decline of activity in the Maltese Islands and Sicily illustrate that there is not a simple relationship between levels of human activity in the two regions. Similarly, the evidence for Sardinia and Corsica, and to lesser extent northern Italy and southeast France, illustrates the parallel cultural trajectories of these regions, thus emphasizing the importance of looking beyond modern national or political borders when trying to come to terms with patterns in the archaeological record. In this regard, a consideration of the western Balkans will be a valuable future step, especially given the important role of the region in the diffusion of culture and technology during the Neolithic (Conati Barbaro, 2019; Pearce, 2013).

Patterns of activity during the central Mediterranean Bronze Age varied by region, and following initial rapid growth, northern Italy saw steady decline. By contrast, central Italy saw an initial slow decline transformed to steady growth until c. 820 BC, when activity levels in most central Mediterranean regions (and beyond) fell dramatically. The causes of this decline were probably rooted in the effects of a worsening climate, changing political and cultural circumstances, and perhaps weakening of agricultural productivity at a time when European society was undergoing restructuring brought about by the introduction of iron. This probably caused activity levels in central Italy to fall to half their previous levels, although from 550 BC they recovered, while in Sardinia the Nuragic period ended rather suddenly. However, our efforts to map out the long-term consequences of the ‘820 BC event’ are hampered by the limited number of dates for later time periods.

Such are the constraints of the current study, in that the application of radiocarbon dating has been uneven and has resulted in greater uncertainty about the underlying trends in some regions. However, the results presented here offer a step towards synthesizing the prehistory of a geographical area where comprehensive

English-language regional syntheses are lacking. Furthermore, the patterns revealed by the analysis illustrate how dynamic the central Mediterranean was. Unlike the similar and predictable patterns of activity that dominate the archaeology of northern Europe, the central Mediterranean was a melting pot of cultures and ideas, within a highly diverse physical landscape. The islands of the central Mediterranean also offer unique microcosms where the pace of development of cultural change in the past can be read from the radiocarbon record and compared to the macro-trends operating in less insular settings. The new results presented in this paper have considerable implications for interpreting demographic history and the ecological relationships between people and their environment, which we hope will stimulate the course of future bioarchaeological and palaeoenvironmental research in the region.

The central Mediterranean landscape is today regarded as an idyll by many; it is certainly rich and diverse, but one recurring trend in the prehistory of its human settlement stands out: since the Neolithic, high levels of human activity and settlement density have not been sustained indefinitely anywhere in this region. Rather, as exemplified in the southern Italian Neolithic, or in the Maltese Islands during the Temple Period, or in Sardinia during the Bronze Age, high activity levels drew society inevitably towards long-term decline when the cumulative demand on resources fell afoul of the capacity of the environment to meet those demands. Some prehistoric societies were more resilient than others, but the recurring pattern was one of instability over the longer term and occasional episodes of crisis. This is a stark reminder from the prehistoric past that the human dimension is as fragile as any other component in an ecosystem, and given our species' long intergenerational period, we tend to be rather slow in the recovery.

## Editor's Note

The publication by *JWP* of two independently-researched palaeodemographic syntheses covering a similar region and timespan affords a rare opportunity to reflect on the relationship between theories, methods and results in our discipline. In particular, it provides a context for assessing the potential of reproducible research for increasing archaeological knowledge security. In order to make the most of this conjunction, the Editor-in-Chief exceptionally invited each team to consider the other's results. These invitations were accepted and, while the empirical contents of each paper remain unaltered from their peer-reviewed acceptance, each now concludes with a short commentary reflecting on the similarities and differences.

*Timothy Taylor, Comenius University in Bratislava, August 2021.*

## Commentary: Parkinson et al. (2021) on Palmisano et al. (2021)

In their paper, Palmisano and colleagues have been more ambitious than we have in framing palaeodemographics front-and-centre in their analysis. Like many works that aggregate radiocarbon dates, they have included attempts to fit their SPDs to demographic models and evaluate these using information criteria. We have attempted something more exploratory and intermediate in scope because we believe dynamic models of changing activity levels remain sensitive to the fact that each moment in time carves out a new fate for itself. After all, the world is more immediately influenced by events occurring adjacently in time and space than events occurring far away or long ago. Hopefully, our two papers will highlight cases where model-based palaeodemography is useful, as well as cases where it is arguably too reductive.

Our papers obviously differ in the wider perspectives they bring to the radiocarbon data. Palmisano et al. have gathered together an impressive number of different regional palaeoclimate records and compared them with the archaeological data, whereas we have drawn on archaeological data from adjacent regions and wider Europe as a kind of ‘super-proxy’ for environmental change occurring at a global scale. It is our hope that splicing together both sets of analysis will reward interested readers of this journal with their own new, independent insights. Indeed, one of the most important aspects of our work is openness and ensuring there is potential for re-use and re-evaluation. The results of our two studies bear striking similarities to each other, thus validating the theoretical underpinnings, rigour of data collection, and methodological approaches of both. The only major difference we can detect is the relatively higher levels of activity in the Bronze Age in southern Italy reported by Palmisano et al., which indicate either that our counterparts had greater success in gathering dates from this period, or that our database contains a relative wealth of dates for the Neolithic that has skewed our respective models accordingly. Despite this, the overall dynamic identified by both papers is similar, with a cycle of growth and decline occurring throughout the second millennium BC. Because both teams have followed best practice and made their data and code available as supplementary materials, we encourage readers to see whether any recently-published data generate updated models.

Despite their overall conceptual similarity, the two papers have employed different—albeit related—methodological approaches in an attempt to synthesise the radiocarbon data for central Mediterranean prehistory. We feel our Kernel Density Estimation (KDE) method better aids in the identification of shorter-term changes than the Summed Probability Distribution (SPD) and permutation testing approach used by Palmisano et al. The narrower confidence intervals in our KDE models allow us to model growth rates dynamically, which has unexpectedly revealed shared dynamics across several regions (e.g. 3000 BC). This implies there were events in prehistory that were large in geographical scale but generated subtle temporal signals, and KDEs are the best apparatus currently available for detecting these. However, we expect the methods we present here will continue to be developed, by ourselves and others.



Perhaps the largest departure our papers make from one another is in our interpretations of the data from the first millennium BC. Palmisano et al. have interpreted the reduction in their SPD models as a weakening signal, which totally succumbs to negative research bias by the time ‘complex societies’ appear (their fig. 11). Whilst we too acknowledge the enormity of the problem of negative bias and ‘edge effects’, we also point out that there is growth as well as decline in some regions during the early first millennium BC, indicating that a demographic signal may still be present, as it is in other, better resolved, European regions. This opens up a number of interesting thought experiments, such as the idea that Neolithic, Copper Age and Bronze Age societies were perhaps not as demographically limited as they are often assumed to be, and the complex processes that led to state formation may be a response to lower population densities rather than the consequence of rising ones. This all serves to illustrate how little we actually know about prehistoric population levels on any absolute scale, which is a challenge that the two papers make for future research in the central Mediterranean and world prehistory more generally.

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s10963-021-09158-4>.

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