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An Environmental and Climate History of the Roman Expansion in Italy In 400 B.C.E., Rome was the largest of the Latin-speaking cities of western central Italy. Political power was monopolized by a group of religiously privileged land-

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owning families known as patricians, but legal reforms in the fourth century B.C.E. created a more open patricio-plebeian elite (or *nobilitas*), whose membership drew from a wider pool of landowning families. At the same time, Rome's legions extended their control over Latium and then progressively across the peninsula in a process of state creation and intensification of state-directed warfare.

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Through this expansion, the Romans encountered a varied ecological landscape occupied by heterarchical communities with diverse political and cultural structures. Urban societies of Magna Graecia and Etruria occupied coastal plains or river valleys that offered access to arable land and maritime trade routes. The less urbanized Sabines and Samnites lived in the upland areas of the Apennines, while societies along the east coast participated in the cultural and economic circuits of the Adriatic world. By the mid-second century B.C.E., Rome had conquered all the way to the Alps, defeating Ligurians, Gauls, and other groups closely linked to the Iron Age cultures of Transalpine Europe. Although Rome's approach to each area variously included extensions of citizenship, colonization programs, or seizures of territory as state property (*ager publicus*), Rome showed little interest in controlling domestic affairs in local communities. Archaeology shows considerable continuity between pre-Roman and Roman cultures in many places into the first century B.C.E.[1]

Although its parameters remain debated, progressive demographic growth characterized the period. During the early expansion, settlements in the Italian countryside grew denser (a process known as rural infilling), and extensive urbanization commenced around 300 B.C.E. The increase in urban population was most evident in the city of Rome itself, which relied on improved access to grain from Sicily, Sardinia, and North Africa to feed a population approaching 1 million residents by the later first century B.C.E. Although Rome was a late adopter of coinage, by the second century B.C.E. a unified monetary zone had spread across Italy. Slavery became entrenched at the core of the productive economy, and trade around Italy and the Mediterranean increased.

1 For an introduction to the historical narrative, see Alan Astin et al. (eds.), *The Cambridge Ancient History* (Cambridge, 1990), VIII; Nicola Terrenato, *The Early Roman Expansion into Italy: Elite Negotiation and Family Agendas* (Cambridge, 2019); Marian Helm, *Kampf um Mittelitalien Roms ungerader Weg zur Großmacht* (Stuttgart, 2021); for pre-Roman Italy, see Stéphane Bourdin, *Les peuples de l'Italie préromaine* (Paris, 2012); for archaeological evidence relating to territory, see Elio Lo Cascio and Alfredina Storchi Marino (eds.), *Modalità insediative e strutture agrarie nell'Italia meridionale in età romana* (Bari, 2001); for imperialism in northern Italy, see Lo Cascio and Marco Maiuro (eds.), *Popolazione e risorse nell'Italia del nord dalla romanizzazione ai Longobardi* (Bari, 2017); for colonization, Tesse Stek and Jeremia Pelgrom (eds.), *Roman Republican Colonization: New Perspectives from Archaeology and Ancient History* (Leiden, 2014); for Roman organizations of landholding, see Saskia Roselaar, *Public Land in the Roman Republic: A Social and Economic History of* Ager Publicus *in Italy, 396–89* BC (Oxford, 2011).

The cumulative effect of these trends was the eventual integration of Italy along sociocultural, economic, and political lines. By the time Augustus established the principate in 29 B.C.E., the diverse societies of Iron Age Italy appeared transformed into what ancient sources referred to as "United Italy" (*tota Italia*).[2]

The character of early Roman imperialism is long debated, but scholarship has recently challenged ideas of Roman exceptionalism and any exclusively Roman ideology conditioning initial imperial success in the fourth and third centuries B.C.E. In that period, competition between Rome and Italian rivals took place amid geopolitical transformations that were sweeping over much of the central Mediterranean. This contextualization of Roman expansion within broader trends shifts scholarly focus away from Rome's intrinsic characteristics to more general and extrinsic forces such as ecology and climate.[3]

A desire to bring scientific data to bear on the history of Roman expansion is not new. In 1962, Ward-Perkins made pioneering use of pollen records from Lago di Bracciano to test ancient accounts of Rome's armies encountering the supposedly pristine Ciminian forest of South Etruria. More than half a century later, evidence from lakes in the region and more effective dating methods offer better possibilities for reconstruction. Improvements in the scientific data are detectable even over the last several years. These advances are not specific to the region and period but belong to wider trends in historical climate studies. Recent refinements of scientific methods along with greater attention to collecting historical and archaeological data allows for the reconstruction of past climate and landscape beyond and between those punctuated

2 For urbanization, Jamie Sewell, "Higher-Order Settlements in Early Hellenistic Italy: A Quantitative Analysis of a New Archaeological Database," *American Journal of Archaeology*, CXX (2016), 603–630; for demography, see Luuk de Ligt, *Peasants, Citizens and Soldiers: Studies in the Demographic History of Roman Italy 225 BC–AD 100* (Cambridge, 2012); Saskia Hin, *The Demography of Roman Italy* (Cambridge, 2013); for economic changes including monetization, see Nathan Rosenstein, *Rome at War: Farms, Families, and Death in the Roman Republic* (Chapel Hill, 2004); Tan, *Power and Public Finance at Rome, 264–49 BC* (Oxford, 2017); Tymon de Haas and Gijs Tol (eds.), *The Economic Integration of Roman Italy: Rural Communities in a Globalizing World* (Leiden, 2017); Roselaar, *Italy's Economic Revolution: Integration and Economy in Republican Italy* (Oxford, 2019).

3 For debate on Roman imperialism, see Craige Champion, *Roman Imperialism: Readings and Sources* (Oxford, 2004); Arthur Eckstein, *Mediterranean Anarchy, Interstate War, and the Rise of Rome* (Berkeley, 2006); Terrenato, *The Early Roman Expansion into Italy*; Padilla Peralta, "Epistemicide: The Roman Case," *Classica*, XXXIII (2020), 151–186.

moments of abrupt change or catastrophe that first attracted attention. The field consequently moves toward more subtle and diachronic histories of human-environment relationships.[4]

Thus far, however, this shift has had less impact on the study of Roman climate, which remains dominated by a focus on later imperial history and the role of climate in the empire's disintegration. In this debate, there starts to appear an implication that the earlier period's climate was more stable and, by extension, more conducive to state formation. Although this view has not been expressed in explicit terms, it often emerges implicitly with references to the end of the empire coinciding with the end of a climate period referred to by climatologists as the "Roman Warm Period" (RWP, also known as the "Roman Climate Optimum"). The RWP has thus come to be understood as an ingredient in Rome's early imperial success. To date, scholarship on the RWP's parameters and its historical implications has been inconsistent in both scientific and historical literature. There is no consensus on the timing of the RWP's onset, with suggested dates ranging from 550 to 200 B.C.E. and even as late as 1 B.C.E. There has also been little explicit consideration of exactly how the RWP supported Roman imperialism. We might imagine, for example, a view that

4 John-Bryan Ward-Perkins, "Etruscan Towns, Roman Roads and Medieval Villages: The Historical Geography of Southern Etruria," *Geographical Journal*, CXXVIII (1962), 389–404; for broader applications of scientific data to historical climate studies, see Dagomar Degroot et al., "Towards a Rigorous Understanding of Societal Responses to Climate Change," *Nature*, DXCI (2021), 539–550; see also Sverker Sörlin and Melissa Lane, "Historicizing Climate Change—Engaging New Approaches to Climate and History," *Climatic Change*, CLI (2018), 1–13; for the Anthropocene and historical climate studies, see Deepak Chakrabarty, "The Climate of History: Four Theses," *Critical Inquiry*, XXXV (2008), 197–222; Adam Izdebski et al., "Realising Consilience: How Better Communication between Archaeologists, Historians and Geoscientists Can Transform the Study of Past Climate Change in the Mediterranean," *Quaternary Science Reviews*, CXXXVI (2016), 5–22; Catherine Kearns, "Mediterranean Archaeology and Environmental Histories in the Spotlight of the Anthropocene," *History Compass*, XV (2017); John Moreland, "AD 536—Back to nature?" *Acta Archeologica*, LXXXIX (2018), 91–111; for Roman antiquity showing focus on later periods, see Michael McCormick et al., "Climate Change during and after the Roman Empire: Reconstructing the Past from Scientific and Historical Evidence," *Journal of Interdisciplinary History*, XLIII (2012), 169–220; Kyle Harper, *The Fate of Rome: Climate, Disease and the End of an Empire* (Princeton, 2017); Harper and McCormick, "Reconstructing the Roman Climate," in Walter Scheidel (ed.), *The Science of Roman History: Biology, Climate, and the Future of the Roman Past* (Princeton, 2018), 11–52; Izdebski and Michael Mulryan (eds.), *Environment and Society in the Long Late Antiquity* (Leiden, 2019); Paul Erdkamp, Joseph Manning, and Koenraad Verboven (eds.), *Climate Change and Ancient Societies in Europe and the Near East: Diversity in Collapse and Resilience* (New York, 2021).

climate was stable enough to fade into the background, granting room for social development, or that the RWP played a more active role by increasing marginal returns on agricultural labor, by allowing for more extensive cultivation, or by facilitating demographic expansion or more reliable maritime trade; these and other historical models remain untested.[5]

Although global indices may reflect a period of an overall warmer climate commencing around 300–200 B.C.E., local data suggest considerable differences of the timing and expression of this trend across Italy, something that makes sense in light of the peninsula's fragmented ecologies. This variability suggests that the idea of a unified RWP is overly simplistic, while human responses to environmental and climatic change were themselves highly complex. We do not dispute the role of climate and environment in Italian state-formation and economic development but focus attention on the human agency and the societal resilience that characterized human-environmental relationships during the Roman expansion in Italy. Drawing upon an array of archaeological, scientific, and historical approaches, we propose that the history of Italy's climate and environment during this period is best studied through the practices by which communities and households mitigated risk. Such inquiry makes clear that Rome intervened in ongoing Italian practices of landscape management, that climate became most historically salient in relation to (or when mediated by) Italian societies' resilience practices, and that such strategies made Italian communities robust in an unpredictable environment.

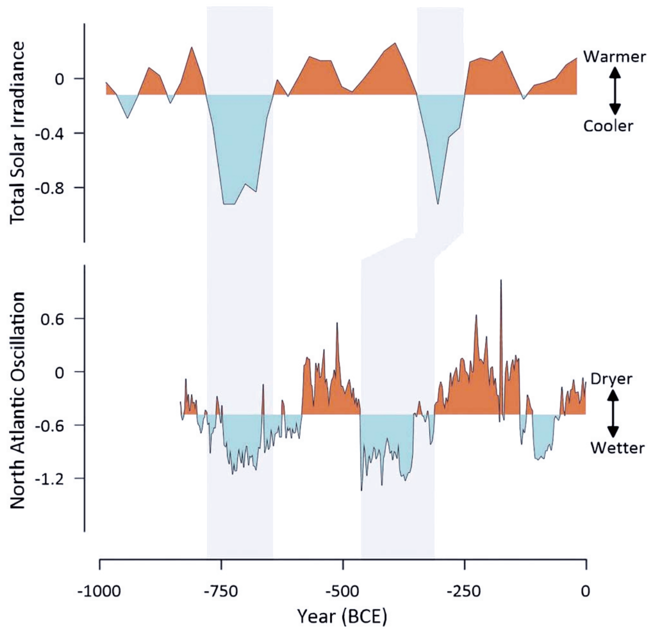
5 For a collection of dates suggested for the RWP's onset, see Harper, *The Fate of Rome*, 321 n. 46. Hubert Lamb, *Climate, History and the Modern World* (London, 1995), 142; see also McCormick et al., "Climate Change during and after the Roman Empire," 203; Harper and McCormick, "Reconstructing the Roman Climate"; Tan, "Climate Change and Rome's Changing Republic," in Mattia Balbo and Federico Santangelo (eds.), *A Community in Transition: Roman History, 200–134 BC* (Oxford, 2022), 21–54; Giulia Margaritelli et al., "Persistent Warm Mediterranean Surface Waters during the Roman Period," *Scientific Reports*, X (2020). For scientific critique of the RWP in Italy, see Bini et al., "Hydrological Changes during the Roman Climatic Optimum in Northern Tuscany (Central Italy) as Evidenced by Speleothem Records and Archaeological Data," *Journal of Quaternary Science*, XXXV (2020), 791–802; for hydrological variability during the Roman period, see John Haldon et al., "Plagues, Climate Change, and the End of an Empire: A Response to Kyle Harper's *The Fate of Rome* (1): Climate," *History Compass*, (2018) XVI, available at doi.org/10.1111/hic3.12508; Elena Xoplaki et al., "Hydrological Changes in Late Antiquity: Spatio-Temporal Characteristics and Socio-Economic Impacts in the Eastern Mediterranean," in Erdkamp, Manning, Verboven, *Climate Change and Ancient Societies*, 533–560.

NATURAL ARCHIVES FOR CLIMATE A synthesis of the current understanding of the environment and climate of central Italy and neighboring regions confirms relatively few short-term extreme climate shifts during the period of Roman expansion. During the first millennium B.C.E., the central Mediterranean saw global and macroregional climate fluctuations related to changes in solar magnetic activity and the North Atlantic Oscillation (NAO, a prominent and recurrent pattern of variability in atmospheric circulation over the North Atlantic). The strength of two hemispherical pressure patterns—a low near Iceland and high over the Azores and the subtropical region—reflects the NAO's positive or negative mode. In a negative mode, these features are weak, tracking storms directly across the western Mediterranean and bringing comparatively more precipitation to Italy and the surrounding region. The NAO thus represents a dominant source of atmospheric variability affecting the climate of the western and central Mediterranean on a multi-decadal scale. Reconstruction of the NAO index from a combination of lake cores, tree rings, and speleothems showed a mainly negative NAO phase interrupted by a positive phase around 750–500 B.C.E. Around 500 B.C.E., the NAO shifted back to negative and then returned to a prolonged positive phase about 150 years later.[6]

Negative phases of NAO correlated with minima in solar energy; reconstruction of Total Solar Irradiance (TSI) showed two solar minima in the first millennium B.C.E. The first

6 Eduardo Zorita et al., "The Global Climate System," in Sam White, Christian Pfister, Franz Mauelshagen (eds.), *The Palgrave Handbook of Climate History* (New York, 2018), 21–26; for NAO, see James W. Hurrell et al., *An Overview of the North Atlantic Oscillation* (2003); Harper and McCormick, "Reconstructing the Roman Climate," 15; Celia Martin-Puertas et al., "Regional Atmospheric Circulation Shifts Induced by a Grand Solar Minimum," *Nature Geoscience*, V (2012), 397–401. Leslie J. Gray et al., "Solar Influences on Climate," *Reviews of Geophysics*, XLVIII (2010), available at doi:10.1029/2009RG000282. Jesper Olsen et al., "Variability of the North Atlantic Oscillation over the Past 5,200 Years," *Nature Geoscience*, V (2012), 808–812; Ilya Usoskin et al., "Grand Minima and Maxima of Solar Activity: New Observational Constraints," *Astronomy & Astrophysics*, CDLXXI (2007), 301–309; Gerard Bond et al., "Persistent Solar Influence on North Atlantic Climate during the Holocene," *Science* CCXCIV (2001), 2130–2136; Johan C. Faust et al., "Norwegian Fjord Sediments Reveal NAO Related Winter Temperature and Precipitation Changes of the Past 2800 Years," *Earth and Planetary Science Letters*, CDXXXV (2016), 84–93; for the tendency of NAO to express differently across the Mediterranean, see Brian J. Dermody et al., "A Seesaw in Mediterranean Precipitation during the Roman Period Linked to Millennial-Scale Changes in the North Atlantic," *Climate of the Past*, VIII (2012), 637–651.

Fig. 1 Global Climate-Forcing Trends Affecting Italy in the First Millennium B.C.E.



SOURCES Johan C. Faust et al., "Norwegian Fjord Sediments Reveal NAO Related Winter Temperature and Precipitation Changes of the Past 2800 Years," *Earth and Planetary Science Letters*, 435 (2016), 84–93; Friedrich Steinhilber et al., "Total Solar Irradiance during the Holocene," *Geophysical Research Letters*, 36 (2009).

(c. 800–600 B.C.E.) is often referred to as the Halstatt or Homeric grand solar minimum. A second minimum with almost identically low levels of TSI but of shorter duration occurred around 375–250 B.C.E. (see Fig. 1). A period of comparatively high solar energy followed from the later third century B.C.E. The link between the NAO and TSI suggests that periods of solar minima are relatively cooler and wetter in the western and central Mediterranean.[7]

7 Bond et al., "Persistent Solar Influence"; Friedrich Steinhilber et al., "Total Solar Irradiance during the Holocene," *Geophysical Research Letters*, 36 (2009); Luis E. A. Vieira et al., "Evolution of Solar Irradiance during the Holocene," *Astronomy & Astrophysics*, DXXXI (2011).

Recent research emphasizes explosive volcanism as the largest driver of short-term global climate variability. This happens when sulfur dioxide gas, a major constituent in volcanic emissions, is transformed in the atmosphere to highly reflective sulfate aerosols that shield the earth from solar radiation, resulting in cooler air temperatures. When the volcanic plume of large eruptions reaches the stratosphere, sulfate aerosols remaining in the atmosphere for months to years can lead to pronounced, long-term cooling at global scales. Because they are highly soluble, sulfate aerosols from smaller eruptions where the volcanic plume only extends into the troposphere are quickly removed by precipitation, leading to relatively small, localized cooling. Ancient sources noted local eruptions of smaller volcanoes like Etna or Vesuvius during our period, but such activity was not significant enough to drive global effects.[8]

Linking climate drivers such as volcanic eruptions first to changes in precipitation and temperature and second to historical events requires exact and independent dating of all records, especially if inferring causality between them. Volcanic sulfur fallout measured in polar and alpine ice cores provides detailed records of thousands of years of explosive volcanism. The magnitude, seasonal timing, and location—the latitude in particular—of the erupting volcano largely determined impacts to the climate.

Technological improvements for ice core analyses have led to a rapid increase in the number of high-resolution volcanic fallout records for Roman antiquity. Ice cores from Greenland and Antarctica suggest that explosive volcanism during the final three centuries B.C.E. was somewhat low relative to the last 2,500 years, at least until early 43 B.C.E. These records indicate that none of the twenty-five largest eruptions of the past 2,500 years, and only three of the forty largest eruptions, occurred between 300 and

8 Michael Sigl et al., "Timing and Climate Forcing of Volcanic Eruptions for the Past 2,500 Years," *Nature*, DXXIII (2015), 543–549; Gill Plunkett et al., "No Evidence for Tephra in Greenland from the Historic Eruption of Vesuvius in 79 C.E.: Implications for Geochronology and Paleoclimatology," *Climate of the Past*, XVIII (2022), 45–65; for textual attestations of eruptions in the region, see Richard B. Stothers and Michael R. Rampino, "Volcanic Eruptions in the Mediterranean before A.D. 630 from Written and Archaeological Sources," *Journal of Geophysical Research*, LXXXVIII (1983), 6358–6360.

44 B.C.E. Two larger eruptions occurred in 430 and 426 B.C.E., and others clustered between 168 and 158 B.C.E.[9]

These records indicate one of the largest eruptions of the past 2,500 years early in 43 B.C.E., which was followed by elevated atmospheric sulfate for nearly three years. Geochemical fingerprinting of volcanic tephra preserved in the ice shows that the source was a massive eruption of the Okmok volcano in Alaska. Atmospheric modelling (Community Earth System Model, CESM, version 1.2.2) of the event suggested pronounced cooling in 43/2 B.C.E. throughout the Northern Hemisphere, with annual average temperatures as much as 5°C cooler. These model results were consistent with global evidence from tree rings and speleothems, which suggested that 43 and 42 B.C.E. were among the coldest of the last 2,500 years. The CESM simulations indicated substantial climate effects in the area of Roman activity, including average summer and fall temperatures that were 4.5°C colder in 43 B.C.E. and 2°C colder in winter and spring in 42 B.C.E. Although precipitation is notoriously difficult to simulate, results suggested that 43 B.C.E. summer precipitation was 50 to 120% above normal in southern Europe, with autumn precipitation up to 400% above normal in some regions. Josephus and Appian recorded extreme weather, famine, and epidemic disease from early 43 to late 42 B.C.E.[10]

9 Jihong Cole-Dai et al., "Comprehensive Record of Volcanic Eruptions in the Holocene (11,000 Years) from the WAIS Divide, Antarctica Ice Core," *Journal of Geophysical Research: Atmospheres,* CXXVI (2021); Sigl et al., "Timing and Climate Forcing of Volcanic Eruptions"; Anders Svensson et al., "Bipolar Volcanic Synchronization of Abrupt Climate Change in Greenland and Antarctic Ice Cores during the Last Glacial Period," *Climate of the Past*, XVI (2020), 1565–1580; McConnell et al., "Pervasive Arctic Lead Pollution Suggests Substantial Growth in Medieval Silver Production Modulated by Plague, Climate, and Conflict," *Proceedings of the National Academy of Sciences of the United States of America*, CXVI (2018), 14910–14915. Uncertainties in the most up-to-date ice chronologies are probably <1 year for antiquity. Sigl et al., "Timing and Climate Forcing of Volcanic Eruptions"; for impact of volcanic activity in the Ptolemaic Empire, see Manning, et al. "Volcanic Suppression of Nile Summer Flooding Triggers Revolt and Constrains Interstate Conflict in Ancient Egypt," *Nature Communications*, VIII (2017); Ram Singh, et al. "Investigating Hydroclimatic Impacts of the 168–158 B.C.E. Volcanic Quartet and Their Relevance to the Nile River Basin and Egyptian History," *Climate of the Past*, XIX (2023), 249–275.

10 Josephus, *Antiquities of the Jews*, Book XIV 12.310; Appian, *The Civil Wars*, Book IV, 122, V, 25; McConnell et al., "Extreme Climate after Massive Eruption of Alaska's Okmok Volcano in 43 BC and Its Effects on the Civil Wars of the Late Roman Republic," *Proceedings of the National Academy of Sciences of the United States of America* (2020); for CESM, see Hurrell et al., "The Community Earth System Model: A Framework for Collaborative Research," *Bulletin of the American Meteorological Society*, XCIV (2013), 1339–1360; for sources, see P. Y. Forsyth, "In the Wake of Etna, 44 B.C.," *Classical Antiquity*, VII (1988), 49–57.

Paleoenvironmental Data Integrating global climate signals with paleoenvironmental data at regional and local scales gives a fuller picture of historical climate. Local paleoenvironmental archives from the Mediterranean offer a typically lower level of resolution and precision than global climate archives, and this is especially true for data relevant to the events of Roman expansion. For example, although alpine glacial ice from Colle Gnifetti at the border between Italy and Switzerland provides geographically proximate information, published records only cover the last 1,000 years. Additionally, the absence of tree ring chronologies extending through the Roman period means the highly resolved dendrological indices of precipitation and temperature achieved for other parts of Europe are unavailable for Italy. Furthermore, although there are abundant pollen records for Italy, discussed below, this material cannot be taken to reflect climate change except in a highly complex manner.[11]

The most useful evidence for local Italian climate reconstruction during our period thus comes from oxygen isotope composition, usually expressed as δ-unit ‰, or $\delta^{18}O$, in different terrestrial carbonate precipitates. These are represented especially by lacustrine marls and speleothems, cave calcite deposits like stalagmites and flowstones. The main advantage of the use of the $\delta^{18}O$ proxy is its supposed large insensitivity to human impacts on environment; in the Mediterranean region, $\delta^{18}O$ of lacustrine marls and speleothems are mainly considered to be controlled by local hydrology, with a more direct link to winter precipitation in speleothems and summer conditions for lacustrine sediments. Uranium-thorium dating can also be used for speleothems, which in some cases provides better chronology control than radiocarbon. Uranium and thorium have longer half-lives than carbon, making them preferable for earlier periods of the Holocene, and their calibration curves are not susceptible to the problems of the Hallstatt plateau.[12]

11 The authors wish to thank Mauro Bernabei for discussion of Italian dendrology. For glacial records, see Enrico Mattea et al., "Firn Changes at Colle Gnifetti Revealed with a High-Resolution Process-Based Physical Model Approach," *Cryosphere*, XV (2021), 3181–3205.

12 Zanchetta et al., "Enhanced Rainfall in the Western Mediterranean during Deposition of Sapropel S1: Stalagmite Evidence from Corchia Cave (Central Italy)," *Quaternary Science Reviews*, XXVI (2007), 279–286; C. Neil Roberts et al., "Stable Isotope Records of Late Quaternary Climate and Hydrology from Mediterranean Lakes: The ISOMED Synthesis," *Quaternary Science Reviews*, XXVII (2008), 2426–2441; Michael D. Jones, Roberts, Zanchetta, "Oxygen Isotopes as Tracers of Mediterranean Variability: Linking Past, Present and Future," *Global and Planetary Change*, LXXI (2010); Bini et al., "The 4.2 ka BP Event in the Mediterranean Region: An Overview," *Climate of the Past*, XV (2019), 555–577.

Well-dated speleothem records from Italy covering the last three millennia at decadal resolution remain limited to samples from a small handful of cave systems in north-central and northern Italy. Figure 3 presents a selection of these speleothem records and one lacustrine succession from Lago di Pergusa in Sicily (for locations, see Fig. 2). The chronological range of the selection starts with the late part of the so-called Homeric solar minimum of 800–600 B.C.E., which, at Pergusa and also Rio Martino in northwest Italy, corresponds to a humid phase. Wetter conditions persisted at Rio Martino between 600 and 400 B.C.E., when conditions also became wetter at Renella in the Apuan Alps. In the northern Alps, a summer cooling phase is recorded between 380 and 300 B.C.E., corresponding to a cooling of sea surface

Fig. 2 Location of Italian and Central Mediterranean Paleoenvironmental Records

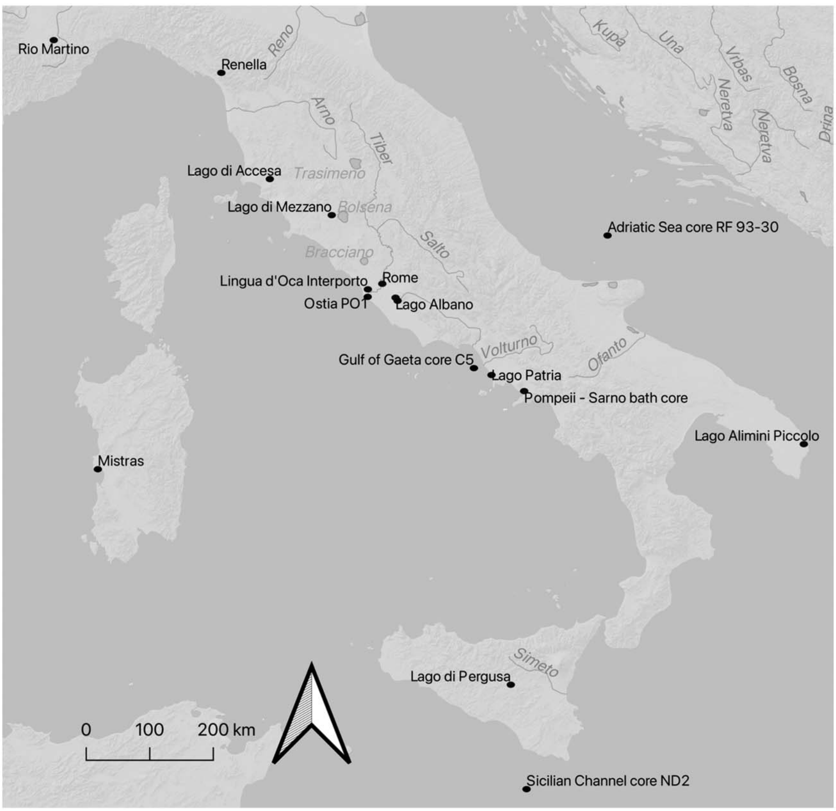
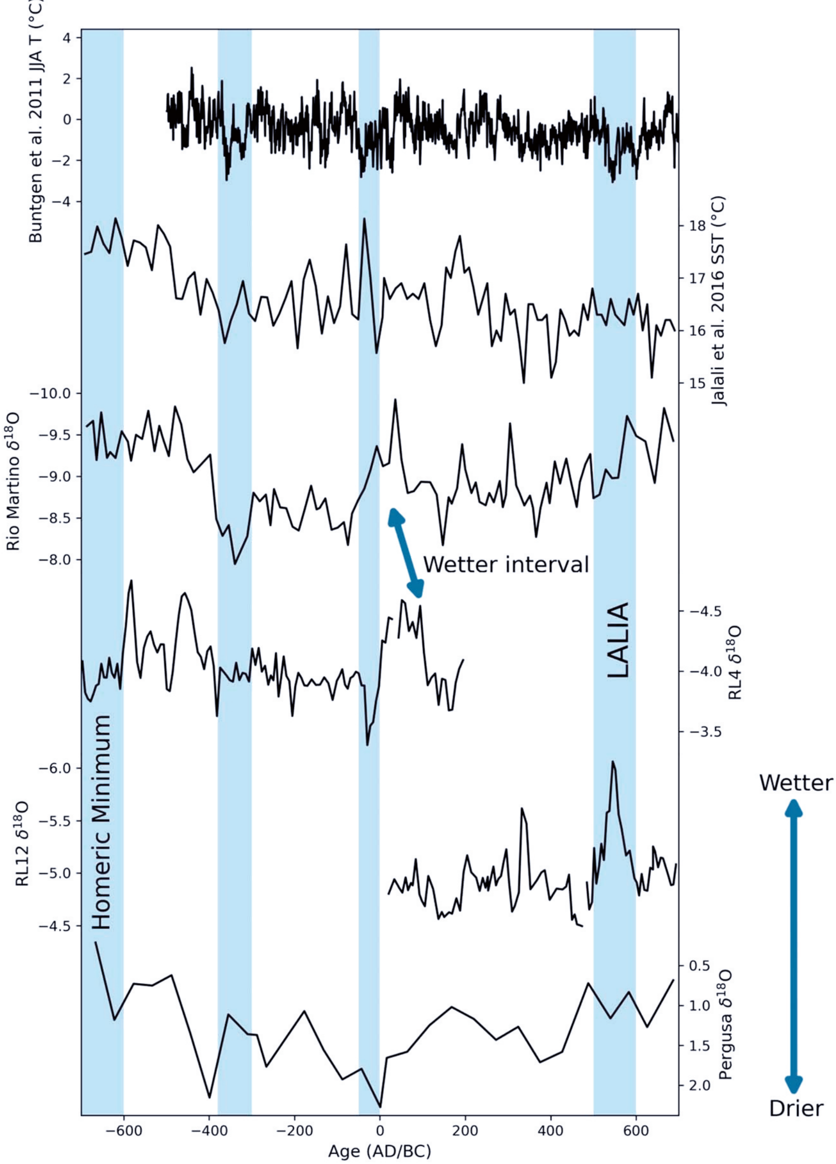


Fig. 3 Selected $\delta^{18}O$ Continental Records from Italy



SOURCES See text.

temperature recorded in the Gulf of Lions. This phase saw drier conditions at Rio Martino and ushered in a long period of drier conditions at Renella. Apuan speleothem $\delta^{18}O$ records show a pattern of drier conditions during the end of first century B.C.E. The drier period corresponds to lower summer temperatures in the northern Alps. This dry-wet pattern is replicated in the Lago di Pergusa lower-resolution record, corroborating the Apuan finding and, within age error, with the Rio Martino record. The wetter period may be linked to increased flooding events attested by historical accounts of Tiber floods, discussed below, and geoarcheological data from northern Tuscany.[13]

The reconstruction of climate in the early centuries of the first millennium C.E. is elusive, either because of the different chronology of various records or the complexity of regional climate articulation and its imprinting in proxy data. In sum, for the latter half of the first millennium B.C.E., comparison of the speleothem $\delta^{18}O$ records shows some linked trends over decadal or centennial scales, but also variability in the more precise local timing or peaks of wetter or dryer phases. We also see regular oscillation between dryer and wetter conditions, suggesting regular climate variability within a certain range.

In summary, available data for later first millennium B.C.E. Italy suggest a highly dynamic environment varying considerably across time and space, even though the period was comparatively free of short-term, abrupt climate changes. Global signals indicate a somewhat warmer period in the western and central Mediterranean

13 There are three published speleothem records from peninsular Italy for our period: Corchia, Renella, and Rio Martino. For a newly published Roman-era record from the Bàsura cave in Toirano, see Hsun-Ming Hu et al., "Stalagmite-Inferred Climate in the Western Mediterranean during the Roman Warm Period," *Climate*, X (2022); for a multi-sample study from Mallorca, see Mercè Cisneros et al., "Hydroclimate Variability during the Last 2700 Years Based on Stalagmite Multi-Proxy Records in the Central-Western Mediterranean," *Quaternary Science Reviews*, CCLXIX (2021). Figure 3 reports summer temperature reconstruction obtained by trees for the North Alpine region after Ulf Büntgen et al., "2500 Years of European Climate Variability and Human Susceptibility," *Science*, CCCXXXI (2011); and temperature from marine records obtained in the Gulf of Lions after Bassem Jalali et al., "Holocene Climate Variability in the North-Western Mediterranean Sea (Gulf of Lions)," *Climate of the Past*, XII (2016), 91–101; for speleothem data, see Bini et al., "Hydrological Changes during the Roman Climatic Optimum"; Eleonora Regattieri et al., "Holocene Critical Zone Dynamics in an Alpine Catchment Inferred from a Speleothem Multiproxy Record: Disentangling Climate and Human Influences," *Scientific Reports*, IX (2019), 17829; Zanchetta et al., "Insight into Summer Drought in Southern Italy: Palaeohydrological Evolution of Lake Pergusa (Sicily) in the Last 6700 Years," *Journal of Quaternary Science*, XXXVII (2022).

regions commencing in the early third century B.C.E., a period that was relatively free of high-impact global volcanic activity. The link between TSI and NAO suggests that this warmer period was also drier in the central Mediterranean area. For regions of Italy where they are currently available, speleothems support the idea of a shift from drier to wetter conditions at the end of the Republican Period. Any synthesis of this material must remain tentative to some degree owing to the available archives, as the NAO and TSI data remain coarse and the geographical coverage of speleothems remains limited. However, the cumulative impression is that it is impossible to reconstruct scientifically a single Italian or Roman climate in this period except at broad spatiotemporal scales not especially salient to historical interpretation.

Pollen Records Although the most abundant forms by far of local paleoenvironmental data for the period of Roman expansion are pollen records, their use in historical climate study is not straightforward. Radiocarbon dating is the primary method applied to stratified sediment records containing pollen, and the earlier years of the expansion fall within the so-called Hallstatt plateau, the time between 750 and 400 B.C.E. when radiocarbon calibration returns dates with uncertainty intervals of several centuries. Additionally, in differentiating climatic from anthropogenic drivers of vegetation change, special attention must be paid to pollen from the *Olea* (olive), *Juglans* (walnut), and *Castanea* (chestnut) (OJC) group, which is known to reflect human cultivation. Recent work modeling large datasets suggests that late-Holocene pollen records reflected demography, which complicates interpretations of the same data as signals of climate. For example, a pilot study comparing isotopic data for precipitation with pollen records at Lago di Pergusa in central Sicily showed periods of enhanced humidity reflected by different feedbacks in vegetation, suggesting anthropic drivers. The broader implication is that distinguishing Holocene climate changes based on pollen records alone is difficult.[14]

14 For OJC, see Anna Maria Mercuri et al., "Olea, Juglans and Castanea: The OJC Group as Pollen Evidence of the Development of Human-Induced Environments in the Italian Peninsula," *Quaternary International*, CCCIII (2013), 24–42; for Lago di Pergusa, see Sadori and Biancamaria Narcisi, "The Postglacial Record of Environmental History from Lago di Pergusa (Sicily)," *Holocene*, XI (2001), 655–671; Sadori et al., "The Last 7 Millennia of Vegetation and Climate Changes at Lago di Pergusa (Central Sicily, Italy)," *Climate of the Past*, IX (2013), 1969–1984; Sadori et al., "Climate, Environment and Society in Southern Italy during the Last 2000 Years: A Review of the Environmental, Historical and Archaeological Evidence,"

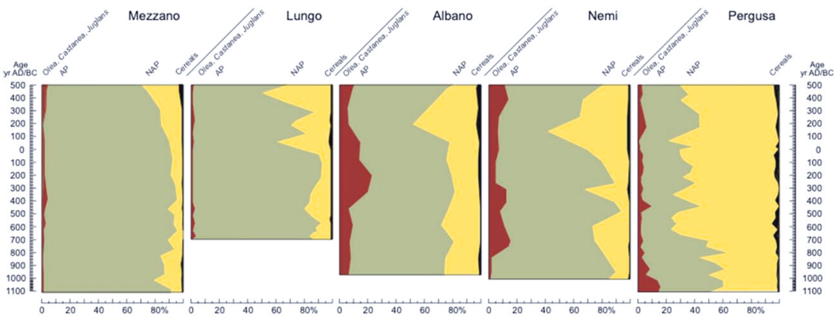
Nonetheless, pollen records remain critical to any reconstruction of Italy's paleoenvironmental history both because of their abundance and their reflection of local human-environmental interactions. Synthesizing a selection of available records revealed the long-term impacts of human activity on vegetation (Figs. 4 and 5; for locations, see Fig. 2). OJC group pollen appeared in late–Bronze Age records from Lago Albano and Lago di Nemi in the Alban Hills. Bronze Age human impact on forest cover also appeared in records from Etruria and the Po plain. The early Iron Age and Archaic period (1000–500 B.C.E.) saw shifts across many Italian pollen records, although the impacts of human activity were neither uniform nor unilinear. Pollen in a marine core from the Sicilian channel records a steady increase in tree cover starting around 700 B.C.E.; in contrast, a record from Lago di Patria in Campania indicate a temporary forest decline corresponding with the founding of Greek colonies such as Cumae.[15]

Lake cores across Etruria, for instance at Lago dell'Accesa and Lago di Mezzano, point to forest clearance during the Iron Age but also shifts from deciduous oaks to olives and OJC pollen, reflecting Etruscan arboriculture and cultivation. Evidence of cereal cultivation appeared in Iron Age samples from several

Quaternary Science Reviews, CXXXVI (2016), 173–188; for pollen and anthropogenic or climatic drivers, see Ralph M. Fyfe et al., "Trajectories of Change in Mediterranean Holocene Vegetation through Classification of Pollen Data," *Vegetation History and Archaeobotany*, XXVII (2018), 351–364; Andrew Bevan et al., "The Changing Face of the Mediterranean: Land Cover, Demography, and Environmental Change: Introduction and Overview," *Holocene*, XXIX (2019), 703–707; for syntheses of Central Italy, see Sadori et al., "Mid-Holocene Vegetation History of the Central Mediterranean," *Holocene*, XXI (2011), 117–129; Katerina Kouli et al., "Regional Vegetation Histories: An Overview of the Pollen Evidence from the Central Mediterranean," in Izdebski and Mulryan, *Environment and Society*, 69–82; Simon Stoddart et al., "Tyrrhenian Central Italy: Holocene Population and Landscape Ecology," *Holocene*, XXIX (2019), 761–775.

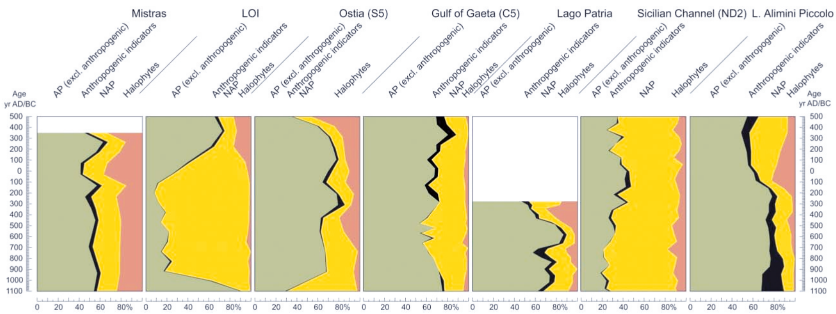
15 Mercuri et al., "A Marine/Terrestrial Integration for Mid–Late Holocene Vegetation History and the Development of the Cultural Landscape in the Po Valley as a Result of Human Impact and Climate Change," *Vegetation History and Archaeobotany*, XXI (2012), 353–372; Carla A. Accorsi et al., "Holocene Forest Vegetation (Pollen) of the Emilia-Romagna Plain, Northeastern Italy," in Franco Pedrotti (ed.), *La vegetation postglaciaire du passé et du présent syngenése* (Berlin, 2004), 110–140; Michelangeli et al., "Three Millennia of Vegetation, Land-Use, and Climate Change in SE Sicily," *Forests*, XIII (2022), 102; Mercuri et al., "The Long History of Cannabis and Its Cultivation by the Romans in Central Italy, Shown by Pollen Records from Lago Albano and Lago di Nemi," *Vegetation History and Archaeobotany*, XI (2002), 263–276; Di Rita et al., "Late Holocene Environmental Dynamics, Vegetation History, Human Impact, and Climate Change in the Ancient Literna Palus (Lago Patria; Campania, Italy)," *Review of Palaeobotany and Palynology*, CCLVIII (2018), 48–61.

Fig. 4 Summary of Terrestrial Pollen Records for the First Millennium B.C.E.



SOURCES See text.

Fig. 5 Summary of Coastal and Marine Pollen Records for the First Millennium B.C.E.



SOURCES See text.

regions, including Etruria, Latium, and areas outside the central Tyrrhenian region, like the Messapian territory, where cereal pollen increased from 600 B.C.E. onward as evidenced in the record from Lago Alimini Piccolo.[16]

16 Michel Magny et al., "Holocene Climate Changes in the Central Mediterranean as Recorded by Lake-Level Fluctuations at Lake Accesa (Tuscany, Italy)," *Quaternary Science Reviews*, XXVI (2007), 1736–1758; Rith Drescher-Schneider et al., "Vegetation History, Climate and Human Impact over the Last 15,000 Years at Lago dell'Accesa (Tuscany, Central Italy)," *Vegetation History and Archaeobotany*, XVI (2007), 279–299; Mariotti Lippi et al., "The Massaciuccoli Holocene Pollen Sequence and the Vegetation History of the Coastal Plains by the Mar Ligure (Tuscany and Liguria, Italy)," *Vegetation History and Archaeobotany*, XVI (2007), 267–277; Sadori, "The Lateglacial and Holocene Vegetation and Climate History of Lago di Mezzano (Central Italy)," *Quaternary Science Reviews*, CCII (2018), 30–44; Di Rita and Magri, "Holocene Drought, Deforestation and Evergreen Vegetation Development in the Central Mediterranean: A 5500 Year Record from Lago Alimini Piccolo, Apulia, Southeast Italy," *Holocene*, XIX (2009), 295–306.

This evidence confirms that pre-Roman populations around the whole of Italy were intensifying the use of local plant resources from an early date. Their efforts responded to settlement change, especially early urbanization, and demographic increase. The overall pattern of progressive increase in human impacts on vegetation characterizes much of the central Mediterranean. In western Sardinia, for example, the pollen record from the Mistras lagoon showed a shift from grape and cereal culture to taxa typical of pasture around 300 B.C.E., before the Roman takeover of that island. A newly published sediment core from the Sarno bath complex just outside the city walls of Pompeii provides the first pollen sequence from the Sarno river floodplain from 900–750 B.C.E. to the eruption of Vesuvius in 79 C.E. Cabbage cultivation was introduced during the city's Samnite period (fourth to second centuries B.C.E.). Planted during summer and harvested in late autumn and winter, this crop was deliberately chosen to suit naturally wet fields, and cabbage cultivation intensified during the city's later Sullan period, after the creation at Pompeii of a Roman colony.[17]

Rome's expansion into a region sometimes corresponded to shifts in vegetation history, although local factors remained influential, and Roman activity is sometimes represented by a subtle intensification of ongoing practices. For example, a marine core from the Gulf of Gaeta in South Latium shows that forest development commenced around 500 B.C.E. and that olive cultivation began around 300 B.C.E., a time of focused Roman interest on the region.[18]

Several studies of the Tiber River estuarine region around the site of Ostia, enable reconstruction of a wide marshland with well-

17 Di Rita and Rita Teresa Melis, "The Cultural Landscape near the Ancient City of Tharros (Central West Sardinia): Vegetation Changes and Human Impact," *Journal of Archaeological Science*, XL (2013), 4271–4282; Cristiano Vignola et al., "At the Origins of Pompeii: The Plant Landscape of the Sarno River Floodplain from the First Millennium BC to the AD 79 Eruption," *Vegetation History and Archaeobotany*, XXXI (2022), 171–186.

18 Di Rita et al., "Late Holocene Forest Dynamics in the Gulf of Gaeta (Central Mediterranean) in Relation to NAO Variability and Human Impact," *Quaternary Science Reviews*, CLXXIX (2018), 137–152; *idem* et al., "Holocene Forest Dynamics in Central and Western Mediterranean: Periodicity, Spatiotemporal Patterns and Climate Influence," *Scientific Reports*, VIII (2018), 8929; *idem* et al., "Climate and Human Influence on the Vegetation of Tyrrhenian Italy during the Last 2000 Years: New Insights from Microcharcoal and Non-Pollen Palynomorphs," *Geografia Fisica e Dinamica Quaternaria*, XLII (2019), 203–214; for the Gulf of Gaeta core C5, see Margaritelli et al., "Marine Response to Climate Changes during the Last Five Millennia in the Central Mediterranean Sea," *Global and Planetary Change*, CXLII (2016), 53–72.

developed sedge and reed swamps throughout much of the first millennium B.C.E. A slight increase in amaranth in the seventh century B.C.E. may reflect early salt extraction. A core (PO1) taken west of Ostia, dated to 403–211 B.C.E. using AMS radiocarbon dating, corresponds to the establishment of the *castrum* at the settlement. Signals of human impact are even clearer in the Imperial Period following the creation of the artificial harbor at Portus in the first century C.E. In this case as elsewhere, Roman impacts on Italian vegetation visible in pollen data from the Republican Period are continuations or amplifications of ongoing trends, rather than abrupt or radical transformations.[19]

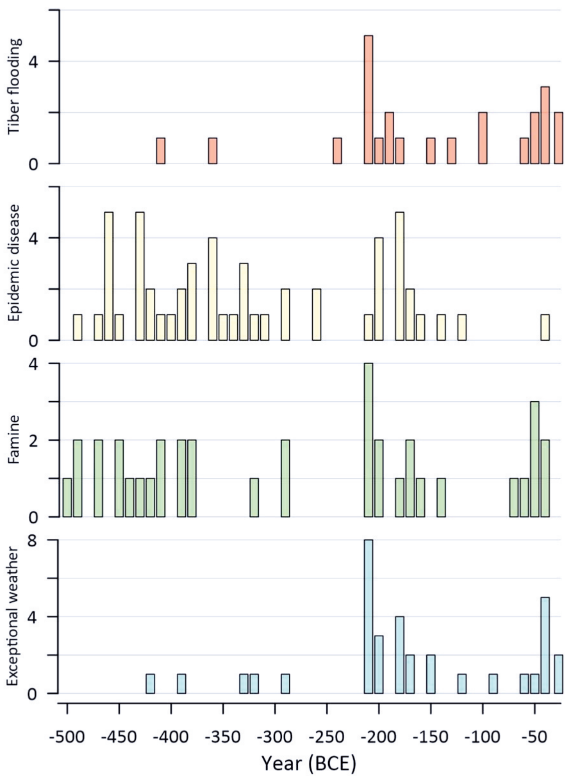
HISTORICAL ARCHIVES Past Mediterranean societies are well known for relatively abundant written information, and such sources often captured details about environmental or climatic shifts in ways that reflected social or cultural attitudes. Thus, information from historical archives occupies a middle ground between observations of environmental trends and evidence for societal responses. Of particular interest is phenological information in histories by authors like Cassius Dio or Livy, who sometimes bracketed discussions of annual events with notices of strange meteorological and natural phenomena.[20]

19 Di Rita et al., "Holocene Environmental Instability in the Wetland North of the Tiber Delta (Rome, Italy): Sea-Lake-Man Interactions," *Journal of Paleolimnology*, XLIV (2010), 51–67; Piero Bellotti et al., "The Tiber River Delta Plain (Central Italy): Coastal Evolution and Implications for the Ancient Ostia Roman Settlement," *Holocene*, XXI (2011), 1105–1116; Jean-Philippe Goiran et al., "Geoarchaeology Confirms Location of the Ancient Harbor Basin of Ostia (Italy)," *Journal of Archaeological Science*, XLI (2014), 389–398; Sadori et al., "Palynology and Ostracodology at the Roman Port of Ancient Ostia," *Holocene*, XXVI (2016), 1502–1512; for early Ostia, see Fausto Zevi, "Appunti per una storia di Ostia repubblicana," *Mélanges de l'École française de Rome—Antiquité*, CXIV (2002), 13–58; Angelo Pellegrino et al., "Un ritrovamento nel c.d. Fiume Morto. Nuove riflessioni su Ostia arcaica," *Mélanges de l'École française de Rome—Antiquité*, CXXX (2019), 269–271.

20 Theophrastus' *On Plants* detailed forests in Latium in the fourth century B.C.E. Starting in the second century B.C.E., a tradition of Roman agronomic literature included works by Cato, Varro, and Columella. Further information is scattered through works like Pliny's *Natural History*. These histories are supplemented by specialized works like Julius Obsequens' book on prodigies, itself epitomizing Livy and other writers. See Elizabeth Rawson, "Prodigy Lists and the Use of the Annales Maximi," *Classical Quarterly*, XXI (1971), 158–169; Catherine Virlouvet, *Famines et émeutes à Rome des origines de la république* (Rome, 1985); Bruce Frier, *Libri annales Pontificum maximorum: The Origins of the Annalistic Tradition* (Ann Arbor, 1999); Steven P. Oakley, *A Commentary on Livy, Books VI–X* (Oxford, 1999), I.

An independent survey of such sources produced an annually resolved record of unusual natural phenomena that is relatively well-preserved from 509 to 293 B.C.E. and from 219 to 12 B.C.E. (Fig. 6). Exceptional weather episodes and Tiber floods were more commonly reported in the second and first centuries B.C.E., the latter of which showed the highest number of Tiber flood attestations of any century in antiquity. These trends might reflect increased wetness also seen in speleothems, discussed above. Reports of famine and pestilence are distributed more evenly, but these phenomena reflect climate in complex ways. Famine, for example, could result from stresses on production caused by drought or environmental conditions but could also arise from institutional

Fig. 6 Attestation of Climate Events in Roman Republican Sources by Decade, 509–27 B.C.E.



SOURCES Cassius Dio, Livy, and Julius Obsequens.

or distributional issues in food supply, from demographic trends, and so forth.[21]

This material's chronological structure is promising, but its integration into historical climate studies is not straightforward. One key challenge is the temporal distance between authors like Livy writing no earlier than the late republic and events occurring sometimes centuries earlier. Information on natural phenomena is assumed to have followed a complex path of transmission originating in now-lost priestly records, which has raised concerns about reliability. Caution is not unwarranted, but there are reasons for optimism. First, it seems certain that Roman priestly archives contained records of meteorological phenomena in Rome and in territory under Roman authority; in the second century B.C.E., Cato differentiated his histories from priestly annals by stating that he did not care to write "how often grain was costly, or how often darkness or whatever obscured the light of the moon or sun." The implication is that priestly annals normally did record harvests and eclipses. Then, circumstantial support for early recording of natural phenomena comes from other Italian societies, particularly Etruria, where fifth-century B.C.E. documents record meteorological information in the framework of the seasonal cycle and calendar. Finally, there are possibilities for independent verification. For example, the record of a solar eclipse in June of the 350th year after the foundation of Rome matched a known eclipse in 400 B.C.E. Additionally, severe outbreak of disease in the 420s B.C.E. attributed to crop failure might be synchronized with a period of global cooling following explosive volcanic eruptions in 430 and 426 B.C.E., documented in ice cores, discussed above.[22]

21 Dates primarily provided by the extant narrative of Livy, continued by Obsequens into the early empire. Simon J. Northwood, "Grain Scarcity and Pestilence in the Early Roman Republic: Some Significant Patterns," *Bulletin of the Institute of Classical Studies*, XLIX (2006), 81–92; John Rich, "Fabius Pictor, Ennius and the Origins of Roman Annalistic Historiography," in Kaj Sandberg and Christopher J. Smith (eds.), *Omnium Annalium Monumenta: Historical Writing and Historical Evidence in Republican Rome* (Leiden, 2018), 15–65; Angela R. Conte, "Per una cronologia degli eventi naturali a Roma dal VII secolo a.C al V secolo d.C." *Traces in Time*, VIII (2019), 1–23; Jane Millar, "Roman Climate Awareness in Pliny the Elder's *Natural History*," *Classical Antiquity*, XL (2021), 249–282; for floods, see Gregory Aldrete, *Floods of the Tiber in Ancient Rome* (Baltimore, 2007).

22 The fragments of Cato are found in Timothy J. Cornell (ed.), *The Fragments of the Roman Historians* (Oxford, 2013); the solar eclipse is noted by Cicero, *On the Commonwealth*, Book I 25. For calendars and environment, see Jean McIntosh Turfa, *Divining the Etruscan World: The Brontoscopic Calendar and Religious Practice* (Cambridge, 2012); Jorg Rüpke, *The Roman Calendar from Numa to Constantine: Time, History, and the Fasti* (London, 2011).

Ultimately, what Roman sources can reveal most directly are not environmental conditions *per se* but shifts in human perceptions and attitudes toward those conditions. The existence of archival records or the emergence of new forms of record-keeping could themselves be read to indicate shifts in societal awareness of environmental instability in Rome.

The function of Republican priestly records means that any inclusion of natural phenomena was due to unusual or exceptional events. Romans and Italians understood such events as divine signs (*prodigia*) forming part of a communication system between humans and gods. Anomalous climate episodes were seen as prophetic indications of future events and prompted religious investigation and response, as in 363 B.C.E. when the Roman historian Livy describes how natural disasters and disease prompted Romans to revive an old expiatory practice of hammering a sacred nail into the wall of the Temple of Jupiter Optimus Maximus. As scholarship on other periods stresses, religious responses to climate change could offer important sources of social cohesion. Specific religious interventions might signal communal recognition of climate variability and collective determination to mitigate them.[23]

HUMAN RESPONSES TO ENVIRONMENTAL CHANGE Integrating scientific, archaeological, and historical evidence yields an understanding of Italy's landscape as both a physical and a sociocultural entity. A landscape's natural parameters affects the way it is used by humans, and vice versa. For example, marginal land could encourage particular modes of utilization, and although climate variability or severe weather could destabilize food systems, cultivation choices also influence how shifts in temperature or precipitation

23 Livy, *From the Foundation of the City,* Book VII, 3. For religious responses to climate, see Haldon et al., "Lessons from the Past, Policies for the Future: Resilience and Sustainability in Past Crises," *Environment Systems and Decisions*, XL (2020), 287–297; Zanchetta et al., "Beyond One-Way Determinism: San Frediano's Miracle and Climate Change in Central and Northern Italy in Late Antiquity," *Climatic Change*, CLXV (2021). In other premodern contexts, dramatic surges in temple building as in Rome in the fourth to second centuries B.C.E. have been linked to changes in precipitation. Indeed, one temple built in the city in the mid-third century B.C.E. was dedicated to the divine personification of bad weather, Tempestas. See Haldon et al., "Demystifying Collapse: Climate, Environment, and Social Agency in Premodern Societies," *Millennium*, XVII (2020), 1–33, esp. 9–11; for temples at Rome, see Padilla Peralta, *Divine Institutions: Religions and Community in the Middle Roman Republic* (Princeton, 2020).

affect productivity. Furthermore, *land* and *landscape* are richly cultural terms with equally strong social, economic, and political implications. Romans felt connected to land; it defined status through ownership, lease, tenancy, or landlessness. Territories were conquered and colonized for land. Land was inherently social, and local histories and people's identities were inextricably embedded in the landscape.[24]

Bioarchaeology Bioarchaeological work on carpological remains or wood artifacts from wells, votive deposits, tombs, ships, domestic and other spaces used for food preparation, consumption, or storage has revealed that new food items reached Italian consumers during the late years of the republic. In addition to native plants used for food (like grape, olive, fig, walnut, hazelnut, chestnut, and dogwood), there were exotic species (peach, date palm, melon, lemon, cedar, coriander, cumin, and sesame). Often associated with elite consumers, however, these foodstuffs likely had less impact on agricultural choices or land use patterns.[25]

Plant and animal remains from archaeological sites have shown that main species of staple crops and livestock in the Republican Period were essentially the same as in the Bronze Age: cattle, sheep, goats, pigs, hulled and naked wheats, barley, millet, emmer, fava beans, peas, and lentils. A diverse repertoire of plants continued to be cultivated, and no major change in crop choice was associated with Roman expansion (there was a decrease in hulled wheat, but the representation of free-threshing wheat in the archaeological record remained largely unchanged). Diversity

24 Alain Bresson, "Fates of Rome," *Journal of Roman Studies*, CX (2020), 233–246; Frits Heinrich and Annette Hansen, "A Hard Row to Hoe: Ancient Climate Change from the Crop Perspective," in Erdkamp, Manning, Verboven, *Climate Change and Ancient Societies*, 25–80; for the social dimensions of land, see Keith Basso, *Wisdom Sits in Places: Landscape and Language Among the Western Apache* (Albuquerque, 1996); Peter Geschiere, *Perils of Belonging: Autochthony, Citizenship, and Exclusion in Africa and Europe* (Chicago, 2009).

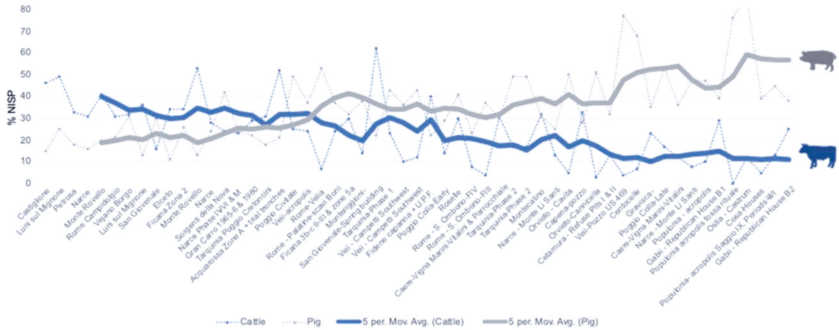
25 Lodwick and Erica Rowan, "Archeobotanical Research in Classical Archaeology," *American Journal of Archaeology*, MXXVI (2022), 593–623; Emilia Allevato et al., "Pollen-Wood Analysis at the Neapolis Harbour Site (1st–3rd century AD, Southern Italy) and Its Archaeobotanical Implications," *Journal of Archaeological Science*, XXXVII (2018), 2365–2375; Mariotti Lippi et al., "The Botanical Record of Archaeobotany Italian Network—BRAIN: A Cooperative Network, Database and Website," *Flora Mediterranea*, XXVIII (2018), 365–374; Clemènce Pagnoux et al., "The Introduction of *Citrus* to Italy, with Reference to the Identification Problems of Seed Remains," *Vegetation History and Archaeobotany*, XXII (2013), 421–438; Sadori et al., "The Introduction and Diffusion of Peach in Ancient Italy," in Jean-Paul Morel and Mercuri (eds.), *Plants and Culture: Seeds of the Cultural Heritage of Europe* (Bari, 2019), 45–61.

in crop types allowed for more than one annual harvest and guarded against seasonal variations in temperature or rainfall; crop rotation and/or bare fallowing helped to maintain or improve soil productivity. Much about the practices of arable agriculture remains obscure, and future work might explore regional or temporal differences in approaches to similar crops.[26]

Zooarchaeological evidence suggests several waves of change in the productive use of core species. First, increases in livestock body size were documented as early as the transition from the Bronze to Iron Age with continued increases over the first millennium B.C.E. and into the Imperial Period. Second, the relative importance of the main types of livestock shifted. Pig production expanded dramatically in central Italy and the southern Po plain, and by the final centuries B.C.E., poultry farming was more widely adopted. Species abundance patterns resembling later imperial strategies appear to emerge in the second to first centuries B.C.E. Zooarchaeologists have repeatedly correlated these developments with changes in socioeconomic organization, particularly urbanization and demographic growth, greater connectivity, and increased focus on surplus production (Fig. 7). Expansion in the production of pigs and poultry in particular points to interest in flexible, fast-maturing food that could be raised in a variety of environments throughout the year. This reconfiguration of animal

26 For synthesis of bioarchaeological material, see Trentacoste and Lodwick, "Republican Agriculture and Animal Husbandry in Context: Towards an Agroecology of the Roman Expansion," in Bernard, Lisa Mignone, and Padilla Peralta (eds.), *Making the Middle Republic: New Approaches to Rome and Italy, 400–200 B.C.E.* (Cambridge, 2023); Laura Motta and Katherine Beydler, "Agriculture in Iron Age and Archaic Italy" in David Hollander and Timothy Howe (eds.), *A Companion to Ancient Agriculture* (Hoboken, 2020), 299–415; Jacopo De Grossi Mazzorin and Claudia Minniti, "Changes in Lifestyle in Ancient Rome (Italy) across the Iron Age/Roman Transition: The Evidence from Animal Remains," in Umberto Albarella et al. (eds.), *The Oxford Handbook of Zooarchaeology* (Oxford, 2017); Girolamo Fiorentino et al., "Le colture agricole in Italia nel corso del'età del Bronzo: Sintesi dei dati e linee di tendenza," in Daniela Cocchi Genick (ed.), *L'età del Bronzo Recente in Italia. Atti del Congresso nazionale di Lido di Camaiore, 26–29 ottobre 2000* (Viareggio, 2004); Milena Primavera et al., "Environment, Crops and Harvesting Strategies during the II Millennium BC: Resilience and Adaptation in Socio-Economic Systems of Bronze Age Communities in Apulia (SE Italy)," *Quaternary International*, CDXXXVI (2017), 83–95; Kim Bowes et al., "Peasant Agricultural Strategies in Southern Tuscany: Convertible Agriculture and the Importance of Pasture," in de Haas and Tol, *The Economic Integration of Roman Italy*, 170–199; for wheat, see Heinrich, "Modelling Crop Selection in Roman Italy: The Economics of Agricultural Decision Making in a Globalizing Economy," in *ibid.*, 141–169.

Fig. 7 Relative Abundance of Pig and Cattle Remains Expressed as Percentage of Number of Identified Specimens (NISP) from Cattle, Sheep/Goat, and Pigs from the Middle Bronze Age to First Century B.C.E.



SOURCE Trentacoste and Lodwick, "Republican Agriculture and Animal Husbandry in Context: Towards an Agroecology of the Roman Expansion," in Bernard, Lisa Mignone, and Padilla Peralta (eds.), *Making the Middle Republic: New Approaches to Rome and Italy, 400–200 B.C.E.* (Cambridge, 2023), 164–190.

production created a supply for urban markets of meat that could be produced without arable land.[27]

Settlement Patterns and Changes in Land Use Great attention has been paid to the emergence in republican Italy of elite villas presumed to have drawn upon newly available slave labor-forces. The villa economy was limited to regions such as the suburb around Rome or parts of Etruria, where villas often occupied well-watered and arable sites. Their appearance thus rarely implied expansion onto marginal land but more often represented the enlargement of preexisting settlement in response to changing markets.[28]

In terms of potential relationship to environmental change, more pertinent seems the phenomenon of rural infilling (the increasing density across the Italian landscape of material culture

27 Trentacoste et al., "New Trajectories or Accelerating Change? Zooarchaeological Evidence for Roman Transformation of Animal Husbandry in Northern Italy," *Archaeological and Anthropological Sciences*, XIII (2021), 25; Trentacoste, Ariadna Nieto-Espinet, and Silvia Valenzuela-Lamas, "Pre-Roman Improvements to Agricultural Production: Evidence from Livestock Husbandry in Late Prehistoric Italy," *PLOS ONE*, XIII (2018), available at doi .org/10.1371/journal.pone.0208109; De Grossi Mazzorin and Minniti, "Changes in Lifestyle in Ancient Rome"; Trentacoste, "Fodder for Change: Animals, Urbanisation, and Socio-Economic Transformation in Protohistoric Italy," *Theoretical Roman Archaeology Journal*, III (2020).

28 Terrenato and Jeffrey Becker (eds.), *Roman Republican Villas* (Ann Arbor, 2011).

scatters suggestive of human activity), which can signify intensifying land use. This change, probably in combination with demographic increase, has been linked with climate change in other periods. Further research is needed to determine the degree to which demographic growth drove changes in rural land use in Italy during the Roman expansion; because the visibility of any given site primarily indicates the use of a class of material at any given time rather than a change in demographic density, a model contextualizing survey results within wider networks distributing building materials or ceramics to rural locales would enhance our understanding of how rural infilling reflected population growth in the countryside.[29]

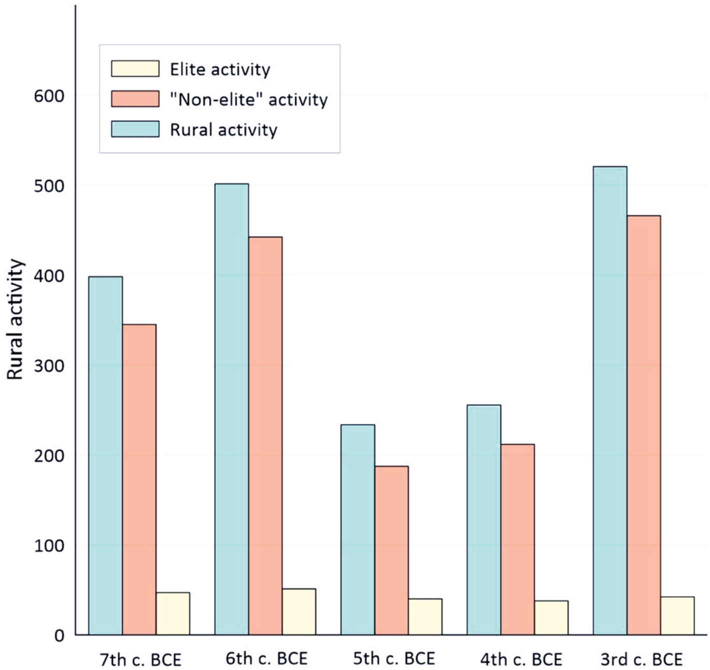
The first systematic field surveys in central Italy revealed a rise in and increased dispersion of rural ceramic scatters dated to the fifth to second centuries B.C.E. These trends were interpreted as the appearance of new, small farm sites linked with Roman territorial expansion, with Rome given primary agency in the change in the landscape. However, synthesis and reanalysis of data from nineteen field surveys and around 2,500 sites from Latium and Etruria during the period 700–200 B.C.E. argues against direct causal links between ceramic scatters and Roman expansion. Instead they suggest landscape transformation driven by fluctuations in exchange networks. These networks related to the distribution of materials that remain archaeologically visible like tile or ceramics and presumably also activities within the landscape like agriculture, ranching, or other productive activities affected by environmental shifts (see Fig. 8). Across Tyrrhenian central Italy, survey data point toward significant growth in rural activity between 500 and 200 B.C.E.[30]

Close examination of each survey suggests that local and regional exchange networks, as well as patterns of material production and consumption across the social spectrum, played significant roles in turning sites "on" or "off" in the landscape. Although the increase in the number of sites took place against a backdrop of aggregate demographic growth, survey results must be understood

29 For demography and climate, see Bevan et al., "Holocene Fluctuations in Human Population Demonstrate Repeated Links to Food Production and Climate," *Proceedings of the National Academy of Sciences* (2017), available at doi.org/10.1073/pnas.1709190114.

30 For a list of surveys considered, see Samuels, "Recovering Rural Non-Elites: Commoner Landscapes and Rural Infill in the Roman Middle Republic," unpub. Ph.D. diss. (Univ. of Michigan, 2019).

Fig. 8 Rural Activity in Central Italy from the Seventh to Third Centuries B.C.E.



SOURCE Samuels, "Recovering Rural Non-Elites: Commoner Landscapes and Rural Infill in the Roman Middle Republic," unpub. Ph.D. diss. (Univ. of Michigan, 2019).
NOTE The chart displays weighted averages. Sites were classified as elite or non-elite based on size and the presence of luxury goods and certain building materials.

primarily as reflections of patterns in the production and consumption of durable material culture.[31]

Evidence for rural activity in most regions indicates long-term continuity to some degree from the seventh and sixth centuries B.C.E., when ceramic scatters were often closely associated with nucleated settlements or elite sites. Nucleation afforded control over production and consumption, especially for archaeologically visible materials like roof tiles and ceramics. Elite sites, located in centralized or more visible locations, dominated exchange mechanisms and shaped the distribution of material culture. During this early period, non-elite sites were either invisible to field survey or tied to elite

31 For the relationship between surface scatters, subsurface archaeology, and demography, see Bowes, *The Roman Peasant Project, 2009–2014: Excavating the Roman Poor* (Philadelphia, 2021).

groups. The fifth and fourth centuries B.C.E. saw fewer total sites across material classes and consumption types. Because ceramics dated to this period were less diagnostic or missing entirely, this decrease in rural sites was associated with patterns of material change.[32]

Rural activity that was mostly invisible in the fifth and fourth centuries B.C.E., and possibly also in the seventh and sixth, became visible in the third century B.C.E. This trend was especially true at sites that were not clearly elite. Surveys suggest movement from nucleated areas to areas closer to rural production such as fields, forests, or groves, with increased activity in areas identified as marginal land. Evidence suggested more intensive production or exploitation of new resources, while dispersed material culture suggested more permanent investment in activities across landscape types. These changes are often hard to correlate with the timing of Roman conquest, militating against interpretations of direct Roman interference. Furthermore, the trend of rural infilling in the later first millennium B.C.E. was not limited to Italy but appears across the Mediterranean, although the timing of rural settlement change becomes even more variable on wider geographical scales.

Etruria Case Study. This picture of an Italian landscape in which Roman interventions encountered long-term dynamics matches trends in the pollen data discussed above. The idea may be further enriched by taking one area of Roman expansion as a case study. Archaeological and paleoenvironmental data from Etruria show intensive pre-Roman human management of the landscape, including attempts to raise the marginal return on agricultural production from the early Iron Age. From this same date, Etruscan interests in fuel production for metallurgical activities implies conscious preference for particular tree species, which impacted local forest cover.[33]

32 Cf. Helen Patterson, *Bridging the Tiber: Approaches to Regional Archaeology in the Middle Tiber Valley* (Rome, 2004).

33 For the environmental history of Etruria, see Sadori et al., "Archaeobotany in Italian Ancient Roman Harbours," *Review of Palaeobotany and Palynology*, CCXVIII (2015), 217–230; David Kaniewski et al., "Holocene Evolution of Portus Pisanus, the Lost Harbour of Pisa," *Scientific Reports*, VIII (2015), 1–14; Mauro Buonincontri et al., "The Problem of the Alternating Dominance of Deciduous and Evergreen Vegetation: Archaeo-Anthracological Data from Northern Maremma," *Annali di Botanica*, III (2018), 165–171; Mariotti Lippi et al., "Plant Remains in an Etruscan-Roman Well at Cetamura del Chianti, Italy," *Archaeological and Anthropological Sciences*, XII (2020), 1–18; for early charcoal selection and the impact of fuel use legible in the pollen record, see Mariotti Lippi et al., "Studi sulla vegetazione attuale e passata della Toscana meridionale (Follonica—Italia) e considerazioni sull'impatto ambientale dell'attività metallurgica etrusca nel VI—V secolo a.C.," *Webbia*, LV (2013), 279–295.

Following Etruria's conquest in the fourth and third centuries B.C.E., Romans reshaped the region's landscape by creating new colonies—accompanied by port installations, canals, and roads and by reclaiming swampy areas for agricultural purposes. The intensive transformation of nutrient-poor soils into arable land in some cases allowed for fuller exploitation of conquered territory.

Rome's expansion of existing human activity in Etruria is encapsulated by the harbor of Pisa, San Rossore. This site, discovered in 1998, represents a remarkably well-preserved fluvial wharf where ships arrived in Pisa from the sea and from inland sites located along a network of canals. The wharf sat along the Arno River a few kilometers from the ancient coastline, a major communication route linking the interior to the coast. Data from the site and the Pisa plain suggest unstable environmental conditions with frequent floods of the Arno during the Roman period, with high flood frequency especially in the second century B.C.E. This trend, which is comparable to the record of Tiber flooding in Rome, is perhaps linked with the wet phase visible in speleothems discussed above. Repeated flooding only prompted a small shift of harbor activities northward, but the general location of the port was largely maintained from the previous period. Rather than any extreme discontinuity of practice, the Roman period brought an intensification of previous efforts to maintain the site's location despite environmental adversity; this is, in short, an indication of increasing resilience.[34]

Marginal Land Roman investment in resilience and infrastructure emphasized the interaction between social and biophysical forces, which is especially apparent in the exploitation of marginal land, or the land that is considered least profitable of all potentially productive land in an area. Such land is crucial for climate history because it is already on the cusp of viability and thus most likely to experience threshold changes based on minor contextual modifications. The addition of marginal land could be

34 Marco Benvenuti et al., "Late-Holocene Catastrophic Floods in the Terminal Arno River (Pisa, Central Italy) from the Story of a Roman Riverine Harbour," *Holocene*, XVI (2006), 863–876; Mariotti Lippi et al., "Pollen Analysis of the Ship Site of Pisa San Rossore, Tuscany, Italy: The Implications for Catastrophic Hydrological Events and Climatic Change during the Late Holocene," *Vegetation History and Archaeobotany*, XVI (2007), 453–465; Benvenuti et al., "Floods, Mudflows, Landslides: Adaptation of Etruscan-Roman Communities to Hydrogeological Hazards in the Arno River Catchment (Tuscany, Central Italy)," in I. Peter Martini and Ward Chesworth (eds.), *Landscapes and Societies* (Dordrecht, 2010), 187–201.

of great importance to the productive portfolio of individual households, and in Roman republican society, shifts could also have aggregate political impact by affecting the overall pool of landowners in a society. In the framework of the Republican census, Roman citizens were classified according to whether they owned land and according to that land's quantity and quality; voting privileges and tax burdens were affected by valuations of potential productivity. Decisions to cultivate marginal land could alter the state's tax base, increase registered landowners (*assidui*), or enfranchise landless Romans. Decisions about marginal land could therefore reconfigure the electoral balance or the pool of manpower available for conscription. Thus, to the extent that it affected land profitability, climate could have had sociopolitical effects in Republican Italy at both the household and state levels.[35]

Climate impacted decisions about whether or how to use marginal land. Lo Cascio and Malanima suggest that one degree of warming raised the altitude threshold of wheat cultivation by 100–200 m in mountainous areas like Italy's Apennines due to longer growing seasons and rarer frosts. Further aspects such as gradient, vegetation, erosion, water availability, and so forth, could also affect this rule. Climate change could alter productivity by drying wetlands or mitigating aridity, thereby improving an area's suitability for profitable production. Alongside biophysical forces were human factors such as crop choices and selection, technology and capital investment, perishability and storage, access to markets, and so on. The effects of biophysical factors often depended on the range of options available to households to diversify, store, or redistribute. The historical impact of climatic change could thus be mitigated or intensified by the capacity of human actions in response.[36]

35 For the social and economic dimensions of marginality, see Jacob H. Hollander, "The Concept of Marginal Rent," *Quarterly Journal of Economics*, IX (1895), 175–187; Shujiang Kang et al., "Marginal Lands: Concept, Assessment and Management," *Journal of Agricultural Science*, V (2013), 129–139; for the historical relationship between landholding and citizenship in the Roman Republic, see Roselaar, *Public Land in the Roman Republic*.

36 Lo Cascio and Paolo Malanima, "Cycles and Stability: Italian Population before the Demographic Transition (225 B.C.–A.D. 1900)," *Rivista Di Storia Economica*, XXI (2005); Hin, *The Demography of Roman Italy*; William V. Harris, "Marginal Land and Population Pressure in the Ancient Mediterranean, 800 BC to 600 AD," *Historia*, LXXVII (2018), 390–417; Erdkamp, "Climate Change and the Productive Landscape in the Mediterranean Region in the Roman Period," in Erdkamp, Manning, Verboven, *Climate Change and Ancient Societies*.

Paleosols Micromorphological analysis of paleosols (old land surfaces rapidly buried and then left undisturbed) can reveal if their soil had been plowed. A consistent distribution of small charcoal fragments may suggest certain components were deliberately and regularly introduced. Such fragments are interpretable as evidence of burning off stubbles and other crop remains that were then plowed into the soil to enrich phosphate content and increase yields. Similarly, manuring is detectable through chemical analysis by measuring phosphates or by studying pottery fragments included in manure scattered over soil.[37]

An unusually large (20 m by 10 m) plowed paleosol was excavated in 2017 from the Terralba district directly adjacent to the Punic farm of Pauli Stincus in western central Sardinia. The association with the Punic farmhouse and thirty-four diagnostic sherds found in the plow soil date it to the third or second century B.C.E. Archaeological, micromorphological, and paleobotanical analyses suggested the field, while not very large, was intensively worked and possibly irrigated for crops like vegetables or pulses.[38]

However fragmentary Italian society was on the eve of Roman expansion, the complexity of the rural economy of Punic Sardinia emphasized by the excavations at Pauli Stincus indicate a connectedness of economy and society that was sufficient to drive some level of adaptation and change. This complexity meant that

37 Hans Kamermans, "Land Evaluation as Predictive Modelling: A Deductive Approach," in Gary Lock (ed.), *Beyond the Map: Archaeology and Spatial Technologies* (Amsterdam, 2000), 124–146; Esther van Joolen, "Potential Land Evaluation in Archaeology," in Peter Attema et al. (eds.), *New Developments in Italian Landscape Archaeology: Theory and Methodology of Field Survey, Land Evaluation and Landscape Perception, Pottery Production and Distribution* (Oxford, 2002), 185–209.

38 Enrique Díes Cusí, van Dommelen, and Carlos Gómez Bellard, "Excavaciones en la granja púnica de Pauli Stincus (Terralba, Cerdeña)," *Saguntum*, XLII (2011), 123–127; Cristiano Nicosia et al., "Land Use History and Site Formation Processes at the Punic Site of Pauli Stincus in West Central Sardinia," *Geoarchaeology*, XXVIII (2013), 373–393; van Dommelen et al., "An Agricultural Field of Hellenistic Date at Pauli Stincus, Terralba (Sardinia)," *Antiquity*, XCII (2018), 365. Although its dates straddle the Roman political takeover of Sardinia, the site remains culturally Punic; see van Dommelen, "Punic Persistence: Colonialism and Cultural Identity in Roman Sardinia," in Joanne Berry and Ray Laurence (eds.), *Cultural Identity in the Roman Empire* (London, 1998), 25–48. For the visibility of manuring in the ceramic record, see Susan Alcock, John Cherry, and Jack Davis, "Intensive Survey, Agricultural Practice and the Classical Landscape of Greece," in Ian Morris (ed.), *Classical Greece: Ancient Histories and Modern Archaeologies* (Cambridge, 1994), 137–170; Hamish Forbes, "Off-Site Scatters and the Manuring Hypothesis in Greek Survey Archaeology: An Ethnographic Approach," *Hesperia*, LXXXII (2013), 551–594.

the impact of environmental change was rarely straightforward or direct. A hallmark of this complex agrarian world was intensification. The proliferation of dispersed rural settlement detectable through survey archaeology, as described above, evinced that same process across Italy, and a case study of a site like this offers a window onto how such intensification was achieved.[39]

HISTORICIZING RESILIENCE Recently developed methodologies enable us to reconstruct the adaptation of pre-Roman people to their ecological settings in considerable detail. The detailed study of Rome's intervention in this already complex world affords the possibility of historicizing an important example of building societal resilience to environmental risk. *Resilience* refers to the ability of a system to withstand disturbance. All the elements of this definition—resilience, disturbance, and system—should be seen as historically specific. By using the term *resilience* here, we mean the ability of Italian societies to maintain their structure or their trajectory of development in the face of environmental unpredictability. Societies created resilience primarily through capital investments and through increased connectedness—that is, by extending networks across multiple ecologies. Such adaptations made Italian communities more resilient, but they also introduced new elements with sometimes unexpected results.[40]

Managing Water Supplies The ways in which Italian communities and the wider society managed food and water supplies can show how they improved their resilience to climate variability and how Rome intervened in long-term human-environment relationships. The later first millennium B.C.E. saw considerable innovations in Italian hydraulic technology, and the resulting building projects were attempts to improve water security through capital investments. In the Pontine region, state investment relating to the construction of the Via Appia in 312 B.C.E. led to the development of a system of canals to drain a marshy landscape and create arable land for incoming colonists. Rome's own aqueducts formed part of this history as impressive, innovative infrastructure requiring

39 For ethnographic and historical study of Italian landscapes, see Emilio Sereni, *Storia del paesaggio agrario italiano* (Bari, 1961); Anthony H. Galt, *Far from the Church Bells. Settlement and Society in an Apulian Town* (Cambridge, 1991).

40 For an introduction to resilience, see Lance H. Gunderson, Craig Allen, and C. S. Holling, *Foundations of Ecological Resilience* (Washington, D.C., 2009).

considerable resources to build and maintain. Ancient sources directly link Rome's first aqueducts to conquest, suggesting they were financed by war spoils.[41]

Imperialism thus could have had an impact on how communities configured their relationship to local water resources. At the same time, many developments in the period of Roman expansion related to earlier and longer term processes of human adaptation. Rome's own early urban drainage system, the sixth-century B.C.E. "great sewer" (*cloaca maxima*), closely resembled the system of the Greek city of Cumae. Rome was one of many urban sites in central and southern Italy developing hydraulic infrastructure by the Archaic period. Roman hydrological management of the Pontine landscape also finds precedent in largescale projects in the hinterlands of Kamarina or Metapontum by the fifth century B.C.E., where local hydrology or bradyseism (fluctuations in the earth related to hydrothermal activity) caused instabillity in water availability.[42]

An inscription known as the *Sententia Minuciorum* (117 B.C.E.), on a bronze tablet found in Serra Riccò in Liguria, describes the Roman senate's legal settlement of a boundary dispute in the Polcevera Valley between the communities of the Viturii and Genuantes. The Latin text contains a lengthy catalog of local names for streams, water courses, and waterworks, knitting together imperial concerns with specific regional knowledge. Such close topographical awareness reveals iterative attempts by these communities to manage their water resources. The surrounding region of Liguria was an archetypal high-risk environment prone to erosion and flooding because of mountainous terrain and centuries of deforestation. Pollen data suggest landscape degradation during the second century B.C.E., which compelled rural communities to mitigate risk of waterlogging while impounding water for their own purposes. At Mogge di Ertola in the Aveto Valley, pollen records reveal decreased tree cover around 200–150 B.C.E.

41 For the Pontine, see Kevin Walsh, Attema, and de Haas, "The Pontine Marshes (Central Italy): A Case Study in Wetland Historical Ecology," *Babesch*, LXXXIX (2014), 27–46. For water management and empire, see Nicholas Purcell, "Rome and the Management of Water: Environment, Culture, and Power," in Graham Shipley and John B. Salmon (eds.), *Human Landscapes in Classical Antiquity: Environment and Culture* (London, 1996), 180–212.

42 Elisabetta Bianchi and Matteo D'Acunto (eds.), *Opere di regimentazione delle acque in età arcaica* (Rome, 2020).

Around the same time, local inhabitants dammed and drained a water basin, sealing it with a layer of clay and diverting nearby streams. Comparable small-scale manipulations of local water systems appeared in other valleys of the Ligurian Apennines. The impulse behind this activity stemmed from communities' desires to confront variable water ecologies around the time of Rome's Ligurian campaigns in the early second century B.C.E.[43]

Expansion and integration could raise demand for water, which intensified local conflicts in situations of fragile hydraulic resources. For example, Roman armies entering the Aosta valley in 140 B.C.E. encountered an ongoing feud between the Salassi and the city of Vercellae. The Greek geographer Strabo described how the diversion of water from the Dora Baltea to the Salassi's gold washing operations negatively affected downstream irrigation; the situation led to violent conflict settled only by Roman intervention. The situation was likely caused by a changing landscape. Recent research reveals how the Dorea Baltea basin was characterized by heavy floods and rains between 200 B.C.E. and 150 C.E., probably linked to glacial retreat near the river's Alpine sources. These factors in tandem with heightened sedimentation pushed the confluence between the Dora Baltea and the Po rivers 10 km westward, creating a series of new riverbeds and terraces. Rising demand for precious metal exacerbated an already precarious situation, driving conflict.[44]

The most obvious way that imperialism affected adaptations was through capital investment. In some cases, the Roman state directly invested in Italian hydraulic infrastructure, although always with a good awareness of the parameters and capabilities

43 The *Sententia Minuciorum* is published in Theodor Mommsen et al. (eds.), *Corpus Inscriptiones Latinarum* (Berlin, 1918), I, n. 584. Maria Angela Guido et al., "A Palynological Contribution to the Environmental Archaeology of a Mediterranean Mountain Wetland (North West Apennines, Italy)," *Holocene*, XXIII (2013), 1517–1527; Bruna Ilde Menozzi et al., "A Non-pollen Palynomorphs Contribution to the Local Environmental History in the Ligurian Apennines: A Preliminary Study," *Vegetation History and Archaeobotany*, XIX (2010), 503–512. Liguria is not the only region where community-based responses are visible; a new study of the Po Delta reaches similar conclusions: James Page, "Riverbed, Banks and Beyond: An Examination of Roman Infrastructure and Interventions in Response to Hydrological Risk in the Po-Venetian Plain," *Papers of the British School at Rome*, XC (2022), 1–30.

44 Strabo, *Geography*, Book IV, 7; Claudio Giraudi, "The Climate-Triggered Western Shift of the Confluence between the Dora Baltea and Po Rivers (North-Western Italy) during the Late Holocene," *Holocene*, XXIX (2019), 432–444.

of a site's hydraulic resources. The location of the Latin colony of Cosa, founded in 273 B.C.E. on a hilly outcrop along the Etruscan coast, provided military advantages but lacked natural water sources, with only modest annual rainfall (460–560 mm). The solution was the construction of paved and slightly canted surfaces; conduits directed seasonal runoff into several large reservoirs. Cosa's story was not one of investment in adaptation leading to unstinted success, but rather shows the difficulty of overcoming scarce hydraulic resources even with state-level investment. The colony initially struggled to maintain its population, requiring a supplement of colonists in the early second century B.C.E. In the end Cosa's system sustained basic needs and eventually supported a thermal bath complex by the early empire.[45]

Large cisterns at other colonial sites reveal a similar pattern of state investment combined with the more continuous or long-term need to build resilience in the face of seasonal and episodic periods of water glut or shortage. At Segni, a sixth-century Roman colony resettled in 495 B.C.E., excavations revealed a monumental cistern dating to the later second century B.C.E. that replaced a previous system of smaller cisterns. In Apulia, the remarkable network of basins and conduits known as the *vasche limarie* of the old Messapian settlement of Brundisium, the site of a Roman colony around 244 B.C.E., showed three phases of expanding configuration, from a modest system of wells and pipelines of the third century B.C.E. to a fully-fledged distribution network by the second century C.E. In these cases, the creation of monumental cisterns around the time of colonial foundation represented important moments in the history of each site's struggle against water fragility, but the elaboration of urban water supplies was always more temporally expansive. Within Roman Italy, investments in local systems of water supply could provide for urban expansion, but the system never became resilient to the point of alleviating concerns over water.[46]

The Development of Food Storage and Distribution The last centuries of the first millennium B.C.E. were formative for Italy's food system. The use of large ceramic containers for household storage

45 De Giorgi, "Sustainable Practices? A Story from Roman Cosa (Central Italy)," *Journal of Mediterranean Archaeology*, XXXI (2019), 3–26.

46 Letizia Ceccarelli et al., "Il Segni Project: prima campagna di scavo," *Lazio e Sabina*, X (2014), 177–183.

went back well into the prehistoric period. A survey of multipurpose storage jars called *pithoi* shows how food storage was closely entangled with arable agriculture and urbanism from eighth to fifth centuries B.C.E. Thanks to their insulating properties, *pithoi* expanded carrying capacity by conserving food. Storerooms, in some cases purpose-built to host one or more *pithoi*, were constructed at various sites during the Iron Age.[47]

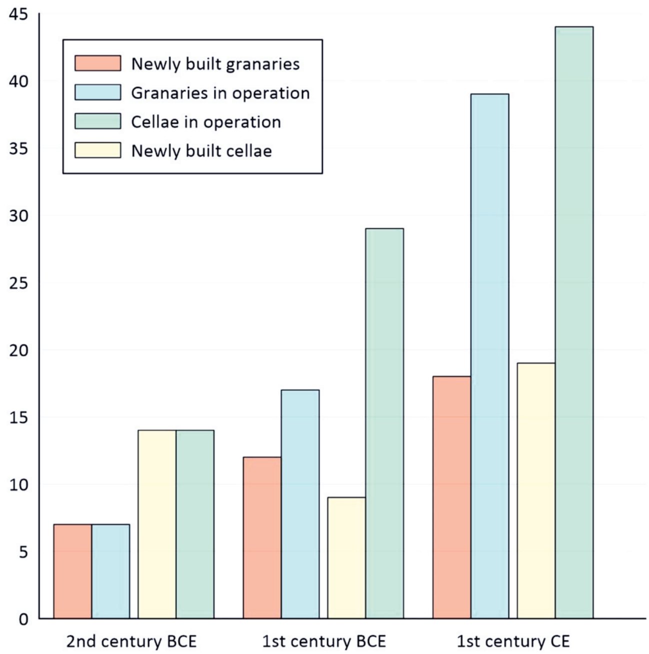
Grain, wine, and olive oil, the three main components of the Mediterranean diet, were readily storable and exchangeable commodities but were nonetheless susceptible to processes of deterioration. Containers and warehouses protected foodstuffs against bad harvests or pests, and against historical forces like warfare, shifting labor supplies, or property ownership. Storage facilities and implements became more archaeologically visible and specialized over the final three centuries B.C.E. Distinct storerooms appeared in rural estates from the second century B.C.E. The earliest granaries, built separately from or on the edge of villas, featured central rows of piers or pillars to divide rooms internally or support upper stories. These were somewhat smaller storerooms, perhaps reflecting a strategy to disperse stored grain across different spaces to mitigate risk. Storage facilities increased, and the total of storerooms in operation during the first century C.E. is almost sixfold more than those in the second century B.C.E. and more than double the first century B.C.E. (see Fig. 9).[48]

Bulk liquid storage of wine and oil became more specialized at rural sites over the same period. From the second century B.C.E., the use of *dolia*, large ceramic jars specifically designed for wine production, grew drastically at elite rural sites in central Italy. Their placement spoke to increased specialization of farming processes, and storerooms with *dolia* (*cellae*) were often connected to pressing rooms. The number of *cellae* in operation doubled from

47 Sara Neri (ed.), *Tecniche di conservazione e forme di stoccaggio in area tirrenica e Sardegna, Officina Etruscologia* (Rome, 2014); Phil Perkins, "The Etruscan *Pithos* Revolution," in Margarita Gleba (ed.), *Making Cities: Economies of Production and Urbanization in Mediterranean Europe, 1000–500 BC* (Cambridge, 2020), 237–258.

48 Annalisa Marzano, *Roman Villas in Central Italy: A Social and Economic History* (Leiden, 2007); Astrid van Oyen, "The Moral Architecture of Villa Storage in Italy in the 1st c. B.C.," *Journal of Roman Archaeology*, XXVIII (2015), 97–124; *idem*, *The Socio-Economics of Roman Storage: Agriculture, Trade, and Family* (Cambridge, 2020), 19–57; Vincenzo Pellegrino, "Granai e spazi per lo stoccaggio e per il trattamento dei cereali nelle villae rusticae vesuviane," *Mélanges de l'École française de Rome—Antiquité*, CXXIX (2017).

Fig. 9 Granaries and *Cellae* Built and in Operation in Italy, c. 200 B.C.E.–100 C.E.



SOURCES Annalisa Marzano, *Roman Villas in Central Italy: A Social and Economic History* (Leiden, 2007); Astrid van Oyen, "The Moral Architecture of Villa Storage in Italy in the 1st c. B.C.," *Journal of Roman Archaeology*, XXVIII (2015), 97–124; *idem*, *The Socio-Economics of Roman Storage: Agriculture, Trade, and Family* (Cambridge, 2020), 19–57; Vincenzo Pellegrino, "Granai e spazi per lo stoccaggio e per il trattamento dei cereali nelle villae rusticae vesuviane," *Mélanges de l'École française de Rome—Antiquité*, CXXIX (2017).

second to first centuries B.C.E. and almost doubled again in the following century. The number of *dolia* in use increased more than sevenfold from second to first centuries B.C.E., from 14 to 103.[49]

Food storage was critical in urban areas, too, where increasingly specialized infrastructures and technologies appeared over the later first millennium B.C.E. In major cities like Ostia and Rome,

49 Cheung, "Precious Pots: Making and Repairing Dolia," in Helle Hochscheid and Ben Russell (eds.), *The Value of Making: Theory and Practice in Ancient Craft Production* (Brepols, 2021); Charlotte Carrato and Francesca Cibecchini (eds.), *Nouvelles Recherches sur les* Dolia. *L'exemple de la Méditerranée nord-occidentale à l'époque romaine (Ier s. av. J.-C.–IIIe s. ap. J.-C.)* (Montpellier, 2020).

storehouses for grain and other goods by the late Republican Period featured multiple rooms with thick, insulating walls, raised floors, and small windows for ventilation.[50]

By the last two centuries B.C.E., converging trends facilitated a robust Italian food supply operating on unprecedented scales. At the same time, Roman agronomic treatises were stabilizing productive knowledge, the reorganized Roman calendar facilitated interregional coordination, and new ports and roads lowered transaction costs. The last three centuries of the republic saw Italy's transportation network bolstered by the construction of a new network of highways.[51]

Increased resilience drove expectations, creating a feedback loop. Starting in the later second century B.C.E., Rome's urban *plebs* received monthly grain subsidies supplied by the state. The capital housed a massive population, and the demands of this *annona* system prompted further investments in storage and trade. By the late Republican Period, the system formed a potent source of political power, as leaders like Clodius, Pompey, and Caesar manipulated public food subsidies in search of popular political support. Rome's *annona* found reflection in Italian towns where elites sought power and status by intervening in local food supply. In a recently published inscription from Pompeii, a local grandee boasted of sustaining the city's population with subsidized bread distributions during a four-year famine.[52]

Food and water management practices in Italy during Roman expansion responded to a similar need but ultimately followed different trajectories. Resilience in systems of water supply was generally a matter of capital investment rather than connectedness. Water resources were always highly local, obedient to available

50 Geoffrey Rickman, *Roman Granaries and Store Buildings* (Cambridge, 1971); *idem*, *The Corn Supply of Ancient Rome* (Cambridge, 1980); Evelyn Bukowiecki, Nicolas Monteix, and Corinne Rousse, "Ostia Antica: entrepôts d'Ostie et de Portus. Les Grandi Horrea d'Ostie," *Mélanges de l'École française de Rome—Antiquité*, CXX (2008), 211–216; Cheung, "Managing Food Storage in the Roman Empire," *Quaternary International* (2020); van Oyen, *The Socio-Economics of Roman Storage: Agriculture, Trade, and Family* (Cambridge, 2020), 122–157.

51 Virlouvet, *Tessera frumentaria. Les procédures de distribution du blé public à Rome à la fin de la République et au début de l'Empire* (Rome, 1995); for the calendar, see Rüpke, *Roman Calendar*.

52 For the Pompeian inscription, see John Bodel et al., "Notes on the *Elogium* of a Benefactor from Pompeii," *Journal of Roman Archaeology*, XXXII (2019), 148–182; for road building, see T. Peter Wiseman, "Roman Republican Road-Building," *Papers of the British School*, XXXVIII (1970), 122–152.

water courses, springs, or aquifers. Close knowledge of local resources remained vital even in situations of state intervention. Aqueducts or canals could extend natural channels over distances, but never to the extent of food supply, which was considerably more scalable by means of long-distance trade. Resilience in the food supply could be created by connecting markets in ways that were unavailable in the case of water supply. The food trade combined with impressive storage infrastructure produced a food supply system with high capital, connectivity, and resilience.

Resilience theory notes how this combination holds potential for the emergence of a rigidity trap (when a system has grown very resilient to ongoing disturbances but struggles to adapt to newly emergent shocks) in which strong feedbacks worked to maintain the status quo. This, we argue, was precisely what happened in the late Roman republic, when an enhanced food supply and concomitantly heightened expectations became closely interwoven into Roman politics. Identification of this rigidity trap lends support to the idea of political fallout from volcano-forced climate change affecting agricultural production, as hypothesized in the aftermath of the eruption of Okmok in 43 B.C.E. At the same time, relating the impact of abrupt climate change to a rigidity trap, which emerged after centuries of development as local practices were scaled up under imperial pressures, reinforces the need for study of the long-term dynamics of human-environmental relationships.[53]

Because the environmental and climate history of Italy during the period of early Roman expansion was a mosaic of complex processes operating at different but interrelated scales, it is best to avoid the overly simplifying idea of a predictably stable or benign RWP contributing to Roman expansion. Global climate patterns trended toward slightly warmer and initially drier conditions over Italy from around 300 B.C.E., but data suggest that the local expression of this environmental and climate change was often variable and sometimes had contradictory effects.

The human side of this history also presents issues of scalar integration, moderating between the integrative and globalizing

53 For rigidity traps, see Gunderson, Allen, and Holling, *Foundations of Ecological Resilience*, 436–437.

force of the republican state and the variability and contingency of local land-use practices. Rome intervened in Italian societies that were already developing land-use practices to suit local parameters, but it is not sufficient to conclude that environmental history in this period was entirely local. Far from being a period of passive disinterest in climate or general climatic favorability, the last centuries of the first millennium B.C.E. were marked by critical developments in Italian communities' adaptations to variability, as histories of water and food supply management especially have revealed. Generally, increasing returns on land—through selection of animals, growing rural settlement, modifying farming practices, or investing in water capture and food storage—improved a community's chances in an environment that was always to some degree stochastic. The drivers behind these changes were often initially local, and adaptations were always oriented toward specific parameters of place, landscape, and local indigenous knowledge. Consequently, in each community or even every farmstead, adaptive responses remained diverse and multilinear.

Roman imperialism intervened in this already complex world; expansion could and did affect local behavior. Rome's impact on landscape could be as straightforward as the establishment of a colony or building infrastructure to support the grain trade. Often, however, its impact was indirect, a fact suggested by the temporal mismatch between the arrival of Roman power and, among other trends, the timing of changes in agricultural and animal husbandry practices detectable by bioarchaeology, of rural infilling detectable by survey, or of vegetation histories visible in pollen data.

Imperialism encouraged market practices, which intensified long-running local trends. By the first century B.C.E., local responses in their aggregate had scaled up to a peninsula-wide food supply system. Increased expectations contributed to the development of a system robust to environmental variability within a certain range but susceptible to disturbances of exceptional magnitude—as may have happened at the end of the republic when massive volcanic eruptions abruptly caused a period of global cooling.

An emphasis on the interplay of Roman expansion with local practices tends to push back against centrist or statist reconstructions focused on Rome. As the study of Roman expansion in Italy increasingly considers indigenous or non-state perspectives, environmental datasets offer considerable potential to reveal histories of places and peoples without the filter of imperial ideology. We should work to incorporate this material not as singular, isolated cases of local practice, but as part of a more complex and dynamic system. In this way, as our picture of the environmental and climate history of the Roman expansion in Italy becomes more detailed, it holds the potential to become more balanced.