8 Graeco-Roman Evidence

Eli J. S. Weaverdyck

8.A Material Evidence

Map 1: Roman settlement in the central part of the Lower Danubian plain, modern Bulgaria.

© Eli J. S. Weaverdyck.

I Introduction

It might be surprising to use a map to introduce a chapter on the sources of economic history in the Greek and Roman world. Other sources have a longer tradition of scholarship and are much more influential in current debates. This map, however, depicts a landscape as modeled in a geographic information system (GIS). It represents the ways scholars are using modern technology to expand the range of sources

Note: This chapter has benefited from the comments of several specialists. I would like to thank Nicholas Hudson for his comments on section 4 (pottery), Hannah Lau for her comments on section 5.3 (isotopes), and Demetrios Brellas for his comments on section 6 (faunal remains). Any errors remain my own.

of evidence for economic history. This technology is providing more data and more ways to analyze data than ever before, allowing us to recontextualize and reanalyze information created by previous scholars. A GIS-based analysis of a landscape will illustrate one of the many ways this can be done.

The evidence in this map shows that, in the late second and early third century, in a distant corner of the empire on the edge of the Danube, the Roman economy was booming. Not only was fine pottery being produced by specialist potters and stone being quarried and carved, the map shows that more people were farming the land more intensively than ever before and selling their products in urban markets.¹ While artifacts and architecture tell us a great deal about the economic activity of a few larger centers, GIS-based analysis of the landscape tells us about the economy of the region as a whole, giving us a broader perspective than would be possible using traditional archaeological evidence.

This chapter cannot cover the entirety of archaeological sources used to write economic history in the ancient Mediterranean in detail. Instead, I try to give an impression of their range while highlighting new sources and techniques. I will provide examples of how different sources have been exploited, emphasizing those that are especially helpful in understanding frontier zone processes. Choosing examples is difficult because ancient economic historians rarely rely on a single type of evidence. There is no single category comprehensive enough to bear the weight of interpretation on its own. Scholars usually start with questions, then collect all the evidence from any source that helps them to craft convincing answers. The examples presented below are of scholarship based primarily, but never exclusively, on one type of evidence. They are meant to illustrate the methods of analysis appropriate to that type, as well as its potential and limitations for economic history. After describing the GIS-based analysis of settlement landscapes, I will discuss digital data and quantification, pottery, human remains, the remains of animals, and air pollution. In parts B and C of this chapter, we discuss written and documentary sources, which enjoy a longer history of scholarship.

II Landscapes and GIS

Geographic information systems are ways of storing, visualizing, and analyzing data with a spatial component.² While spatial data distinguishes GIS from other methods of analysis, it is the linkage of location to other types of information that gives GIS its power. The locational data can be analyzed in the context of information about other phenomena that also have a spatial aspect, like the shape of the terrain, soil

¹ Weaverdyck 2016.

² GIS today refers to computer software, but in principle a GIS need not be digital. Indeed, it is often said that John Snow's contemporary map of the 1854 cholera epidemic in London represents one of the first uses of GIS.

types, and other archaeological features. Spatial data have been central since the inception of the field of archaeology, and the use of GIS software was quickly and widely adopted when it became available in the 1980s.³

For economic historians, the ability to quantify and analyze ancient landscapes is one of GIS's most useful capabilities. Here, the term 'landscape' refers to the physical environment, both natural and cultural, as experienced by its inhabitants. The landscape emerges from the relationship between subjective, strategic actors and their surroundings. By integrating archaeological remains (traces of human behavior) with information about the natural environment, we can begin to reconstruct the landscapes in which people lived, the constraints and opportunities afforded by those landscapes, and the economic strategies that were most likely pursued in the past.⁴

The archaeological data on which landscape archaeology depends come primarily from a combination of extensive and intensive survey.⁵ Extensive survey consists of compiling information about all known archaeological sites in an area and may involve expeditions aimed at discovering new sites. This type of survey can cover a very large area, but will usually only capture the most visible archaeological material, such as architecture or large quantities of pottery. The most serious problem with extensive survey is discovery bias. It can be difficult to know whether the absence of a site in a given place reflects a lack of archaeological material or a lack of investigation.⁶ Intensive survey involves the systematic observation of the ground surface. Often this is done by a group walking in a line at specific intervals and counting and/or collecting archaeological material. This technique facilitates the discovery of smaller sites and permits investigation into small-scale processes of land use. It also allows for systematic sampling of an area, enabling more secure generalizations about the nature of the archaeological material found. Nevertheless, increasing the intensity of survey also means decreasing the area that can be surveyed, which can make it difficult to arrive at sample sizes large enough to support interpretation.⁷

3 Overviews on the use of GIS in archaeology, both monographs and edited volumes, have been published periodically since the late 1980s. Howey and Brouwer Burg 2017 is only the most recent. For precursors from the 1970s, see Clarke 1977; Hodder and Orton 1976.

4 For this definition of 'landscape,' see Ingold 1993. For an introduction to landscape archaeology, see David and Thomas 2008.

5 Remote sensing – the detection of archaeological features through the analysis of satellite imagery, LiDAR data, ground-based subsurface prospection, etc. – is also an important source of evidence, but it cannot be treated here. For introductions, see Parcak 2017; Forte and Campana 2016. Campana 2018 calls for greater integration of different methodologies, including remote sensing and field walking, in landscape analysis.

6 The relationship between archaeological sites and ancient behaviors is not straightforward, but most archaeologists still find the site to be a useful heuristic tool. For the problem of the site, Dunnell 1992.

7 Banning 2002 provides an excellent overview of surface survey methods. For the Mediterranean in particular, the articles collected in Francovich, Patterson, and Barker 2000 and Alcock and Cher-

Once collected, archaeological data are interpreted to gather information about the distribution of human activity areas – particularly settlements – across the landscape. In agricultural societies, the smallest sites are usually taken to indicate the locations of ancient farming settlements.⁸ Since the daily routines of agriculturalists usually begin and end in settlements, these provide an emic perspective from which to view the ancient environment, a crucial step in reconstructing the ancient experienced landscape.

Site catchment analysis (SCA) is a method of analyzing the landscape surrounding a settlement to understand the resources available to its inhabitants and which economic strategies they might have followed.⁹ Recently, Helen Goodchild has used a version of this technique with GIS analysis to understand Roman agricultural systems in central Italy.¹⁰ Using ancient agricultural writings and scientific knowledge, she models the agricultural productivity of the landscape under different cultivation regimes. She then estimates production and consumption in the areas around known sites to determine how surpluses might have been generated and how large they might have been. While these models cannot be considered accurate portrayals of the agricultural strategies pursued in antiquity, they are good representations of the web of interconnected factors influencing production. They reveal the limits of what was possible in a given landscape and the consequences of different strategies. They also reveal the extent of regional and local variation in productivity, which can be compared to archaeological evidence about the nature of the settlements. In one area, villas (wealthier rural estates) that were inhabited in both the Late Republic and the Early Principate had better land than the poorer farms with similar occupation histories. However, when comparing new foundations in the Early Principate, the farms actually had better land. This could be related to tenancy arrangements, in which the villa owners were less interested in production around the villa itself than in the productivity of the farms from which they extracted rents, but other explanations cannot be ruled out. In any case, Goodchild's GIS-enabled analysis of site catchments has deepened our understanding of agricultural production in central Italy and raised interesting new questions.

In my analysis of the rural economy on the Lower Danube, I followed a different method.¹¹ Rather than starting from ancient and modern agricultural knowledge to deductively estimate the productive capacity of the landscape, I inductively examined the location preferences of settlements. I compared the prevalence of various

ry 2004 introduce the most commonly used methods and issues, including the debate about the value of increasing survey intensity, for which, see especially Fentress 2000; Terrenato 2004.

⁸ The essays collected in Attema and Schörner 2012 discuss the difficult issue of characterizing small sites.

⁹ First proposed by Vita-Finzi and Higgs (1970). See also Roper 1979. Farinetti applies the closely related 'community area theory' to Boiotia in Greece (2011).

¹⁰ Goodchild 2013; Goodchild and Witcher 2009.

¹¹ See for the following Weaverdyck 2016; Weaverdyck 2019.

landforms in settlement territories to their overall prevalence in the study area to determine which were favored and avoided at different periods. Interpreting the results in light of Roman agricultural literature, I found that settlements in the Roman period preferred features identified as agriculturally productive, but in Late Antiquity, they favored features associated with defensible locations. This suggests that Roman-period settlers felt safe enough to maximize productive capacity, while those in Late Antiquity compromised productivity for security. Alternatively, the Late Antique settlers could have engaged in agricultural strategies that were less dependent on the condition of the land surrounding their settlement. As with Goodchild's models, my own have generated interesting conclusions while raising further questions.

GIS modelling is also useful for understanding the ways that different places in the landscape interacted, providing evidence about local-scale marketing, for example. If farmers regularly sold their crops at a nearby marketplace or anticipated doing so when they established a farm, most farms ought to minimize the distance to that place while simultaneously maintaining access to productive land. Multivariate statistical analysis can separate the influence of marketplace proximity on settlement patterns from the influence of landscape productivity. Furthermore, by comparing how well different multivariate models fit the observed data, it becomes possible to test hypotheses about the role of different places within an entire marketing system. In the frontier zone of the Lower Danube, for example, I was able to determine that auxiliary forts – despite their access to money and their lack of resident farmers – did not function as marketplaces in the local, rural economy.

By using GIS to analyze archaeological and environmental data, it becomes possible to examine behavior that leaves little trace in the archaeological record. The tools used in agricultural production are rarely found and difficult to date. Local marketing of agricultural surplus involves perishable goods carried in perishable containers. If the location of settlements can be found, however, the landscape can provide hints about production strategies, and if the locations of possible markets can be identified, the importance of marketing in the rural economy can be assessed. Excavation of rural settlements adds valuable detail and nuance, but is extremely costly and only a few sites will ever be excavated. GIS allows us to take advantage of data that would otherwise be too vague to be useful and allows us to draw conclusions that are generalizable to an entire region.

III Digital Data and Quantification

The Roman Empire has enjoyed a long history of scholarship, resulting in a truly massive amount of data compared to other ancient societies. The development of digital technology and the internet is making those data not only more accessible than ever before, but accessible in very different ways. Large encyclopaedias and

ancient texts reach a wider audience by being available in digital format.¹² More transformational are the efforts of projects and individuals to create and publish databases. These data are structured and interlinked in a way that makes it easier to query, organize, summarize, and analyze them for the purpose of answering a specific question. Online databases now exist for a range of types of evidence and at a variety of scales. We are still in the early phases of database construction, however, so while the number of databases is growing, the variety in scope, structure, and functionality means that some topics, regions, and periods are better covered than others. The rapid pace at which the field is developing means that any printed overview will soon be out of date, but a few examples of the most widely used databases are described here nevertheless.

Data about ancient places are currently collected by Pleiades.¹³ It started with a focus on the ancient Graeco-Roman world, but is expanding. Ancient geographical data are often fragmented, incomplete, and vague, so Pleiades uses a tripartite data structure that allows it to include the maximum amount of data possible. The three types of data are: place, a conceptual entity like ‘the city of Rome’; location, a set of geographic coordinates that might represent the center of the city, the outlines of walls, the forum, and so on; and name, a linguistic identifier of the place. This allows Pleiades to include both unnamed places attested through archaeological remains and places that are attested in ancient sources but lack a known location. Pleiades maintains a Unique Resource Identifier (URI) for every place, which other online resources can use to specify places precisely and link their data to a location. The coin data base Nomisma.org, for example, uses Pleiades’s URIs to identify mint locations. Although the website so far provides only simple search capability, the data are downloadable, allowing for use and manipulation in other software.

Like Pleiades, Nomisma seeks to establish stable URIs for a variety of concepts related to a single phenomenon, in this case, coins.¹⁴ These concepts include things like denomination, material, mint, issuing authority, etc. By using these URIs, different databases of coins and coin types can be integrated.¹⁵ It also allows users to construct queries about various typological and metrical aspects and quickly generates graphs of the output. So, for example, one can easily create a graph of how the average weight of the *denarius* changed over a given time period or one showing the relative proportion of different denominations issued by Augustus. Crucially, the data behind these graphs are downloadable in .csv format for verification and further manipulation.

Epigraphic databases segregate Latin from Greek inscriptions, and the coverage of the two is uneven. For Latin inscriptions, the Epigraphik-Datenbank Clauss/Slaby

¹² See, e.g., Brill’s New Pauly Online (<https://referenceworks.brillonline.com/browse/brill-s-new-pauly>) and the Perseus Digital Library (<http://www.perseus.tufts.edu/hopper/>).

¹³ <https://pleiades.stoa.org/>

¹⁴ <http://nomisma.org/>

¹⁵ <http://nomisma.org/datasets>

is the most comprehensive to date, with information about 513,521 inscriptions as of this writing.¹⁶ In addition to simple text searches, available queries include publication, province, place, date range, inscription type, and even personal status. For example, querying by inscription type, province, and date range, one quickly finds that the number of mile stones in the province of Syria dating to each of the first three centuries CE is 7, 41, and 10. Each entry includes the text, a reference to the original place of publication, precise dating, and find spot. The best resource for Greek epigraphy is the Packard Humanities Institute's Searchable Greek Inscriptions, but the only queries available are for text and region.¹⁷

Several databases useful for the study of the Roman economy have been constructed and published as part of the Oxford Roman Economy Project (OxREP), a research program that seeks to better understand the Roman economy through the construction, analysis, and publication of quantitative archaeological and documentary data.¹⁸ The project currently hosts databases about cities, mines, olive oil and wine presses, shipwrecks, stone quarries, and water technology from the entire Roman Empire, and tax rolls from the Egyptian village of Karanis.¹⁹ They are designed to be easily queried, and visual representations of the data are often available in the form of timelines, maps, or both.

All of these databases are part of a larger quantitative turn in the study of the ancient economy. Although quantitative data have long been used by some economic historians, the popularity of quantification has grown quickly in recent years due to the increased availability of data and the development of new methods to exploit them.²⁰ Quantitative evidence is often seen as more empirically sound and amenable to more rigorous analysis than qualitative evidence, but the reasoning is rarely made explicit. After all, humans understand the world in qualitative terms, and numbers in themselves are often meaningless.²¹ The significance of the figures derived from quantitative analysis comes from the interpretive context. Above all, quantification allows for greater precision than qualitative descriptors such as 'large' or 'significant,' which, in turn, allows for comparison on a variety of axes. By reducing complex, unique phenomena to numbers, we can decide whether the Roman economy was more or less productive than, for example, that of classical Greece, the High Middle Ages, or Han China. We might also compare the relative contributions of various factors to a certain phenomenon. Quantification can also

¹⁶ <http://www.manfredclauss.de/>

¹⁷ <http://inscriptions.packhum.org>. For papyrological databases, see von Reden, ch. 8.C, this volume.

¹⁸ <http://www.romaneconomy.ox.ac.uk/>

¹⁹ <http://oxrep.classics.ox.ac.uk/databases/>

²⁰ For a historical perspective on quantitative approaches to the ancient economy, see de Callatay 2014; von Reden, ch. 8.C, this volume.

²¹ One is reminded of Douglas Adams's absurdly quantitative answer to the question of "life, the universe and everything" in *The Hitchhiker's Guide to the Galaxy* (1979).

allow us to compare how well different models fit empirical data, as in the analysis of rural marketing systems described above. Numbers also make it possible to track diachronic change, as in the example of lead and copper pollution below. It is the comparability provided by (more-or-less) precise numbers that makes quantitative analysis more empirically robust than qualitative analysis. Even so, the use to which scholars put these numbers depends heavily on the questions they ask and their theoretical background. Quantification is not a unified methodology or approach. It is a tool, or better, a type of tool, for there are many ways to quantify and many ways of analyzing numbers.²²

IV Pottery

Pottery is ubiquitous in the Mediterranean.²³ It is the single most commonly encountered type of artifact in any archaeological investigation and therefore has played a large role in the study of the ancient economy. The simple ubiquity and quality of Roman pottery has been taken as evidence for high standards of living.²⁴ Most commonly, however, it has been used to identify trade networks and to trace their development over time. Pottery has also been used to study the nature of the exchange mechanisms that distributed it, sometimes over very long distances.

IV.1 Pottery as Data

Pottery can support these analyses because it is often possible to assign a particular vessel, with more or less precision, to a particular place of origin and chronological period. This is done primarily on the basis of typologies. Ceramic vessels can be classified in a number of ways. At a general level, most archaeologists working in the Mediterranean recognize functional categories like table service, storage and/or transport vessels, cooking pots, and so on. Typologies are more precise classifications, usually built to understand a certain category of material from a specific site or region. They classify material based on several criteria, often including form (the

²² For a theoretically oriented examination of quantification, see Morley 2014.

²³ Hayes 1997 provides an introduction to Roman pottery. For manuals on the archaeological study of pottery in general, see Orton and Hughes 2013; Sinopoli 1991. Peacock 1982 is a fundamental study framing Roman pottery production while Peña 2007 is foundational for the use, reuse, and discard of Roman pottery. The study of Greek pottery has historically been dominated by figural vases that largely predate our period, but the foundation of the International Association for Research on Pottery of the Hellenistic Period (IARPotHP) in 2011 shows that interest in this material is increasing (<http://iarpothp.org>). The essays collected in Fenn and Römer-Strehl 2013 demonstrate the breadth and promise of the field.

²⁴ Ward-Perkins 2005.

shape of the vessel and its component parts), fabric (the fired clay material from which it is made), subtle indications of production techniques, and surface treatment.²⁵ By classifying groups of pottery into types on the basis of well-defined criteria, archaeologists can understand how the pots relate to each other, identifying sets of vessels that share certain production techniques or tracing how types change over time, for example. Vessels that come from a certain potting tradition and share distinctive characteristics are called a ‘ware.’²⁶ In some cases, these have been identified at a large number of sites, and broader typologies describing material from many sites have been constructed.²⁷

To mobilize these data, it is necessary to quantify the amount of pottery of different types present in a given assemblage.²⁸ This is difficult because the archaeological assemblage consists of broken and incomplete pots. Four measures are commonly used: sherd count, weight, minimum number of individuals (MNI), and estimated vessel equivalent (EVE). Simply counting sherds (broken pieces of pottery) is straightforward but problematic because pots break into different numbers of pieces depending on their physical properties and the processes that have affected them since they stopped being used (these are called ‘transformation processes’). These same processes and the collection method employed by archaeologists also affect recovery, meaning that some portion of the sherds from a pot are never found. Thus, all samples are biased, and that bias changes between assemblages that have been submitted to different transformation processes. Weighing pottery types is better because, although the sample is biased toward heavier types, the bias does not vary as much between assemblages, allowing the proportions of different types to be compared across assemblages. MNI is calculated by grouping all sherds that could belong to the same vessel and counting them once. Since most vessels have only one rim and base, these are often used. EVE measures quantity in terms of the fraction of vessels represented, usually using rims. Using a rim chart, one measures the fraction of a circle represented by each rim sherd and sums these to arrive at a total estimated vessel equivalent. Clive Orton has compared these measures and argued that weight and EVE provide the most reliable basis for interassemblage comparison, but sherd count and MNI are still commonly used as well.²⁹

25 Typologies can be constructed in a variety of ways using different criteria for different purposes. For overviews, see Orton and Hughes 2013, 190–202 and Sinopoli 1991, 43–67. For a theoretical examination of how archaeological typologies are formed, see Adams and Adams 1991.

26 The term ‘ware’ is also sometimes used when referring to functional categories, e.g., ‘tableware’ or ‘cookware,’ but here it will be used in a narrower sense.

27 The definition of wares and typologies is subject to a great deal of interpretation. Bes (2015, 11–26) describes in detail the eight red-slipped wares most commonly found in the Eastern Mediterranean, including a history of their typological definition, which illustrates the process of constructing broad typologies.

28 For an accessible introduction to pottery quantification, see Orton and Hughes 2013, 203–218. Verdan 2011 presents recommendations for standard practices.

29 Orton 1993.

The place where a type of pottery was produced can be determined in several ways. Scientific analysis of the fabric can reveal the source of the clay and is usually seen as the most certain indication.³⁰ Some types of clay, however, are too widely dispersed for fabric analysis to be useful. The excavation of a production center also provides definite evidence for the origin of some types. For many wares and types, however, origin is inferred on the basis of distribution on the assumption that a type will appear most frequently in the area in which it was produced.³¹

In Mediterranean archaeology, pottery is the primary method of dating archaeological deposits.³² Pottery forms can be put into a relative sequence within a typology by observing the stratigraphic sequence of deposits in which they are found and by observing subtle differences between otherwise similar pots that mark the evolution of a form over time. Absolute dates come from other artifacts associated with the pottery in a stratigraphic deposit. Coins and wood (dated through dendrochronology, see below) as well as other types of pottery with a better known chronology are common sources of such information.

Another method, used when secure stratigraphic information is not available, is seriation. This technique is based on the assumption that, after it is introduced, types of pottery generally grow and then fade in popularity. Archaeologists quantify the abundance of a type in multiple assemblages and then rearrange the assemblages until the frequency grows and diminishes smoothly. When this is done for multiple types of pottery that occur in a set of assemblages, a larger sequence showing the relative chronology of different types can be built. Additional information is necessary to determine the direction of the sequence and its absolute chronology.³³

The chronological evidence provided by pottery, then, is indirect, inferred from the identification of a given artifact as an example of a certain type within a typology that itself is dated more or less securely and precisely through association with other remains. Furthermore, many types of pottery remain in use unchanged for a long period of time. It is very rare that pottery can be dated to the quarter century or less; ranges of several centuries are much more common.

One method of dealing with this lack of precision that is becoming more popular is aoristic dating. In this method, a range of possible dates is established for each member of the group under investigation, be it a potsherd, a settlement, or a shipwreck. Then, that member is divided and a fraction assigned to each time-slice within that range such that the total adds up to one. Thus, in a graph showing the frequency of shipwrecks by century, a wreck dated to the second and third century CE would appear as half of a wreck in the second century and half of a wreck in the

³⁰ Orton and Hughes 2013, 150–189; Hunt 2017.

³¹ Orton and Hughes 2013, 235–245.

³² Sinopoli provides a clear introduction to reconstructing chronologies (1991, 74–81). Orton and Hughes go into more detail (2013, 219–234).

³³ There are several more or less statistically sophisticated methods of seriation. For an overview, see Orton and Hughes 2013, 226–232.

third century.³⁴ In this way, the uncertainty inherent in the data is preserved in the analysis.

IV.2 Archaeological Ceramics in the Mediterranean

Mediterranean pottery differs from that found in many parts of the world in three ways. First, the amount of pottery discovered from archaeological excavations and surface surveys is massive. One not very large project in northern Greece discovered almost 100,000 sherds weighing over half a metric ton in its first season alone.³⁵ Recording practices in each project must be tailored not only to address individual research questions, but to deal effectively with the quantity of material given limited resources. This leads to variation between projects that must be accounted for when comparing assemblages.

Second, there are certain broad classes of pottery that are common in the region and enjoy a long history of scholarship. The two most extensively studied functional classes of pottery are transport amphorae and fine table service.³⁶ The latter consist of vessels made from fine clay used for serving and consuming food. They are usually covered with a glossy black or red slip, and are often otherwise decorated.³⁷ Amphorae – large jars with a narrow mouth, two handles, and normally a spiked toe – were the most common type of shipping container in the ancient Mediterranean used to ship liquids, especially wine and olive oil, and other goods.³⁸

34 Keith Hopkins (1980) was the first to use a graph showing the changing frequency of shipwrecks in the Mediterranean as evidence for economic growth. The data were more fully published by Parker in 1992, and OxREP expanded the dataset and published it online (n. 18 above). Wilson (2009) redrew the graph using aoristic dating. For a detailed discussion of chronological uncertainty in quantitative analysis with a focus on settlement patterns, see Crema 2015

35 Arrington et al. 2016, 12.

36 Cooking ceramics – vessels used for food preparation – are equally important, but the history of scholarship on them is much shorter. The essays in Spataro and Villing 2015 provide an overview.

37 For a concise summary of Hellenistic table service, see Hayes 1991. The terms '*terra sigillata*' and 'Samian ware' (more common in the UK) refer to ceramics made of fine clay with a glossy red surface. The most recent and comprehensive studies of the vessels and the stamps are Oxé, Comfort, and Kenrick 2000 (Italian sigillata); Hartley and Dickinson 2008–2012 (Gaulish sigillata); Bes 2015 (Eastern Sigillata). The data are also available online in two different databases: <https://www.rgzm.de/samian> for the Gallic and Italian material, <http://icrates.arts.kuleuven.be/icrates/> for the Eastern Mediterranean.

38 For a useful introduction to Roman amphorae as evidence for economic history, see Peacock and Williams 1986. The online database Roman Amphorae provides an introduction to Roman amphora studies and a catalog of amphora types (http://archaeologydataservice.ac.uk/archives/view/amphora_ahrb_2005/index.cfm). For an overview of Greek amphora studies, see Eiring and Lund 2004 (with a focus on the Eastern Mediterranean) and Whitbread 1995 (with an emphasis on petrography).

Third, there are several types of amphorae and table service wares that were produced on a very large scale and distributed over long distances.³⁹ The widespread distribution of inexpensive vessels and of containers for inexpensive food-stuffs shows that long-distance trade was not restricted to items with a high value-to-weight ratio, as in other historical contexts. Since the production of pottery formed a relatively small part of the overall economy, we will focus here on its distribution as a marker for more substantial economic activities.

IV.3 Pottery as Evidence for Exchange Networks

On archaeological sites from Graeco-Roman antiquity, it is common to encounter a great deal of ceramic material with distant and diverse origins. This fact in itself is notable since pottery is not particularly expensive and clay is ubiquitous. No region holds a natural comparative advantage that could explain long-distance pottery trade. Therefore, pottery is usually seen as indicating trade in other goods. For amphorae, this was the contents of the vessel.⁴⁰ For table ceramics, grain or other agricultural products are usually seen as the primary cargo.⁴¹ In both cases, however, other primary cargoes, such as precious metals, are possible.⁴² Whatever it was, pottery filled in the gaps left by the more important and valuable cargoes that drove exchange. The ceramics that we find are traces of ancient exchange networks, but we have reason to suspect that they are incomplete: literary and documentary evidence show that Egypt exported grain in massive quantities to Rome, but Egyptian pottery is very rare outside of Egypt.⁴³ Bearing this in mind, the distribution of pottery provides valuable evidence for broader exchange networks.

This evidence can be used in several ways. When examining a single site, pottery provides some information about the ancient inhabitants' economic connections. It is not valid, however, to assume a direct connection between the places of production and consumption. Trade in the ancient Mediterranean was a heterogene-

³⁹ Modern debate about the organization of Roman ceramic production is based on Peacock 1982. For large-scale production of standardized goods in the Roman world, see Wilson 2008; Jiménez 2017.

⁴⁰ Many amphora types have been associated with a specific product – usually wine, olive oil, or fish sauce – on the basis of painted inscriptions (*tituli picti*), literary evidence, close association between amphora production sites and regions or sites known to produce certain products, or the presence of a pitch coating, which prevents wine and fish sauce from soaking through the walls of the vessel but dissolves in oil and renders it inedible. As techniques of residue analysis become more sophisticated, some of these associations are being questioned. Bonifay and Garnier (2007) critically examine the evidence for the contents of North African amphorae. See also Foley et al. 2012; Pecci et al. 2017.

⁴¹ Lewit 2011 provides a good overview.

⁴² Mattingly (1988, 52–53) argues that Spanish olive oil accompanied silver.

⁴³ Lewit 2011.

ous combination of small-scale, ad hoc tramping and planned journeys with strategically selected cargoes. In both cases, the collection and reexport of goods from harbors was common.⁴⁴ When examining a single class of pottery, the distribution map shows the zone in which that pottery circulated, occasionally shedding light on the route by which it travelled when find spots form a linear pattern.

The best evidence for exchange networks, however, comes from comparing multiple types of pottery from many different sites. If each site provides a sample of the pottery that circulated across the exchange networks in which it was embedded, the comparison of site assemblages can reveal the geographic extent and limits of the various exchange networks. Sites with similar assemblages are seen as participating in similar exchange networks.⁴⁵ By comparing sites that produce large ceramic assemblages spanning several centuries, archaeologists can examine how these exchange networks changed over time. The number of sites with assemblages amenable to this type of analysis is growing. In 1993, Roberta Tomber analyzed assemblages from five sites.⁴⁶ In 2018, Paul Reynolds, while focusing on Beirut (Lebanon) and Butrint (Albania), was able to incorporate comparative data from over 20 other sites.⁴⁷

While various statistical techniques for comparing site assemblages have been suggested, it is more common for scholars to treat pottery quantities as ordinal scale data and to rely on impressionistic comparisons. Both approaches are quantitative in that the object of comparison is a measured quantity, usually the percentage of an entire assemblage or ceramic class accounted for by a particular type of vessel.

Roberta Tomber first proposed the application of multivariate statistics to artifact assemblages in the early 1990s and was able to show, using discriminant analysis, that there were significant differences not only between all five sites she analyzed, but that the three sites in the Western Mediterranean and the two sites in the Eastern Mediterranean formed distinct groups, despite some overlap in their assemblages.⁴⁸ More recently, a team led by Xavier Rubio-Campillo analyzed a massive database of amphora stamps coming from over 1,200 different sites in the Western Mediterranean.⁴⁹ They quantified the similarity of each site to all others and the

⁴⁴ Horden and Purcell (2000, 123–172) argued that tramping, or ‘cabotage,’ was the normal method of trade in the ancient Mediterranean, but this view has been challenged (Rice 2016).

⁴⁵ This is a rather positivist and somewhat simplistic presentation of the logic that ignores complicating factors such as irregularities in the production of pottery and differences in its consumption both between sites and between different places within a site. For a critical examination of the theoretical linkage between archaeological pottery and the Roman economy, see Greene 2005.

⁴⁶ Tomber 1993. The sites are Carthage (Tunisia), Rome (Italy), Naples (Italy), Benghazi (Libya), and Caesarea Maritima (Israel).

⁴⁷ Reynolds 2018. This is partially a result of methodological differences but primarily of the massive increase in the amount of archaeological data that has been published in the last 25 years.

⁴⁸ Tomber 1993.

⁴⁹ Rubio-Campillo et al. 2018.

similarity of each site to the others in the same province and compared the two values. Even though the two levels of similarity were very close, they were able to show that within-province similarity was higher than global similarity and that the difference was statistically significant. They concluded, therefore, that provincial borders did impact trade networks. These two examples highlight the primary advantage of statistical analysis: it is able to identify subtle patterns in the data and distinguish significant differences from those that could result from the random element of archaeological sampling.

Paul Reynolds's recent survey of pottery assemblages from around the Graeco-Roman world, however, shows that impressionistic comparison has advantages as well. First, it is less dependent on the structure of the data. Rubio-Campillo's analysis works because amphora stamps are a unitary object and quantities can be treated as count statistics. Tomber could only compare sites with similarly large assemblages that spanned similar time frames and were quantified in similar ways. Reynolds could incorporate any data set available and adjust the interpretive weight placed on it to the nature of the data. Thus, some sites appear only when he considers a particular period or a particular type of vessel, while others serve as more consistent and broadly applicable points of comparison. By focusing on which wares dominate, are present in, or are absent from different assemblages rather than on specific quantities, Reynolds also sidesteps some of the problems involved in pottery quantification.

The second advantage is the nuance and fine-grained texture of the interpretations that Reynolds can achieve. So, for example, Reynolds argues that, because the ranges of Black Sea amphorae are similar in Beirut, Athens, and Knossos but Beirut had more Sinopean amphorae, there was a special relationship between these two cities that existed within a more general flow of Black Sea goods into the Aegean and Eastern Mediterranean. He is also able to distinguish a network that brought Aegean cook wares and fine wares into the Adriatic that excluded Black Sea goods, even though the latter were circulating throughout the Aegean. These are just two specific arguments pulled from a larger study that demonstrates the existence and intensification of 'close regional' networks of pottery circulation in the Levant and elsewhere from the second through the seventh centuries CE. If Reynolds had taken a more statistically rigorous approach, these detailed conclusions might have been obscured by larger patterns.

IV.4 Pottery as Evidence for the Nature of Exchange

Pottery distribution maps have played an important role in debates about the extent to which exchange in the Roman economy was driven by market forces versus political forces.⁵⁰ Transportation costs provide the link between spatial distribution and

⁵⁰ See Orton and Hughes 2013, 235–241 for an introduction.

the nature of exchange. In free, market-based exchange, the price of a good includes the cost of moving it from its place of production to the place of exchange. As one moves farther from the place of production, the price rises and the number of people willing to buy it falls. The archaeological result is that sites near the place of production have a higher percentage of a given type of pottery than sites farther away. Deviations from this pattern suggest that transportation costs did not affect consumption, presumably because they were borne or subsidized by the state.

Michael Fulford's analysis of the distribution of several types of Gaulish tableware provide a recent example that also incorporates the function of the sites of consumption.⁵¹ Fulford plots the spread of *terra sigillata* from several different production centers in Gaul, using the number of stamps found at different sites as the basis of quantification. With a single exception, none of the distributions follow the pattern predicted by free market exchange. Instead, there are gaps where no pottery is found close to the places of production and large quantities are found farther away, particularly in Britain. Fulford concludes that the state had a hand in organizing the pottery's production and distribution but then must explain why the consumption sites in Britain include not only military bases but civilian and urban sites as well. He suggests that the state also supplied the *cursus publicus* – the official communication network consisting of inns and changing stations discussed in chapter 7 – with table ware that was then sold to the general public.

On the basis of distribution maps, Fulford cannot say what the relationship between the state, the producers, and the transporters was like, so it is not quite right to say that the pottery is evidence for state redistribution.⁵² If state representatives negotiated contracts with the other parties that involved subsidized transportation and a mutually agreed upon price, then the state acted as a uniquely privileged player within market-based exchange. It is also possible, however, that production or transport were provided at a fixed price or simply as an obligation, in which case the same distributions are produced by nonmarket redistribution or transfer. It is best, then, to interpret pottery distributions as evidence for the influence of transportation costs on consumption. To go further requires other evidence.

Until recently, it was difficult to interpret distribution maps centered on the Mediterranean because sea travel made transportation costs much less dependent on straight-line distance than it is on land. Furthermore, most voyages involved a combination of carriage methods each with different costs and unknown transshipment costs as well. A recent Stanford project has made a major contribution that addresses these problems.⁵³ ORBIS is a digital network model of the Roman world

⁵¹ Fulford 2018. Peacock and Williams (1986, 61–63) were the first to suggest that consumer site function could be used to distinguish market exchange from state-led redistribution.

⁵² Fulford does not make this claim here, but distribution maps of oil amphorae have been interpreted in these terms (Weaverdyck, ch. 7, this volume).

⁵³ Orbis.stanford.edu hosts the model and the user interface along with extensive documentation. See Scheidel 2014 for an overview.

consisting of 632 sites and the links between them. The model makes it possible to calculate the cost of travelling between any two sites in time or money, at different seasons, prioritizing the fastest, cheapest or shortest routes, and using different modes of transportation. The model incorporates a wide variety of factors affecting sea, river, and overland travel, making it possible to construct distribution maps that more accurately reflect the real costs of transportation beyond simple, Euclidean distance. Nevertheless, because of the scale of the model, some simplifications are inevitable, and it is best used to model long-distance traffic. It is also important that users understand how the different parts of the model work together and the effects of the various options available on the calculations. Luckily, ORBIS provides extensive and lucid documentation.

In the last few years, interest in using computer-based models to analyze pottery distributions as evidence for testing larger, more abstract models of the Roman economy has grown. Tom Brughmans and Jeroen Poblome, for example, have constructed an agent-based model (ABM) that simulates the flow of four types of pottery through a social network of traders located at different sites. The aim was to test Peter Bang's vision of a weakly integrated Roman economy against Peter Temin's vision of a strongly integrated one.⁵⁴ Rather than focusing on the spread of pottery across geographic space, they ask what types of networks spread pottery across a large number of sites and what would cause one type of pottery to be spread more widely than others, as observed in the distribution of four types of *terra sigillata* across the Eastern Mediterranean. They find that wide distributions of pottery are only possible in a network that includes many links between sites, supporting Temin's model over Bang's, and that the dominance of one type over the others could result from differences in the scale of production.⁵⁵

Complex as they are – Brughmans's and Poblome's model contains 17 independent and 15 dependent variables that govern how the social network is constructed and how pottery flows through it – computer models like this require simplification and it is open to debate whether the simplifying assumptions adopted in any particular case are appropriate and useful.⁵⁶ On the other hand, the necessity to simplify is also the greatest benefit of this type of modeling. It requires all of the underlying assumptions and parameters of conceptual models to be stated simply and clearly, allowing others to engage with them. It then shows how changing the values of these parameters affects the outcome in ways that are directly comparable both to other versions of the model with different parameter values and to the observed archaeological record.

⁵⁴ Brughmans and Poblome 2016.

⁵⁵ See von Reden, ch. 17, this volume for models of the Roman economy.

⁵⁶ See Van Oyen 2017 for a constructive critique of Brughmans's and Poblome's model.

V Human Remains

Human remains have begun to play a major role in debates about the Roman economy as evidence for economic outcomes.⁵⁷ They are a direct, if incomplete, indicator of physical well-being and therefore allow us to approach something akin to ancient quality of life. In addition, they provide valuable evidence for diet and mobility. Skeletal remains also have the advantage of comparability. Unlike culturally determined consumption patterns, human biology is similar across all populations and through time, so we can ask whether the Romans were healthier than, for example, medieval Italians or early modern European populations.⁵⁸ On the other hand, the relationship between economic complexity or performance and biological health is not a simple one. Urbanization and increased population, both linked to economic growth, can cause malnutrition and the spread of disease, producing a population that is simultaneously richer and sicker than before.⁵⁹

V.1 Stature

Stature has received the most attention recently.⁶⁰ In the modern world, economists have established a correlation between average height and GDP, suggesting that height is positively correlated with economic development.⁶¹ There are, of course, complications. Adult height is the result of many different, interacting factors. An individual's adult height is the result of sexual dimorphism, genetics, and the conditions in which they grew up.⁶² In periods of stress, the body maintains life at the expense of growth, so children who are malnourished, overworked, or diseased will grow into shorter adults than those who are healthy. At the same time the composition of the diet is consequential: the contribution of dairy, particularly milk, to the

⁵⁷ Harper 2017, 74–79; Scheidel 2012 with literature. The study of human skeletal remains is called bioarchaeology or osteoarchaeology. For a good introduction to the field, see Larsen 2015. For an overview of bioarchaeology in Roman history, see Sperduti et al. 2018.

⁵⁸ Kron (2005) was the first to make systematic comparisons between the average height of Roman skeletons and early modern populations. For long-term and large-scale comparisons of stature in Europe, see Koepeke 2016; Martella, Brizzi, and Sanna 2018.

⁵⁹ This happened in the United States in the nineteenth century (Steckel 2013). For Rome, see Harper 2017, 74–79.

⁶⁰ For an overview of the use of stature in economic history, see Steckel 2013. For the use of stature in Roman history, see Gowland and Walther 2018.

⁶¹ Steckel 2013, 408–409.

⁶² Genetic variation between individuals is controlled by averaging heights across a population. The degree to which genetic differences between populations influence average height is not certain, but recent work on modern populations suggests that environmental factors might be more influential (Stulp and Barrett 2016).

diet is positively correlated with height.⁶³ This could explain why ancient populations in northern Europe, which raised cattle in larger numbers than those around the Mediterranean, were generally taller than their southern European neighbors.⁶⁴ Therefore, average adult stature can be a good indicator of childhood well-being, but a large sample size is necessary to control for genetic variation between individuals, and simple interpretations correlating height and economic prosperity must be avoided.

Estimating height from archaeological remains also presents methodological difficulties. Since whole skeletons rarely survive, height is usually estimated from the length of long bones, especially the femur. However, the ratio between femur length and height is not constant across populations. Using formulas developed for modern populations to estimate the heights of ancient people can be misleading, so analysis should be based on femur length itself.⁶⁵ Furthermore, a femur must be associated with a skull or pelvis so that sexual dimorphism can be controlled in the analysis. This reduces the size of the sample that can be analyzed. As sample size decreases, the probability that any given population's average height will reflect the genetics of its members more than the environment in which they grew up increases. To avoid the problem, researchers can expand the geographic and chronological scale of analysis, but this will blur local and short-term dynamics. In addition, to increase the sample size it becomes necessary to rely on data recorded and published by others, raising the risk of interobserver bias. Nevertheless, the amount of data available is growing rapidly and a consensus is beginning to emerge: the Roman Empire made people short.⁶⁶

V.2 Pathology

Skeletons also provide evidence that might suggest why this was the case. Malnutrition and some diseases leave traces on the skeleton. Pitting in the crown of the skull (*porotic hyperostosis*) and in the eye sockets (*cribra orbitalia*) result from anemia, caused by a variety of stressors including poor diet and unsanitary living conditions. In particular, gastrointestinal parasites, chronic diarrhea, and a diet poor in animal proteins have all been linked to *porotic hyperostosis* and *cribra orbitalia*. These kinds of nutritional stresses can also arrest enamel production temporarily, causing visible lines in teeth called linear enamel hypoplasias (LEH). While pitting

⁶³ Stulp and Barrett 2016, 211–212 with literature.

⁶⁴ Koepke and Baten 2008.

⁶⁵ Klein Goldewijk and Jacobs 2013.

⁶⁶ Both Koepke 2016 (relying on others' measurements to assemble a very large database that spanned all of Europe at century-scale resolution) and Giannecchini and Moggi-Cecchi 2008 (relying on their own measurements from archaeological sites in Italy) come to this conclusion. Kron 2005 (relying on heights reconstructed by others) argued that Romans were taller than early modern European populations.

and LEH provide evidence for stressful conditions, they both have multiple precise causes, so it is usually impossible to tell exactly what led to the pathology.⁶⁷

Both these conditions, pitting and enamel hypoplasia, occur during childhood, and so reflect the conditions in which the individual grew up, much as stature. Nutritional deprivation during adulthood leaves fewer traces on the skeleton, although dental caries (cavities in teeth) indicate a diet rich in carbohydrates and thus an overreliance on grain.⁶⁸ Some diseases, like leprosy or tuberculosis, gradually alter bones, but many others do not.⁶⁹ Routine physical activity, on the other hand, often leads to changes in bone morphology – usually a thickening of load-bearing bones – or pathologies like osteoarthritis in certain joints, making it possible to reconstruct the types of labor that people were engaged in.⁷⁰ This can be particularly helpful in identifying gendered or class-based division of labor. At the same time, age and genetics are also influential causes of these types of pathologies and morphological changes might not be related to occupation, so some caution is warranted in interpreting this type of evidence.⁷¹

V.3 Isotopes

Because bones and teeth are living tissue, they preserve chemical traces of the food and water that individuals consumed during their lifetime. This can be used to reconstruct certain aspects of their diet and mobility.⁷² In order to address these issues, archaeologists most frequently assess isotopic forms of four elements: carbon, nitrogen, oxygen, and strontium. The first two provide evidence for diet, the second two for paleomobility.⁷³ Here again, the fact that bones and teeth form at different ages strongly affects the way the evidence can be used. Tooth enamel forms in early childhood, while bones remodel over the course of an individual's lifetime and thus may reflect the later years of life. Comparison between isotopic values derived from enamel and bone samples, then, permits archaeologists to assess changes in an individual's diet and mobility over the course of their lifetime.

67 For an overview of these and other skeletal markers of stress and deprivation, see Larsen 2015, 30–57.

68 The other major pathology reflecting adult nutrition is osteoporosis, the resorption of bone tissue as one ages. Bone mass is also affected by mechanical stress, however, complicating the interpretation of these data (Larsen 2015, 57–60).

69 Larsen 2015, 66–114. For an overview of epidemiological studies in Roman history along with a critical analysis of the methodological limitations, see Sperduti et al. 2018, 134–141.

70 Larsen 2015, 178–255.

71 Sperduti et al. 2018, 142–143.

72 For a convenient introduction to chemistry for archaeologists, see Pollard et al. 2007, 217–321.

73 See Larsen 2015, 301–356 for an introduction, Pollard et al. 2007, 169–191 for the way isotopes are detected and measured and a review of archaeological applications, and Sperduti et al. 2018, 144–153 for the use of isotope analysis in Roman archaeology.

Isotopes are an attractive source of evidence because they are a biological reflection of normal ancient diets. They are free from the distortions of literary and artistic representation and are equally applicable to powerful and marginalized members of society. Nevertheless, they come with their own complications and problems. First, the information they provide is vague. Not only do isotopes come from various sources that cannot be disentangled, but the isotopic composition of bones and teeth are a composite reflection of the food consumed over a long period of time. Second, the information is incomplete. The carbon and nitrogen in collagen – the organic portion of the bone whose chemistry is less affected by burial conditions – derives largely from proteins, with carbohydrates and lipids contributing a much smaller portion. Thus, isotopes are less helpful for understanding the roles of wheat, barley, wine, and olive oil – staples that form the foundation of the Mediterranean diet. Finally, the isotopic composition of human remains is best understood in relation to the compositions of various potential food sources, which should be measured on a case-by-case basis. Ideally, associated animal and plant remains can be identified and tested, but this is often not the case.

Nevertheless, the fact that isotope analysis provides biologically determined evidence that can be tied to specific individuals at a range of social statuses sets it apart from most other types of evidence for the ancient economy. The technology enabling this type of analysis is advancing, as is our understanding of the way different isotopes move through the food web and through organisms, so we can expect more and better studies in the coming years. With a firm grasp of the nature of the evidence and its limitations, isotopic data can become a powerful tool in the economic historian's toolkit.

VI Faunal Remains

Faunal remains – primarily animal bones but also mollusk shells and other remains of nonhuman animals – are a valuable source of information about the ancient economy.⁷⁴ Of these, the most commonly encountered remains in the Graeco-Roman world are those of large, domesticated mammals. This group is composed of cattle, pigs, and the often indistinguishable remains of sheep and goats. These are most often used to study meat consumption and animal husbandry, but bones also provide information about many other topics, including the ways carcasses were processed for meat and other products and even about the relationships between producers and consumers. While these data are collected and analyzed first in the

⁷⁴ The study of faunal remains is called zooarchaeology or archaeozoology. For an overview of the discipline, see Albarella 2017. Methodological issues are treated in depth in Giovias and LeFebvre 2018. MacKinnon 2007 surveys the study of both human and animal bones within classical archaeology.

context of a single site, they become most interesting when combined with and compared to data from other sites in regional, supra-regional, cross-cultural, and diachronic analyses. However, this requires a detailed understanding of the formation processes that shaped a site's faunal assemblage as well as the recovery and recording techniques that produced the published data.

Eating meat requires the frequent slaughter of animals, so most animal bones are related to consumption practices. By comparing faunal assemblages across space and time, we can detect regional and diachronic variation in both the types and amount of meat being consumed.⁷⁵ Increased meat consumption is particularly interesting for economic historians because it indicates broad-based prosperity. Meat is an expensive food, so the very poor do not consume very much. At the same time, there is a limit to how much even a very rich person can eat, so large increases in animal bones often indicate a sizeable group of moderately wealthy people rather than a small group of very wealthy people.⁷⁶

The potential value of faunal remains goes beyond consumption patterns, however.⁷⁷ They can also reveal which animal products were being produced. The age and sex distributions of slaughtered animals reflect the purposes for which they were raised. Animals raised for meat will usually be slaughtered as young adults when their growth rate slows. Of course, if pasture, fodder, or stable space are abundant, the age at slaughter might be later than optimal from an economic perspective.⁷⁸ Dairy herds will be dominated by adult females who have given birth, so an assemblage dominated by the bones of slaughtered young animals, particularly young males, indicates that milk was the most important product. Both male and female sheep provide wool throughout their lives, so wool production generally produces an assemblage dominated by older individuals of both sexes. Similarly, cattle that are kept for traction and manure will be killed later in life.⁷⁹

The size, shape, and morphological features of a bone specimen can help determine the species, sex, and part of the animal from which it came. The most common methods to deduce age at death rely on the degree to which teeth have erupted

⁷⁵ King (1999) gathered data from all over the Roman Empire to trace regional variations in diet. His data were later used by Jongman (2007) to argue for increasing levels of meat consumption both in Italy and the provinces during the Principate.

⁷⁶ Jongman 2007, 613. This simple correlation between animal bones and prosperity assumes broadly consistent economic strategies and cultural attitudes toward meat consumption. It also glosses over potential shifts in the species being consumed and how different parts of the animal were valued.

⁷⁷ Groot 2016, 57–67 provides an excellent introduction to the ways in which zooarchaeological data can be used to reconstruct practices of animal production and distribution.

⁷⁸ The demand for meat must also be taken into account. There is no point slaughtering an animal if no one wants to eat it.

⁷⁹ Of course, animals can also serve multiple purposes, and factors other than production efficiency influence slaughter patterns – for example, breeding selection or cultural preferences. Thus, real assemblages are more complex than the models summarized here.

through the mandible and the fusion of long-bone ends. Once these identifications are made, quantification is the next critical step. The two most commonly used estimates are number of identified specimens (NISP) and minimum number of individuals (MNI).⁸⁰ NISP is simply the number of bone fragments that can be assigned to a certain taxon.⁸¹ MNI is the smallest number of animals necessary to produce the assemblage. The biggest problem with NISP is that every animal has many bones of which some unknown portion is deposited, and it is usually impossible to tell which bones in an assemblage come from the same individual.⁸² MNI solves this problem, but introduces another, that of aggregation.⁸³ The total MNI and the ratios between MNIs for different taxa change depending on whether one calculates them for all bones found at a site or separately for different archaeological contexts, and it is not always clear what the most appropriate units for aggregation are. Since NISP is a simple count of specimens while MNI is a derived measurement, and because it is the more commonly reported statistic, synthetic studies usually rely on NISP rather than MNI when assessing species abundance.⁸⁴

In addition to the demographic profile of the slaughtered animal populations, zooarchaeologists study skeletal elements to understand how animals were processed. Marks left on the bones can reveal which animals were butchered for meat and how they were butchered. A comparison of butchery at urban and rural sites in Roman Britain, for example, showed that urban butchers used cleavers to divide carcasses quickly and skillfully.⁸⁵ The relative ubiquity of different parts of the animal can also reveal specialized production. An abundance of skulls and foot bones has been linked to leather production since hides were transported with the skulls and feet attached.⁸⁶ A large quantity of meat-bearing bones suggests the consumption of joints of meat that had been prepared elsewhere. Similarly, a dearth of such bones could indicate a butchery site from which meat has been removed to be consumed elsewhere.⁸⁷

At the same time, it must be remembered that the presence or absence of both species and skeletal elements might have more to do with what happens between

80 For a detailed discussion of NISP and MNI, see Lyman 2008, 21–82.

81 A taxon is the group to which an organism belongs at any level of classification (e.g., family, genus, or species).

82 Other problems include differential rates of fragmentation, identifiability, and frequency of bones between species.

83 Another significant problem is that there are multiple ways of calculating MNI, and the method used is not always made explicit. MNI also tends to exaggerate the importance of rare species because a species with an NISP of 1 has an MNI of 1, whereas a species with an NISP of 3 might have an MNI of 3, 2 or 1.

84 Lyman (2008, 78–82) argues forcefully for the use of NISP over MNI.

85 Seetah 2006.

86 For ancient leather production, see Driel-Murray 2008.

87 For examples, see Groot 2016, 59–62.

the moment of deposition and the moment of discovery than with ancient behavior. Small or fragile bones – like bird and fish bones or low-density bones from sheep, goats, and pigs – are easily destroyed by erosion or scavengers and easily missed by archaeologists unless the soil is sieved.⁸⁸

The mobility of animals and animal products makes it especially critical to compare faunal assemblages from different sites to fully understand the economics of animal products. Meat production might not yield the signature of young adult bones at the place of production if the animals were driven somewhere else to be slaughtered. By comparing assemblages of production and consumption sites, however, it is possible to draw conclusions about market relations. Maaïke Groot has examined faunal assemblages from rural, sacred, urban, and military sites near the Roman frontier on the Lower Rhine.⁸⁹ She not only found a great variety in production strategies on rural sites, she also showed that the species distributions in consumer and producer sites were similar, meaning consumers were eating locally produced meat. Furthermore, cattle were most abundant and therefore the most important source of meat, but the age profile of cattle bones on consumer sites showed a mixture of young and old animals. This means that the farmers were not being forced to supply the most desirable animals to the consumers but were able to use their cattle for labor and manure before sending them to market.

Unlike most types of archaeological material, faunal remains derive directly from ancient food. This makes them invaluable in understanding the production, distribution and consumption of meat. As animals make more than meat, faunal remains are also relevant for the production of leather, wool, bone, glue, grease, and, through manure and labor, even grain. In order to make use of this material the researcher must account for the formation processes, recovery strategies, and methods of quantification and recording that turn bones into data.

VII Pollution

The smelting of ore to extract metal causes air pollution, which deposits trace amounts of metals in peat bogs, lakes, and glaciers. Beginning in the 1990s, environmental scientists have identified elevated levels of copper and lead pollution dating to antiquity, which historians have interpreted as evidence for increased mining activity.⁹⁰ In particular, the levels of lead deposited in Greenland ice sheets

88 For the influence of taphonomic processes on skeletal elements, see Faith and Thompson 2018. For their influence on taxonomic representation, see Fisher 2018. For the use of bones as evidence for taphonomy, see Lyman 2008, 264–298.

89 Groot 2016.

90 Scheidel provides citations to all the relevant evidence from the 1990s and 2000s (2009, 47–48, n. 7). The evidence has been used by de Callatay 2005; Kehoe 2007; Scheidel 2009; Wilson 2002.

reflect silver mining, which occurred predominantly in Spain in the Roman period. However, the limited number of samples, the low chronological resolution of the data and uncertainty about the source of the lead have cast doubt on the usefulness of the results.⁹¹ Recently, however, a new analysis of an ice core from Greenland has addressed these problems.⁹² A team lead by Joseph McConnell at the Desert Research Institute in Reno, Nevada analyzed trace elements in an ice core over 400 m long. They achieved sub-annual chronological resolution by identifying annual fluctuations in the concentrations of different chemicals and elements. Absolute dates were established by aligning the record with a known volcanic eruption in 1257 CE that left a distinctive concentration of sulfur in the core.

The origin of the lead pollution was confirmed through comparison with published records from peat bogs where a Roman origin had been inferred or supported by isotopic analysis. Because the concentrations of lead followed similar diachronic trends they must have come from the same source, and because lead concentrations declined with distance from southern Spain, that source must have been the Spanish silver mines. McConnell's team also used a newly developed climate model to calculate how sensitive the records from the ice core and the peat bogs were to changes in lead emissions around the world. They found that these sites were much more sensitive to emissions from southwestern Europe and northwestern Africa than other parts of the world like China and that the ratios of lead concentration between the sites was consistent with a source in Spain. On the other hand, the Greenland ice core record was much more sensitive to emissions from Britain, but because archaeological and historical evidence suggests much lower levels of mining in Britain than Spain, they still conclude that the record primarily reflects Spanish mining activity. Nevertheless, the possibility that British mining accounts for some unknown portion of the variation should be kept in mind.⁹³

As a result, it is now possible to correlate lead emissions, and thus mining activity in Spain, to historical events. In particular, the civil war of the Late Republic corresponds to a steep decline in lead pollution, which then grew rapidly under Augustus and peaked in the first century CE. Emissions in the second century continued at a slightly lower level until the mid-160s, when they declined precipitously and did not recover until the Middle Ages. This suggests that the Antonine Plague (165–180 CE) can be blamed for decreased silver production – also visible in the declining levels of silver present in Roman coins from this time.

How these new data will be incorporated into scholarship on the Roman economy remains to be seen.⁹⁴ It will be important to keep in mind that fluctuations in

⁹¹ Wilson 2014, 156–157.

⁹² McConnell et al. 2018.

⁹³ The authors also discuss the influence of mines in Germany on the record, McConnell et al. 2018, 5728.

⁹⁴ For a first attempt, see Manning 2018.

the deposition of lead pollution in Greenland do not directly reflect fluctuations in total silver production in the Roman Empire because some sources, such as those in Britain, are overrepresented while others, like those in the Balkans, are underrepresented. Further, although the chronological resolution of the data is higher than any other source at our disposal, variations in the atmospheric transmission and deposition of lead undermine any conclusions based on very short-term fluctuations. Finally, silver production is not the same thing as money supply, which also depended on gold and nonmetallic forms of money.⁹⁵

VIII Other Material Evidence

The selection presented above represents types of data that have historically been prominent within discussions of the Roman economy or are currently rising in prominence. It would be wrong, however, to omit entirely a few other important sources of evidence. These include archaeobotanical remains, stone, and production facilities.

Archaeobotanical evidence, the remains of ancient plants, consists of both palynological data and macro-remains. Palynology is the study of ancient pollen, the grains of which are recovered from soil cores extracted from lakes and wetlands.⁹⁶ Pollen collects in these environments and sinks to the bottom, forming sequences that can span thousands of years. By comparing the prevalence of pollen from trees to that from other plants, one can trace the fluctuating extent of forests and open land. By tracking the prevalence of pollen from specific plant species, including crops but also weeds that are known to grow on the edges of fields, it is possible to trace changes in agricultural regimes over time. At the same time, pollen diagrams are not simple representations of the vegetation in the area around the core. Wind-pollinated species, which produce more pollen that travels farther than insect-pollinated species, are often overrepresented. Furthermore, the chronological resolution of these cores can be coarse, which obscures short-term dynamics.

Macro-remains are larger than pollen.⁹⁷ They include primarily seeds, but also other parts of the plant and provide valuable evidence about the types of crops that were being grown and consumed. They can even shed light on the ways in which crops were processed and stored. Seeds can also reveal the introduction of new crops to an area or, if the species does not grow locally, their importation. Macro-remains also include wood fragments, which can be assigned to a species and sometimes dated dendrochronologically. Sequences of rings that stretch thousands of years into

⁹⁵ Von Reden, ch. 8.C, this volume.

⁹⁶ See Izdebski et al. 2016 for a specifically economic application of palynological evidence.

⁹⁷ Van der Veen 2018.

the past have been compiled by combining preserved wood samples. The rings in newly discovered samples can then be compared to the master sequence to find the date the tree was felled. Plant macro-remains are usually preserved through charring, but arid and waterlogged environments can also yield well-preserved specimens.

Stone is much more durable than plant remains and can be found in numerous archaeological contexts.⁹⁸ Most of the stone used by people in the ancient world was quarried locally, but some rare types could be imported over long distances, as for example from the quarries in the Eastern Desert of Egypt. These included exotic decorative stones such as marble, porphyry, or alabaster, but also stones with particular utilitarian characteristics. In the ancient Mediterranean, the latter were mostly volcanic stones used for grinding. The origins of these stones can be determined through petrographic and chemical analyses, allowing for the reconstruction of trade networks.

The remains of production facilities have been used to reconstruct the scale on which certain goods were produced. Olive oil and wine presses, which often included large stone elements with characteristic shapes, have long been used for this purpose.⁹⁹ The output of a press can be estimated based on ethnographic comparison, so by counting the number of presses in a region, it is possible to estimate annual production. This type of study has revealed production on a scale that can only be explained by large-scale exports in certain areas, particularly in the southwestern part of the Iberian Peninsula. More recently, fish-salting facilities have proven similarly illuminating. These consist of large vats often made of concrete. Measuring the vats provides an indication of the scale of production, which was also massive in certain areas.¹⁰⁰

IX Conclusion

The range of sources for archaeological evidence about the ancient world is immense and diverse. Each type requires its own set of interpretive techniques to transform remains into useful evidence. Nevertheless, the potential of archaeological evidence is also immense. While those who have the means to consume in larger quantities will usually be overrepresented in the archaeological record, people from all segments of the population could leave traces. Furthermore, these traces can often be directly related to the economic activities in which we are interested. The archaeological record is not evenly distributed across space. Some conditions are

⁹⁸ Russell 2013.

⁹⁹ Mattingly (1988), working in North Africa and Spain, was the first to quantify oil production based on presses. Marzano (2013) has examined large-scale pressing facilities around the empire.

¹⁰⁰ Wilson 2006; 2014, 157–160.

more conducive to preservation than others, and some areas have enjoyed a longer, more intensive history of investigation. Nevertheless, archaeological remains can potentially be found almost anywhere. In many places they are the only evidence we have for the ancient economy.

The archaeological record is also growing fast. More people are producing more data from more places than ever before. New techniques are being invented, like DNA analysis, that are producing new types of data, while digital tools allow us to analyze old types of data in new ways. Most radically, perhaps, the internet is making this flood of data widely accessible. Archaeologists and historians are still developing ways to link, organize, and harness these data for the purpose of understanding the past. Just over 30 years ago, Kevin Greene published a book arguing for the relevance of archaeology to the study of the Roman economy.¹⁰¹ Today, it would be impossible to write about the ancient economy without archaeology.

References

- Adams, D. 1979. *The hitchhiker's guide to the galaxy*. London: Pan Books.
- Adams, W. Y., and E. W. Adams. 1991. *Archaeological typology and practical reality: A dialectical approach to artifact classification and sorting*. Cambridge: Cambridge University Press.
- Albarella, U. 2017. "Zooarchaeology in the twenty-first century: Where we come from, where we are now, and where we are going." In U. Albarella, M. Rizzetto, H. Russ, K. Vickers, and S. Viner-Daniels (eds.), *The Oxford handbook of zooarchaeology*, 3–21. Oxford: Oxford University Press.
- Alcock, S. E., and J. F. Cherry, eds. 2004. *Side-by-side survey: Comparative regional studies in the Mediterranean world*. Oxford: Oxbow.
- Arrington, N. T., D. Terzopoulou, M. Tasaklaki, M. L. Lawall, D. J. Brellas, and C. E. White. 2016. "Molyvoti, Thrace, archaeological project: 2013 preliminary report." *Hesperia* 85.1, 1–64.
- Attema, P., and G. Schörner, eds. 2012. *Comparative issues in the archaeology of the Roman rural landscape: Site classification between survey, excavation and historical categories*. Portsmouth, RI: Journal of Roman Archaeology.
- Banning, E. B. 2002. *Archaeological survey*. New York, NY: Kluwer Academic.
- Bes, P. 2015. *Once upon a time in the East: The chronological and geographical distribution of terra sigillata and red slip ware in the Roman East*. Oxford: Archaeopress.
- Bonifay, M., and N. Garnier. 2007. "Que transportaient donc les amphores africaines?" In E. Papi and M. Bonifay (eds.), *Supplying Rome and the empire: The proceedings of an international seminar held at Siena–Certosa di Pontignano on May 2–4, 2004 on Rome, the provinces, production and distribution*, 8–31. Portsmouth, RI: Journal of Roman Archaeology.
- Bughmans, T., and J. Poblome. 2016. "Roman bazaar or market economy? Explaining tableware distributions through computational modelling." *Antiquity* 90.350, 393–408.
- Campana, S. R. L. 2018. *Mapping the archaeological continuum: Filling 'empty' Mediterranean landscapes*. Cham: Springer.
- Clarke, D. L. 1977. *Spatial archaeology*. London: Academic Press.

¹⁰¹ Greene 1986.

- Crema, E. R. 2015. "Time and probabilistic reasoning in settlement analysis." In J. A. Barcelo and I. Bogdanovic (eds.), *Mathematics and archaeology*, 314–334. Boca Raton, FL: CRC.
- David, B., and J. Thomas, eds. 2008. *Handbook of landscape archaeology*. Walnut Creek, CA: Left Coast Press.
- de Callatay, F. 2005. "The Graeco-Roman economy in the super long-run: Lead, copper, and shipwrecks." *Journal of Roman Archaeology* 18, 361–372.
- . 2014. "Long-term quantification in ancient history: A historical perspective." In F. de Callatay (ed.), *Quantifying the Greco-Roman economy and beyond*, 13–27. Bari: Edipuglia.
- Driel-Murray, C. van 2008. "Tanning and leather." In J. P. Oleson (ed.), *The Oxford handbook of engineering and technology in the classical world*, 483–495. Oxford: Oxford University Press.
- Dunnell, R. C. 1992. "The notion site." In J. Rossignol and L. Wandsnider (eds.), *Space, time, and archaeological landscapes*, 21–41. New York, NY: Plenum.
- Eiring, J., and J. Lund, eds. 2004. *Transport amphorae and trade in the Eastern Mediterranean: Acts of the international colloquium at the Danish Institute at Athens, September 26–29, 2002*. Aarhus: Aarhus University Press.
- Faith, J. T., and J. C. Thompson. 2018. "Low-survival skeletal elements track attrition, not carcass transport behavior in quaternary large mammal assemblages." In Giovas and LeFebvre (2018), 109–126.
- Farinetti, E. 2011. *Boeotian landscapes: A GIS-based study for the reconstruction and interpretation of the archaeological datasets of ancient Boeotia*. Oxford: Archaeopress.
- Fenn, N., and C. Römer-Strehl, eds. 2013. *Networks in the Hellenistic world: According to the pottery in the Eastern Mediterranean and beyond*. Oxford: Archaeopress.
- Fentress, E. 2000. "What are we counting for?" In Francovich, Patterson, and Barker (2000), 44–52.
- Fisher, J. L. 2018. "Influence of bone survivorship on taxonomic abundance measures." In Giovas and LeFebvre (2018), 127–149.
- Foley, B. P., M. C. Hansson, D. P. Kourkoumelis, and T. A. Theodoulou. 2012. "Aspects of ancient Greek trade re-evaluated with amphora DNA evidence." *Journal of Archaeological Science* 39.2, 389–398.
- Forte, M., and S. Campana, eds. 2016. *Digital methods and remote sensing in archaeology: Archaeology in the age of sensing*. New York, NY: Springer.
- Francovich, R., H. Patterson, and G. Barker, eds. 2000. *Extracting meaning from ploughsoil assemblages*. Oxford: Oxbow.
- Fulford, M. 2018. "Procurators' business? Gallo-Roman sigillata in Britain in the second and third centuries AD." In A. Wilson and A. K. Bowman (eds.), *Trade, commerce, and the state in the Roman world*, 301–325. Oxford: Oxford University Press.
- Giannechini, M., and J. Moggi-Cecchi. 2008. "Stature in archeological samples from central Italy: Methodological issues and diachronic changes." *American Journal of Physical Anthropology* 135.3, 284–292.
- Giovas, C. M., and M. J. LeFebvre, eds. 2018. *Zooarchaeology in practice: Case studies in methodology and interpretation in archaeofaunal analysis*. New York, NY: Springer.
- Goodchild, H. 2013. "GIS models of Roman agricultural production." In A. K. Bowman and A. Wilson (eds.), *The Roman agricultural economy: Organization, investment, and production*, 55–83. Oxford: Oxford University Press.
- Goodchild, H., and R. Witcher. 2009. "Modelling the agricultural landscapes of Republican Italy." In J. Carlsen and E. Lo Cascio (eds.), *Agricoltura e scambi nell'Italia tardo-repubblicana*, 187–220. Bari: Edipuglia.
- Gowland, R., and L. Walthers. 2018. "Human growth and stature." In W. Scheidel (ed.), *The science of Roman history: Biology, climate, and the future of the past*, 174–204. Princeton, NJ: Princeton University Press.

- Greene, K. 1986. *The archaeology of the Roman economy*. London: Batsford.
- . 2005. “Roman pottery: Models, proxies and economic interpretation.” *Journal of Roman Archaeology* 18, 34–56.
- Groot, M. 2016. *Livestock for sale: Animal husbandry in a Roman frontier zone: The case study of the civitas Batavorum*. Amsterdam: Amsterdam University Press.
- Harper, K. 2017. *The fate of Rome: Climate, disease, and the end of an empire*. Princeton, NJ: Princeton University Press.
- Hartley, B., and B. M. Dickinson. 2008–2012. *Names on terra sigillata: An index of makers' stamps & signatures on Gallo-Roman terra sigillata (Samian ware)*. 9 vols. London: Institute of Classical Studies.
- Hayes, J. W. 1991. “Fine wares in the Hellenistic world.” In T. Rasmussen and N. Spivey (eds.), *Looking at Greek vases*, 183–202. Cambridge: Cambridge University Press.
- . 1997. *Handbook of Mediterranean Roman pottery*. Norman, OK: University of Oklahoma Press.
- Hodder, I., and C. Orton. 1976. *Spatial analysis in archaeology*. Cambridge: Cambridge University Press.
- Hopkins, K. 1980. “Taxes and trade in the Roman Empire (200 BC–AD 400).” *Journal of Roman Studies* 70, 101–125.
- Horden, P., and N. Purcell. 2000. *The corrupting sea: A study of Mediterranean history*. Malden, MA: Blackwell.
- Howey, M. C. L., and M. Brouwer Burg, eds. 2017. “Archaeological GIS today: Persistent challenges, pushing old boundaries, and exploring new horizons.” Special issue, *Journal of Archaeological Science* 84.
- Hunt, A. M. W. 2017. *The Oxford handbook of archaeological ceramic analysis*. Oxford: Oxford University Press.
- Ingold, T. 1993. “The temporality of the landscape.” *World Archaeology* 25.2, 152–174.
- Izdebski, A., G. Koloch, T. Słoczyński, and M. Tycner. 2016. “On the use of palynological data in economic history: New methods and an application to agricultural output in central Europe, 0–2000 AD.” *Explorations in Economic History* 59, 17–39.
- Jiménez, A. 2017. “Standard time: Typologies in Roman antiquity.” In A. Van Oyen and M. Pitts (eds.), *Materialising Roman histories*, 75–84. Oxford: Oxbow.
- Jongman, W. 2007. “The early Roman Empire: Consumption.” In W. Scheidel, I. Morris, and R. P. Saller (eds.), *The Cambridge economic history of the Greco-Roman world*, 592–618. Cambridge: Cambridge University Press.
- Kehoe, D. 2007. “The early Roman Empire: Production.” In W. Scheidel, I. Morris, and R. P. Saller (eds.), *The Cambridge economic history of the Greco-Roman world*, 541–569. Cambridge: Cambridge University Press.
- King, A. 1999. “Diet in the Roman world: A regional inter-site comparison of the mammal bones.” *Journal of Roman Archaeology* 12, 168–202.
- Klein Goldewijk, G., and J. Jacobs. 2013. “The relation between stature and long bone length in the Roman Empire.” *Research Report 13002-EEF*. Research Institute SOM, University of Groningen.
- Koepke, N. 2016. “The biological standard of living in Europe from the Late Iron Age to the Little Ice Age.” In J. Komlos and I. R. Kelly (eds.), *The Oxford handbook of economics and human biology*, 70–108. Oxford: Oxford University Press.
- Koepke, N., and J. Baten. 2008. “Agricultural specialization and height in ancient and medieval Europe.” *Explorations in Economic History* 45.2, 127–146.
- Kron, G. 2005. “Anthropometry, physical anthropology, and the reconstruction of ancient health, nutrition, and living standards.” *Historia* 54, 68–83.
- Larsen, C. S. 2015. *Bioarchaeology: Interpreting behavior from the human skeleton*. 2nd ed. Cambridge: Cambridge University Press.

- Lewit, T. 2011. "Dynamics of fineware production and trade: The puzzle of supra-regional exporters." *Journal of Roman Archaeology* 24, 313–332.
- Lyman, R. L. 2008. *Quantitative paleozoology*. Cambridge: Cambridge University Press.
- MacKinnon, M. 2007. "Osteological research in classical archaeology." *American Journal of Archaeology* 111.3, 473–504.
- Manning, J. G. 2018. *The open sea: The economic life of the ancient Mediterranean world from the Iron Age to the rise of Rome*. Princeton, NJ: Princeton University Press.
- Martella, P., M. Brizzi, and E. Sanna. 2018. "Is the evaluation of millennial changes in stature reliable? A study in southern Europe from the Neolithic to the Middle Ages." *Archaeological and Anthropological Sciences* 10.3, 523–536.
- Marzano, A. 2013. "Capital investment and agriculture: Multi-press facilities from Gaul, the Iberian Peninsula, and the Black Sea region." In A. K. Bowman and A. Wilson (eds.), *The Roman agricultural economy: Organization, investment, and production*, 107–141. Oxford: Oxford University Press.
- Mattingly, D. J. 1988. "Oil for export? A comparison of Libyan, Spanish and Tunisian olive oil production in the Roman Empire." *Journal of Roman Archaeology* 1, 33–56.
- McConnell, J. R., A. I. Wilson, A. Stohl, M. M. Arienzo, N. J. Chellman, S. Eckhardt, E. M. Thompson, A. M. Pollard, and J. P. Steffensen. 2018. "Lead pollution recorded in Greenland ice indicates European emissions tracked plagues, wars, and imperial expansion during antiquity." *Proceedings of the National Academy of Sciences* 115.22, 5726–5731.
- Morley, N. 2014. "Orders of magnitude, margins of error." In F. de Callatay (ed.), *Quantifying the Greco-Roman economy and beyond*, 29–42. Bari: Edipuglia.
- Orton, C. 1993. "How many pots make five? An historical review of pottery quantification." *Archaeometry* 35.2, 169–184.
- Orton, C., and M. Hughes. 2013. *Pottery in archaeology*. 2nd ed. Cambridge: Cambridge University Press.
- Oxé, A., H. Comfort, and P. M. Kenrick. 2000. *Corpus vasorum Arretinorum: A catalogue of the signatures, shapes and chronology of Italian sigillata*. 2nd ed. Bonn: Habelt.
- Parcak, S. H. 2017. "GIS, remote sensing, and landscape archaeology." *Oxford Handbooks Online*. <https://doi.org/10.1093/oxfordhb/9780199935413.013.11>.
- Parker, A. J. 1992. *Ancient shipwrecks of the Mediterranean and the Roman provinces*. Oxford: Tempus Reparatum.
- Peacock, D. P. S. 1982. *Pottery in the Roman world: An ethnoarchaeological approach*. London: Longman.
- Peacock, D. P. S., and D. F. Williams. 1986. *Amphorae and the Roman economy: An introductory guide*. London: Longman.
- Pecci, A., J. Clarke, M. Thomas, J. Muslin, I. van der Graaff, L. Toniolo, D. Miriello, G. M. Crisci, M. Buonincontri, and G. Di Pasquale. 2017. "Use and reuse of amphorae: Wine residues in Dressel 2–4 amphorae from Oplontis Villa B (Torre Annunziata, Italy)." *Journal of Archaeological Science: Reports* 12, 515–521.
- Peña, J. T. 2007. *Roman pottery in the archaeological record*. Cambridge: Cambridge University Press.
- Pollard, M., C. Batt, B. Stern, and S. M. M. Young. 2007. *Analytical chemistry in archaeology*. Cambridge: Cambridge University Press.
- Reynolds, P. 2018. "The supply networks of the Roman East and West: Interaction, fragmentation, and the origins of the Byzantine economy." In A. Wilson and A. K. Bowman (eds.), *Trade, commerce, and the state in the Roman world*, 353–396. Oxford: Oxford University Press.
- Rice, C. 2016. "Shipwreck cargoes in the Western Mediterranean and the organization of Roman maritime trade." *Journal of Roman Archaeology* 29, 165–192.
- Roper, D. C. 1979. "The method and theory of site catchment analysis: A review." *Advances in Archaeological Method and Theory* 2, 119–140.

- Rubio-Campillo, X., J.-M. Montanier, G. Rull, J. M. Bermúdez Lorenzo, J. Moros Díaz, J. Pérez González, and J. Remesal Rodríguez. 2018. "The ecology of Roman trade: Reconstructing provincial connectivity with similarity measures." *Journal of Archaeological Science* 92, 37–47.
- Russell, B. 2013. *The economics of the Roman stone trade*. Oxford: Oxford University Press.
- Scheidel, W. 2009. "In search of Roman economic growth." *Journal of Roman Archaeology* 22, 46–70.
- . 2012. "Physical well-being." In W. Scheidel (ed.), *The Cambridge companion to the Roman economy*, 321–333. Cambridge: Cambridge University Press.
- . 2014. "The shape of the Roman world: Modelling imperial connectivity." *Journal of Roman Archaeology* 27, 7–32.
- Seetah, K. 2006. "Multidisciplinary approach to Roman-British cattle butchery." In M. Maltby (ed.), *Integrating zooarchaeology: Proceedings of the 9th conference of the International Council of Archaeozoology, Durham, August 2002*, 111–118. Oxford: Oxbow.
- Sinopoli, C. M. 1991. *Approaches to archaeological ceramics*. New York, NY: Springer Science & Business Media.
- Spataro, M., and A. Villing, eds. 2015. *Ceramics, cuisine and culture: The archaeology and science of kitchen pottery in the ancient Mediterranean world*. Oxford: Oxbow.
- Sperduti, A., L. Bondioli, O. Craig, T. L. Prowse, and P. Garnsey. 2018. "Bones, teeth, and history." In W. Scheidel (ed.), *The science of Roman history: Biology, climate, and the future of the past*, 123–173. Princeton, NJ: Princeton University Press.
- Steckel, R. H. 2013. "Biological measures of economic history." *Annual Review of Economics* 5.1, 401–423.
- Stulp, G., and L. Barrett. 2016. "Evolutionary perspectives on human height variation." *Biological Reviews* 91.1, 206–234.
- Terrenato, N. 2004. "Sample size matters! The paradox of global trends and local surveys." In Alcock and Cherry (2004), 36–48.
- Tomber, R. 1993. "Quantitative approaches to the investigation of long-distance exchange." *Journal of Roman Archaeology* 6, 142–166.
- Van der Veen, M. 2018. "Archaeobotany: The archaeology of human-plant interactions." In W. Scheidel (ed.), *The science of Roman history: Biology, climate, and the future of the past*, 53–94. Princeton, NJ: Princeton University Press.
- Van Oyen, A. 2017. "Agents and commodities: A response to Brughmans and Poblome (2016) on modelling the Roman economy." *Antiquity* 91.359, 1356–1363.
- Verdan, S. 2011. "Pottery quantification: Some guidelines." In S. Verdan, T. Theurillat, and A. Kenzelmann Pfyffer (eds.), *Early Iron Age pottery: A quantitative approach: Proceedings of the international round table organized by the Swiss School of Archaeology in Greece (Athens, November 28–30, 2008)*, 165–170. Oxford: Archaeopress.
- Vita-Finzi, C., and E. S. Higgs. 1970. "Prehistoric economy in the Mount Carmel area of Palestine: Site catchment analysis." *Proceedings of the Prehistoric Society* 36, 1–37.
- Ward-Perkins, B. 2005. *The fall of Rome and the end of civilization*. Oxford: Oxford University Press.
- Weaverdyck, E. J. S. 2016. "Isolation or integration? A spatial analytical approach to the local impact of the Roman army on the northern frontier." PhD diss., University of California, Berkeley.
- . 2019. "The role of forts in the local market system in the Lower Rhine: Toward a method of multiple hypothesis testing through comparative modelling." In P. Verhagen, J. Joyce, and M. R. Groenhuizen (eds.), *Finding the limits of the Limes: Modelling demography, economy and transport on the edge of the Roman Empire*, 165–190. New York, NY: Springer.
- Whitbread, I. K. 1995. *Greek transport amphorae: A petrological and archaeological study*. Athens: British School at Athens.

- Wilson, A. I. 2002. "Machines, power and the ancient economy." *Journal of Roman Studies* 92, 1–32.
- . 2006. "Fishy business: Roman exploitation of marine resources." *Journal of Roman Archaeology* 19, 525–537.
 - . 2008. "Large-scale manufacturing, standardization, and trade." In J. P. Oleson (ed.), *The Oxford handbook of engineering and technology in the classical world*, 393–417. Oxford: Oxford University Press.
 - . 2009. "Approaches to quantifying Roman trade." In A. K. Bowman and A. Wilson (eds.), *Quantifying the Roman economy: Methods and problems*, 213–249. Oxford: Oxford University Press.
 - . 2014. "Quantifying Roman economic performance by means of proxies: Pitfalls and potential." In F. de Callatay (ed.), *Quantifying the Greco-Roman economy and beyond*, 147–167. Bari: Edipuglia.