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Health and wealth in the Roman Empire

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ABSTRACT

Ancient Rome was the largest and most populous empire of its time, and the largest pre-industrial state in European history. Recent though not universally accepted research suggests that at least for the most populous central periods of its history standard of living was also rather higher than before or after. To trace whether this is also reflected in Roman biological standard of living, we present the first large and more or less comprehensive dataset, based on skeletal data for some 10,000 individuals, covering all periods of Roman history, and all regions (even if inevitably unequally). We discuss both the methodologies that we developed and the historical results. Instead of reconstructing heights from the long bones assuming fixed body proportions or from one individual long bone, we apply exploratory factor analysis and calculate factor scores for 50-year periods. Our measure of the biological standard of living declined during the last two centuries B.C. and started to improve again, slowly at first, from the second century A.D. It correlated negatively with population, but also with other aspects of standard of living such as wages or diets.

1. Introduction

Ancient Rome was one of the largest and longest lasting world empires of preindustrial history, stretching from the North of England and the Danube to western Morocco, and the Syrian Desert. At the peak of its political power in the first and early second century A.D. it had a population that has been variously estimated between 60 and 90 million inhabitants. That population was so large because of the geographical extent of the Empire, but also because of relatively high population densities.

Unfortunately there is virtually no documentary evidence on Roman population numbers. There is a little bit from Roman Egypt, but that is it. This is not because the Roman state did not collect such data (it did), but because outside Egypt none of these administrative documents survived. For Roman Italy we also have some census numbers for the second and first century B.C. reported in literary sources, but already for a century scholars have disagreed about who were included in the census, and if this changed over time. And that is effectively all we have for written data. Fortunately archaeological research of the last few decades has given us far better data from archaeological field surveys (collections of hundreds of thousands of surface finds from a small region), and they show a pretty consistent pattern of substantial increases in rural site numbers and site sizes. This went hand in hand with a substantial urban growth from existing and new towns. In Italy this rural and urban growth mostly occurred from the late fourth or early third century B.C., and in the provinces often following Roman conquest (see Deru, 2017 for some good provincial examples). Numbers mostly peak in the first and early second century A.D., followed by often quite dramatic decline, mostly from the late second century A.D., after the so-called Antonine Plague, an epidemic of probably smallpox that began to ravage the Empire from AD 165. The effect is quite visible in the field survey data, even if smoothed by the low chronological resolution of the African red slip pottery that covers precisely the date range of A.D. 100 to 250.

One limitation of such data was that the original data are site numbers, so to arrive at population numbers we have to assign estimates for numbers of inhabitants to the different site size categories. Fig. 1 shows precisely such recent population reconstructions for two parts of Roman Italy, and the similarities are obvious. Admittedly this graph reports only two small regions, but a current Dutch, Italian and British project aims to homogenize and then integrate a large number of such surveys into one dataset for future aggregate analysis, beginning with three well know surveys around the city of Rome (the Dutch Pontine Region Project, the Italian Suburbium Project and the British Tiber valley Project).

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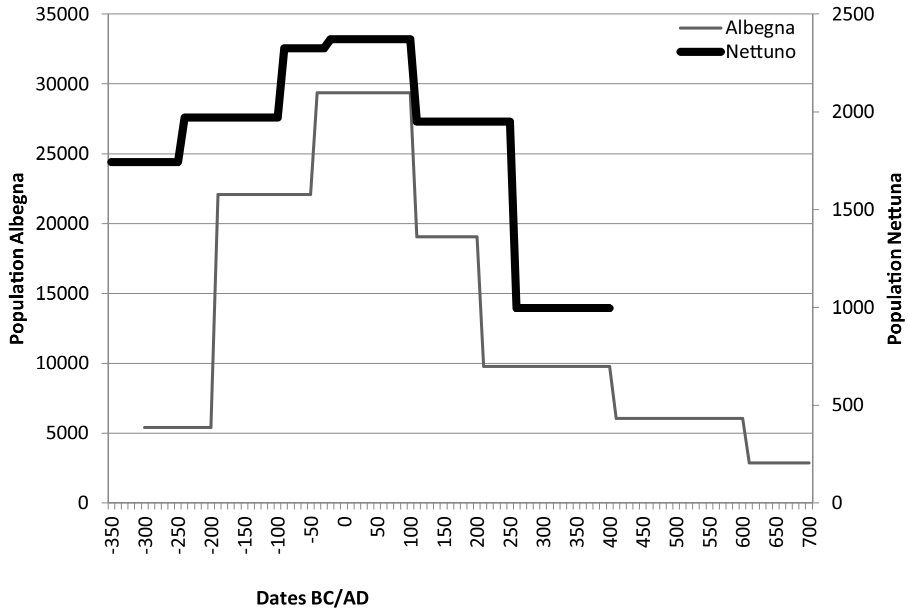


Fig. 1. From sites to population: Albegna (left axis) and Nettuno (right axis). Based on Fentress, 2009 and De Haas et al., 2011.

The historical question is about the consequences of this quite massive growth and subsequent decline in population: did standard of living respond in Malthusian fashion or, alternatively, was the population boom the response to increased prosperity, and the subsequent decline the response to increased poverty?

In this paper we exploit the link between stature, the biological standard of living and economic development (Komlos, 1994). However in contrast to studies covering more recent periods in which heights come from conscripts archives (see e.g. Coppola, 2013) or convicts records (see e.g. Morin et al., 2017), our biological standard of living measure is based on 'bones'. We report on thus far the largest dataset on biological standard of living in the Roman Empire, covering its entire geographical extent for a period of more than one thousand years, and collected by Klein Goldewijk. We are preparing a monograph to document our data and methodologies in greater detail (Klein Goldewijk et al., in preparation). We compare our results with related studies based on skeleton remains (Koepke and Baten, 2005; Koepke, 2016 and Galofré-Vilà et al., 2018), and other data on different aspects of standard of living.

We find that Roman biological standard of living was lowest precisely in the period with highest population densities and levels of urbanization in the last one or two centuries B.C. and the first one or two centuries A.D. However, we also observe that indicators of material standard of living such as diet followed an inverted pattern from that of the biological standard of living. Popular prosperity was highest in the peak period of Roman power and population density, when biological standard of living was lowest.

2. Data and methods

We are interested in the biological standard of living, which is often approximated by the stature of the men and women (Steckel, 2009). For earlier periods of history where documentary data are few or non-existent this has to be done from skeletal data. Previous projects on Roman biological standard of living had been based on datasets that only used a part of the existing skeletal material. Such smallish datasets can potentially be misleading, as we also discovered ourselves, with an early pilot study with a far smaller dataset: those results have now been refuted by the much larger current dataset (Jongman, 2007b).

Our project set out to collect the largest possible dataset of skeletal data on body length for the entire territory of the Roman Empire, and for the entire period of more than 1000 years: we collected published and unpublished osteological reports on human skeletal remains found in the Roman Empire, and dated between 500 B.C. and A.D. 750. This Roman stature database contains over 10,000 adult men and women born between 500 B.C. and A.D. 750 and buried in the territory of the Roman Empire at its largest extent. It

Table 1
Number of individuals in the Roman stature database.

			men	women
number of individuals		minimum[a]	5745	4261
		maximum	7879	5926
leg bones	femur	measure nr. 1[b]	4198	3164
		measure nr. 2	1789	1306
	tibia	measure nr. 1	3522	2537
		measure nr. 1a	219	74
		measure nr. 1b	738	585
	fibula	measure nr. 1	746	546
arm bones	humerus	measure nr. 1	3564	2554
		measure nr. 2	715	485
	radius	measure nr. 1	2922	2121
		measure nr. 1b	228	159
		measure nr. 2	337	227
	ulna	measure nr. 1	1928	1316
		measure nr. 2	304	225
sum of bone measures			21283	15339

[a] We do not know how many individuals the database contains exactly, as some publications only mention the average long bone length of a group of skeletons.
[b] Bone measure numbers refer to Martin (1928).

Table 2
Factor loadings.

	All		Males		Females	
	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2
femur	0.973	−0.134	0.954	−0.158	0.946	−0.252
tibia	0.967	−0.202	0.950	−0.247	0.945	−0.202
fibula	–	–	–	–	–	–
humerus	0.970	0.165	0.945	0.252	0.943	0.150
radius	0.968	0.171	0.948	0.156	0.929	0.310
ulna	–	–	–	–	–	–
eigenvalues	3.759	0.115	3.603	0.174	3.541	0.223

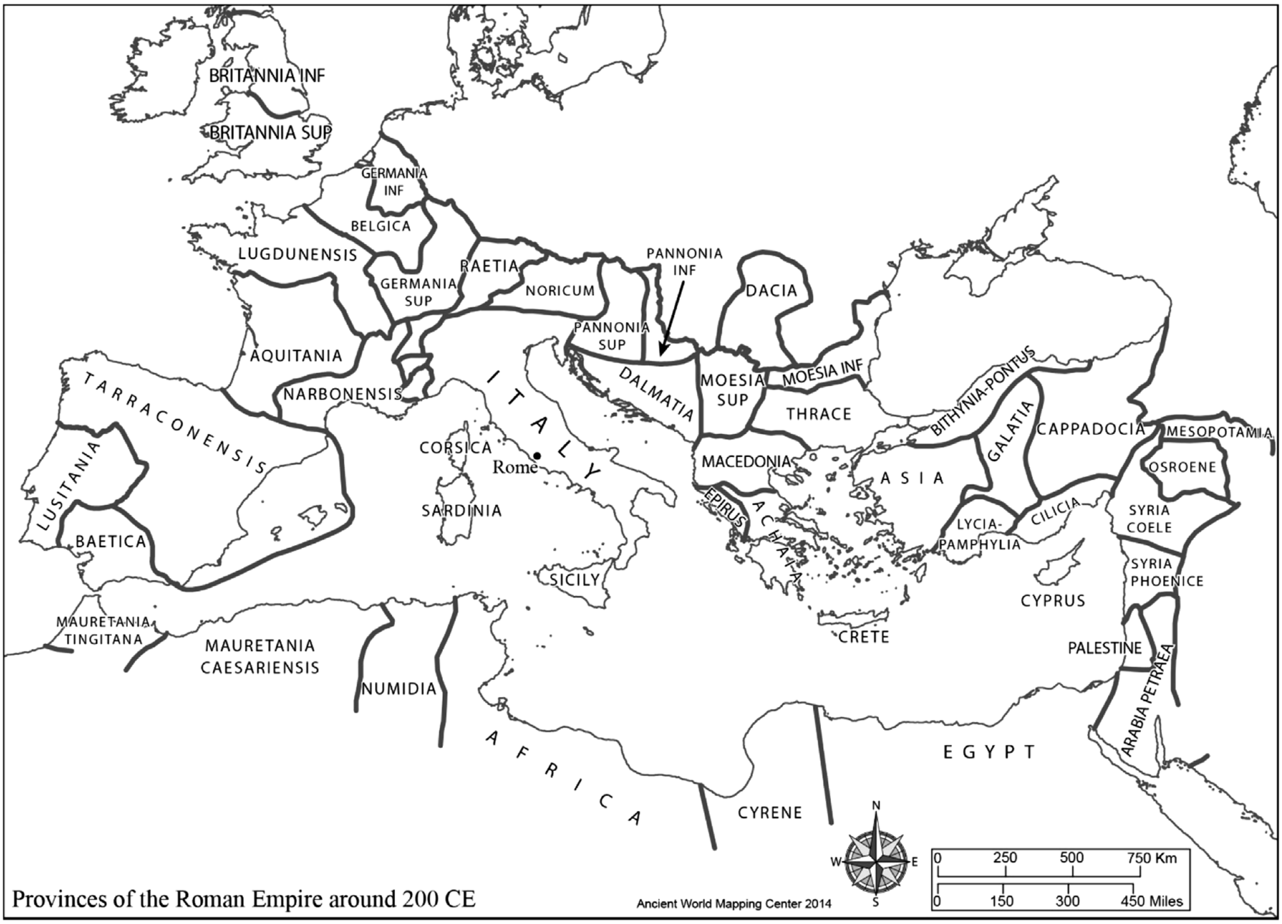


Fig. 2. The Roman Empire, around AD 200 (Source: Talbert, 2017).

includes all available length measures of the six long bones, the femur, the tibia and the fibula in the leg, and the humerus, the radius and the ulna in the arm – over 35,000 in total (see Table 1).

Unfortunately these data do not give us the stature/total body length information of the kind that is mostly used in research on more recent populations. Skeletal length is not the same as body length, and for most people in our dataset not even all long bones have survived: we mostly know the length of only one or more of the long bones. The literature distinguishes several methods to nevertheless obtain a summary measure (proxy). The first method reconstructs stature from the skeleton implicitly assuming fixed body proportions (see e.g. Koepke and Baten, 2005 and Galofreé-Vilaà et al., 2018). The most popular of these stature reconstruction methods are based on (early-) modern populations. However, Klein Goldewijk and Jacobs (2013) show that such stature construction methods do not fit the pre-modern population of the Roman Empire.

An alternative measure for the biological standard of living is to look at individual long bone length (Koepke, 2016). Focusing on the length of one single bone would be an obvious choice, but should we use only the femurs because those have survived in the largest numbers, or only the tibia, because it varies most in length? And, even if we standardize the available femur or tibia lengths for the different traditions by which they were originally measured, a lot of information on the lengths of the other bones would be lost.

Therefore, our preferred method is exploratory factor analysis, which allows us to look at the long bones simultaneously. This statistical method screens the structure of correlations between the long bones (after normalization, i.e. subtracting the mean and scaling by the standard deviation), and it distils the variance that they share. From this shared variance it reconstructs the latent variables that drive the observed variables, the long bone lengths.[1] The latent variables are called factors, and the values that they take are called factor scores. The relationship of each variable to each underlying factor is expressed by factor loadings. Unlike constructed heights or individual bone lengths, the factor scores are dimensionless and cannot be expressed in centimetres.

High correlations between our six long bones led us to drop the ulna and the fibula from the analysis.[2] Based on the scree plot we retain one factor for males and females, and males and females separately. Identification of this factor is non-trivial but one of the factors behind the long bone lengths should be the biological standard of living. We interpret the factor we obtain as the biological standard of living. This interpretation is more or less confirmed by the factor loadings in Table 2, which are approximately equal and fairly close to one for the first factor.[3]

For a historical analysis we obviously want to know how these factor scores change over time, and how they compare with other changes in Roman economy and society. Therefore, we classified the information on long bones into fifty-year birth year cohorts, but given the low chronological resolution of some sites, we had to

[1] We could also use the label principal components here, which aims at the creation of one or more components using linear combinations of a set of measured variables.

[2] Computations are done in IBM SPSS Statistics, Version 25.

[3] We do not believe that robust interpretation of the statistically insignificant second factors is possible at this moment.

Table 3
Italy and provinces (AD 117), regions and number of individuals in the Roman stature database.

Provinces (AD 117)	western Mediterranean (including Italy)	the east	south-east	north-western provinces
Achaea	0	0	83	0
Aegyptus	0	53	0	0
Africa	67	0	0	0
Alpes Cottiae	0	0	0	0
Alpes Maritimae	0	0	0	0
Alpes Poeninae	83	0	0	0
Arabia Petrae	0	0	0	0
Armenia	0	0	0	0
Asia	0	11	0	0
Assyria	0	0	0	0
Bithynia et Pontus	0	0	0	0
Britannia	0	0	0	1901
Cappadocia	0	9	0	0
Cilicia	0	0	0	0
Corsica et Sardinia	114	0	0	0
Creta et Cyrenaica	0	0	0	0
Cyprus	0	123	0	0
Dacia	0	0	1	0
Dalmatia	0	0	16	0
Epirus	0	0	0	0
Galatia	0	41	0	0
Gallia Aquitania	0	0	0	60
Gallia Belgica	0	0	0	435
Gallia Lugdunensis	0	0	0	459
Gallia Narbonensis	98	0	0	0
Germania Inferior	0	0	0	40
Germania Superior	0	0	0	535
Hispania Baetica	10	0	0	0
Hispania Tarraconensis	623	0	0	0
Italia	1528	0	0	0
Iudaea	0	244	0	0
Lusitania	71	0	0	0
Lycia et Pamphylia	0	0	0	0
Macedonia	0	0	29	0
Mauretania Caesariensis	23	0	0	0
Mauretania Tingitana	0	0	0	0
Mesopotamia	0	0	0	0
Moesia Inferior	0	0	1	0
Moesia Superior	0	0	2	0
Noricum	0	0	402	0
Pannonia Inferior	0	0	938	0
Pannonia Superior	0	0	818	0
Raetia	0	0	0	1859
Sicilia	42	0	0	0
Syria	0	53	0	0
Taurica	0	0	0	0
Thracia	0	0	5	0

spread observations over longer time periods when necessary, which obviously dampens the visibility of rapid changes.[4] Below we report factor scores to proxy the biological standard of living for the Roman Empire as a whole, and of four regions exploiting information on where the skeletons were found, which is also included in the data base, see Fig. 2 and Table 3.

Of course, over 10,000 individuals sounds great, but we have to call attention to two obvious biases of our dataset. The first is geographic, and is the product of the intensity of archaeological work, and more particularly of the quality of archaeological publication. We have far more data for the Roman North West than for the Roman East, and for the East disproportionally from modern Israel and its excellent archaeological service.

The other bias is chronological, and it is potentially more problematic, see Fig. 3. We have far more data for the late antique and early mediaeval period than for the period at the height of Rome's power and economic success. This is true for most regions of the Empire, and particularly for north Western Europe (which was by no means the most prosperous region in that period). The economically successful Roman East is an exception, with a declining number of observations in late antiquity.

Table 4 lists some characteristics of our data set and related studies based on skeletal remains. Our data set is the largest on the Roman Empire, allowing the finest grid, 50-year periods, in the analysis.

Given the limitations of our data, do they show an improvement in the biological standard of living when the Roman Empire was at the height of its power and economic success, or do they show a low biological standard of living when population pressure was highest?

3. Results

We can now present our factor scores, first for the Empire at large, and for males and females combined. As Fig. 4 shows, these factor scores declined steadily from the second century B.C. at the latest, and more clearly from the first century B.C., even if for the early period data quality is questionable for any region other than

[4] Even our large dataset suffers from missing observations. These have been taken care of by the Expectation-Maximization (EM) algorithm, originally proposed by Dempster et al. (1977).

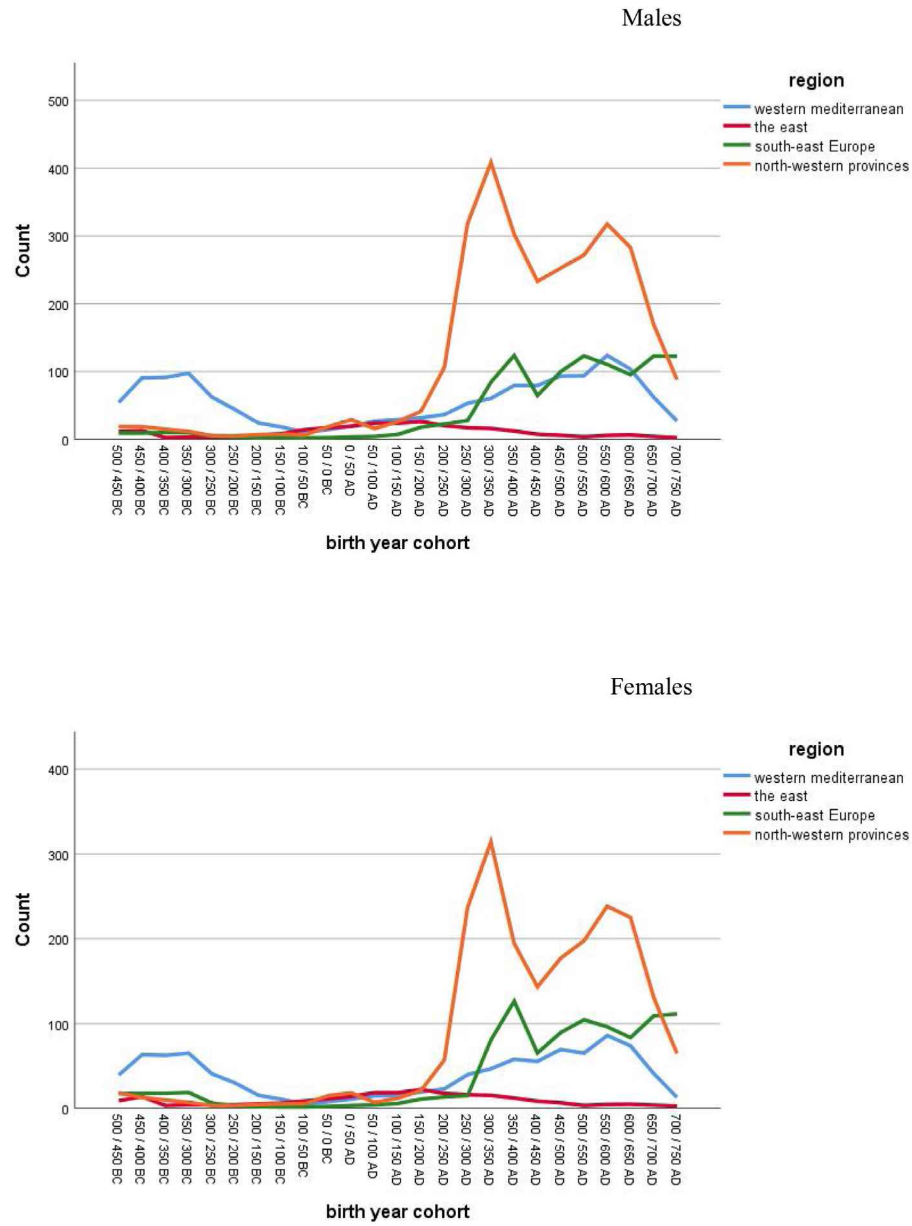


Fig. 3. Number of individuals by time period and region.

the western Mediterranean. The low point of this declining trend was reached in the second half of the first century A.D., after which we see a recovery, slowly at first, and dramatically more quickly from the fifth century A.D.

When we separate the results for males and females we see that the patterns for males and females are very similar (Fig. 5). To avoid misunderstanding, we have to point out that these factor scores are not absolute numbers, so the fact that in late antiquity the female

Table 4
Comparison of data sets.

	Baten and Koepke (2005)	Koepke (2016)	Galofré-Vilà et al. (2018)	Our data set
Coverage	Central- Western, Mediterranean and North-East Europe	Central- Western, Mediterranean and North-East Europe	England	Roman Empire
Period	100–1700	800 BC – AD 1800	200–1800	500 BC –AD 750
Time interval	Century	Century	Different lengths	50-year periods
Number of individuals	Around 9,500	Around 18,500	Around 4,750	Over 10,000
Measure	Reconstructed height assuming fixed body proportions	Reconstructed height from femur	Reconstructed height assuming fixed body proportions	Factor scores

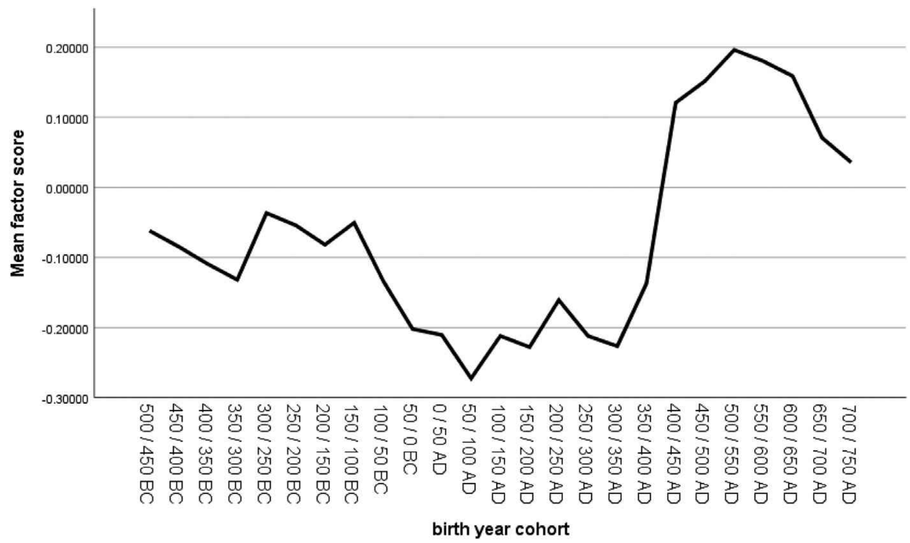


Fig. 4. The biological standard of living in the Roman Empire.

scores exceed the males ones does not mean that women were taller than men, but only that compared to men they were taller relative to earlier periods. If there were differences in the health of men and women, as may well have been the case, these did not change over time.

If we look at the data for each region in Fig. 6, we can see that the pattern is repeated more or less clearly in nearly all regional subsets, which would argue against migration as an explanation for the chronological pattern (currently available historical DNA data are too few to help here). The biggest exception to this is in the data from the Roman East, largely based on data from modern Israel. Males and females from that region show low or even declining factor scores in late antiquity, but based on only few observations. Males and females from the East also show low scores for a century and a half from the middle of the fourth century B.C., perhaps reflecting the impact of the conquest of the region by Alexander the Great and the unrest under his Ptolemaic, Seleucid and Hasmonean successors in Judaea. The low scores from the middle of the first century A.D. may similarly reflect conditions after the Jewish Revolt. However, it must be stressed that we only have very few data for these periods in the region.

Comparison of our biological standard of living series to the height series obtained by Koepke and Baten (2005) and Koepke (2016) reveals that our series alternates much less than the height series they obtained, even though they used one-hundred year periods and we use fifty year periods. Koepke and Baten (2005) date the height acceleration a century later than we do, and do not pick up the preceding gradual increase in the biological standard of living from the second to the fifth century. Koepke (2016) also identifies a growth acceleration in the fifth century in Mediterranean Europe, but not in North Eastern Europe, and much less pronounced in Central Western Europe.

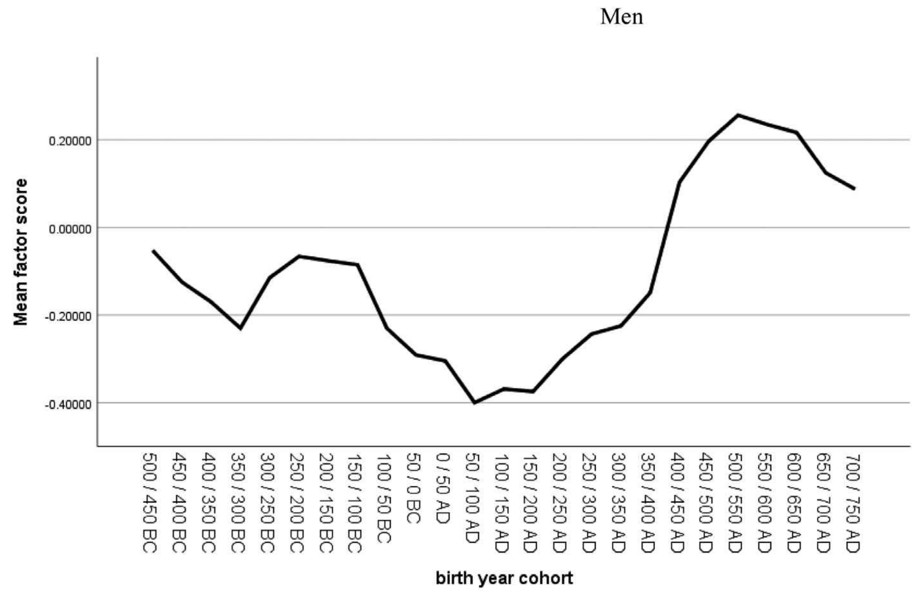
Galofré-Vilà et al. (2018) present heights across the period AD 200–1800 in England, based on the femurs of skeleton remains. They find that heights increased during the Roman period, but only have three observations for this period. Fig. 7 shows the development of our measure for the biological standard of living for the Roman province of Britannia. Factor scores are more or less constant from 50 B.C. to A.D. 250, show a dip from A.D. 250–350, steadily increase from A.D. 350 to A.D. 550, and more or less stabilize from A.D. 550 onwards. This may be related to genetic changes due to immigration from the continent, but without relevant scientific data connecting origin (based on DNA and stable isotope analysis of skeletons such as in Härke, 2011) to stature this is as yet impossible to decide. In our view this demonstrates the importance of larger datasets for more robust conclusions.

4. Discussion

The challenge is to decide what these results mean, because the larger pattern obviously correlates negatively with the trends in population and urbanization that we have suggested earlier. This has, therefore, been interpreted as a Malthusian pattern, and all the more so since we have reason to believe that life expectancy during the peak period of Rome's history was also low, even if robust mortality data are lacking (Jongman, 2009; Hopkins, 2018a; Scheidel, 2012). However, as we shall see instantly, almost all other indicators of standard of living that we have for the Roman world show the opposite pattern from the two health indicators of biological standard of living and life expectancy.

The first of these indicators is wage data, even if they are not very good, to put it mildly, and not nearly as good as from any later periods of history, but even so we think the pattern seems quite clear. For the second and first century B.C. we only have slave prices, or more precisely, about 800 prices of manumissions from Delphi, rather than actual wages (Hopkins, 1978). Following Domar's argument that these should represent the net present value of the wage above subsistence enjoyed by free labour, it is clear that first slave prices were high, and hence that wages for free labour must have been well above subsistence (Domar, 1970). Second, there is a clearly upward trend from about 3500 kg of wheat equivalent in the first half of the second century to about 7000 kg of wheat equivalent in the last half of the first century B.C. (Hopkins, 1978; Jongman, 2007a). By that time and using the same logic, implied wages for free labour were about four times subsistence. The rising trend of slave prices in this period also demonstrates that slavery in this period did not increase because of the increased supply, but because of the even larger increase in demand.

The second set of wage data is from Roman Egypt, and was recently studied again by Kyle Harper (Harper, 2016), see Fig. 8. The number of data points is obviously limited, but we observe a quite clear growth of family incomes from about two times subsistence at the beginning of the first century A.D. to about four times subsistence in the 160′s, just before the Antonine Plague. Using Harper's data we estimate two different trend lines



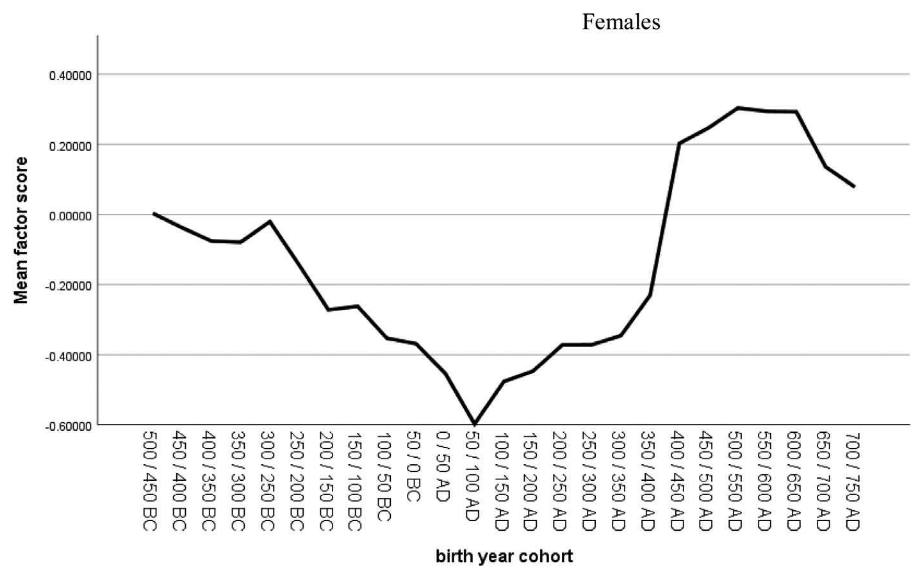


Fig. 5. Mean factor scores of males and females, Roman Empire.

allowing for an unknown structural break (Bai and Perron, 1998, 2003). The break occurs at the year AD 175, close to the Antonine Plague.[5] Before the break wages in Roman Egypt are rising, after the break wages tend to decrease. This break occurs not just in wage levels, but also in the quantity of documentation, a change that is also reflected in many other administrative documents (Duncan-Jones, 1996).

The third data type is from Diocletian's edict on maximum prices, promulgated in A.D. 301. Bob Allen has used these to calculate for that period what he calls the welfare ratio, i.e. the extent to which a family could live above subsistence (Allen, 2009). At the time of Diocletian family incomes were only just above subsistence. Clearly by that time Romans were not doing very well anymore.

So between them these three groups of fragmentary wage data suggest a growth in wages from the mid second century B.C. to the mid second century A.D., followed by substantial and quite rapid decline.

Interestingly that picture of increasing prosperity followed by quite dramatic decline is mirrored in archaeological data on consumption patterns. The value of such data is on the one hand that they document actual consumption, but also and perhaps more importantly that these data are at times available in enormous quantities, even though not necessarily in aggregate form. A few years ago Jongman (2007a) introduced a dataset of Roman animal bone assemblages as a proxy for meat consumption, see Fig. 9. These are just bones, rather than meat weight. For that, we have to realize that precisely during this period Roman pigs, sheep, goats and cows were also significantly larger than before or after, with perhaps a double meat weight as a result.

[5] The estimation results are as follows: Real Wage = (8.39 + 0.041*Year Value) {before the break} + (12.04 - 0.01*Year Value) {after the break}. The constants are significant at the 1% level; the slopes are significant at the 5% and 10% level, respectively. The estimation outcomes are robust for the assumption regarding the break. Here we assumed one globally determined break.

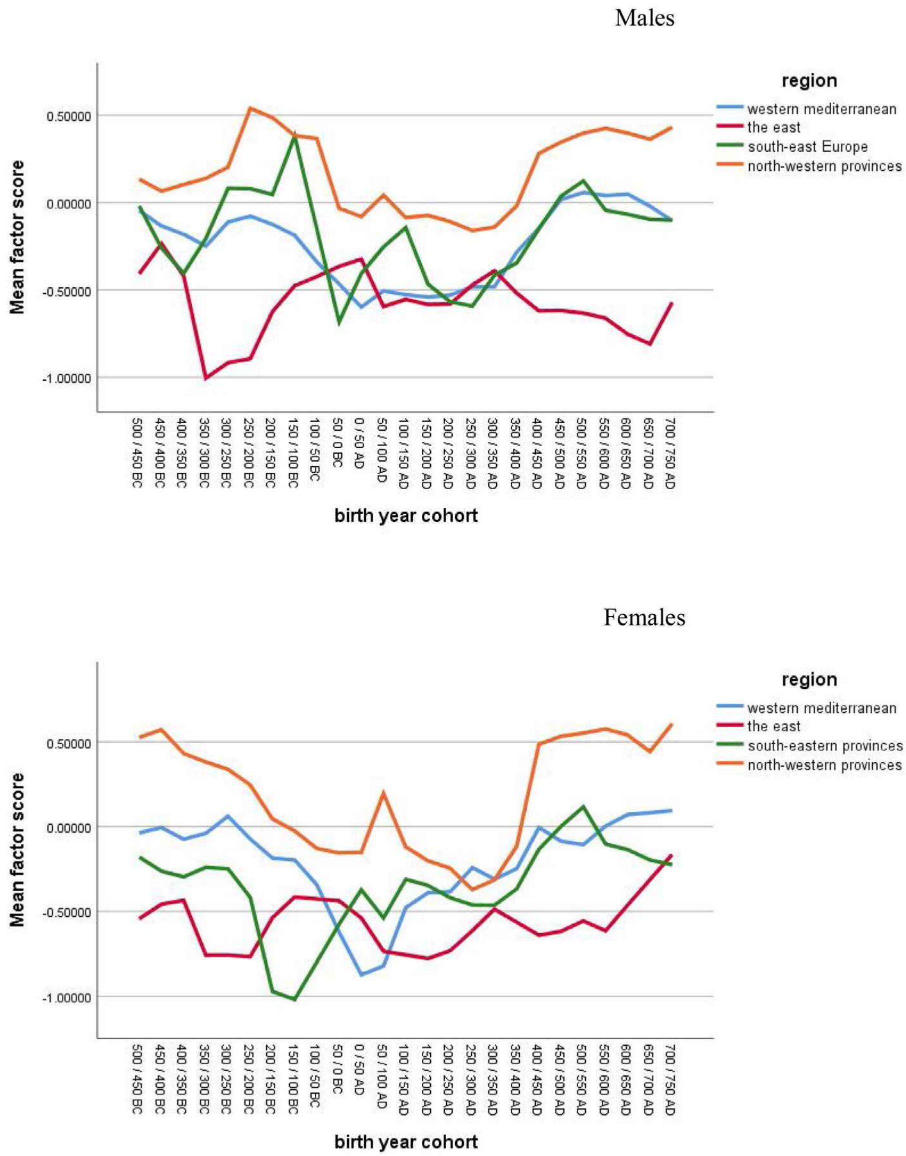


Fig. 6. Mean factor scores over time and per region.

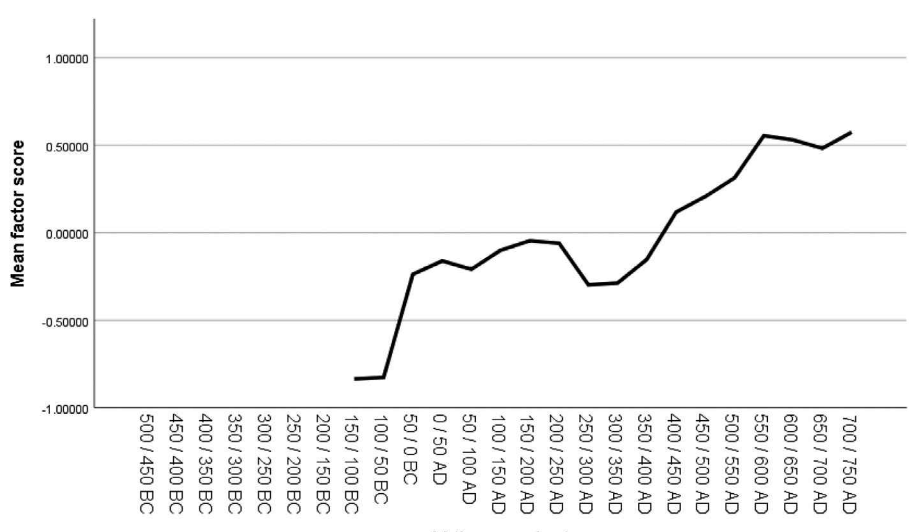


Fig. 7. Mean factor scores over time in the province of Britannia.

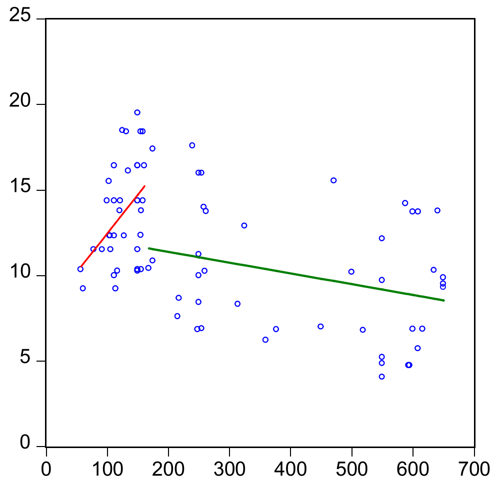


Fig. 8. Annual wages in Egypt before and after the Antonine Plague (in wheat). Source: Harper (2016); trend lines show scatter regression lines.

Scheidel (2012) argues that the decline in the later period masks a shift to fewer but larger animal species and hence does not mean a decline in meat consumption. The subdivision by species in Fig. 9 shows that this is not supported by these data. Similar trends of increased meat consumption are becoming visible for chicken of which Mark Maltby's team is now showing that many more were eaten in a Roman Britain than before or after (Maltby et al., 2018).

An estimate by Andrew Wilson of the installed capacity of surviving Roman fish salting installations shows a similar pattern, though in less dramatic form (Wilson, 2006). A recent snapshot of Roman diet is afforded by Erica Rowan's analysis of the content of the main sewer at Herculaneum in relation to the houses above (Rowan, 2017). The range and quality of fruit and vegetables are quite staggering, and so are meat and fish remains, and not just for the houses of the wealthy. This was not limited to the Italian core of the Empire: archaeobotanical remains from mostly the north-western provinces show a dramatic increase in the range of fruits and vegetables, precisely from the time of Roman conquest, and lasting little beyond the demise of the Roman Empire in the West (Bakels and Jacomet, 2003). The demand for high income elasticity food is similarly visible in the boom in the consumption of olive oil and even more so wine (Brun, 2003). Those were expensive calories, and particularly in the case of wine (Jongman, 2016). In short, there is overwhelming evidence for improvements in the diet precisely during the peak period of Roman power and population, both in Italy and in the provinces.

This prosperity was not limited to food consumption either. Roman housing stock was of far better quality than what had come before or would come after. One sign of this is the time series for building wood recovered from rivers in Western Germany (Fig. 10, with data from Holstein, 1980).

These houses were also increasingly equipped with metal fixtures such as door and window hinges or locks, and even window glass. Inside such houses we find metal kitchen utensils, furniture, nice ceramic tableware, glass and items for personal-care. As every field archaeologist knows, the quantity and quality of Roman material culture was far better than what came before or would come after. This is also shown in the data from the Nettuno survey that we mentioned earlier. Fig. 11 repeats the population estimates per time period for the region. It also plots the trend of two types of objects of comfortable material culture (amphora sherds and fine ware ceramics) divided by the population trend. The resulting two trend lines are rough approximations of trends in the per capita availability of these high income elasticity goods over time.

So what do we make of all this? How can it be that the trend in the biological standard of living is negatively correlated to other aspects of standard of living? One interpretation would be to argue that suggestions of Roman economic growth are wrong. Walter Scheidel, for example, has questioned both the pertinence of the archaeological time series, and the reality of the importance of the Antonine Plague (Scheidel, 2002, 2009). We do believe that he is wrong, and we do believe the story of the archaeological time series is a convincing one, and all the more so because each and every new series that we discover or create shows the same pattern.

A second interpretation is that the skeletal data are quite simply not good enough, and more specifically that the chronological bias represents a social bias. This is a much more plausible criticism, because funerary habits did indeed change over time. From the third century B.C. to the early to mid-first century A.D. many Romans were cremated rather than inhumated, and perhaps more so the higher their social status. We admit that there may be some of this, but we doubt it could completely explain the trend. It would imply that social differences were far more important than changes over time. Interestingly, it would also imply that what we are missing for the late republican and early imperial period is a large middle class that was significantly healthier than those at the very bottom of the social hierarchy. Unfortunately the published data that we use do not normally give enough indication of the social status of the deceased.

The third possible explanation is that body length may reflect health but not wealth, and for now this is the most plausible hypothesis in our view. We know that nutritional status can be impaired very seriously by infectious disease, as the body has to work so much harder to fight off the infection, or cannot absorb the nutrients. But apart from the three major epidemics that we know about, there were also many endemic infectious diseases. For Rome and Italy we now know that malaria was a big killer in the late summer, and intestinal worms have recently been singled out as another pathogen, brought along in part by the Roman predilection for *garum*, a fish sauce (Sallares, 2002; Mitchell, 2016). Another lifestyle hazard was the Romans' love of the baths, particularly recommended as a cure for skin or bowel diseases (Scobie, 1986). By and large, Romans really had no idea what made them sick: in many houses the toilet was right in the kitchen! Thus infectious diseases, the proximity of humans and the contacts that they had with each other were potentially decisive factors. As we have already seen, population densities in many parts of the Roman Empire were significantly higher than before or after. But that was not all: Roman culture and society were decidedly urban, with more and far larger cities than Europe would see until the modern age (Table 5).

The city of Rome was of course exceptional with its one million inhabitants, but there were quite a few other large cities with hundreds of thousands of inhabitants (Jongman, 2003, 2014, 2016; Hanson, 2016). Therefore, if most cities were small, the majority of the urban population lived a truly urban life in large cities, unlike for much of mediaeval and early modern Europe. Such high levels of urbanization are likely to have had serious consequences for mortality levels, as is amply documented for early modern European cities (Wrigley, 1978; De Vries, 1984; Jongman, 2003). This was caused by the combination of low levels of sanitation and people living in close proximity, creating a perfect environment for infectious diseases of all kinds (Scobie, 1986; Scheidel, 2003).

To make matters worse, Roman cities were not isolated islands in a rural sea, but were hubs in a network of travel and transport. Most of them were close to the Mediterranean, the big ones in particular, or close to good river transport. The importance of long distance transport by sea was pointed out by Hopkins (2018b, originally 1980) with a graph of the numbers of dated Roman

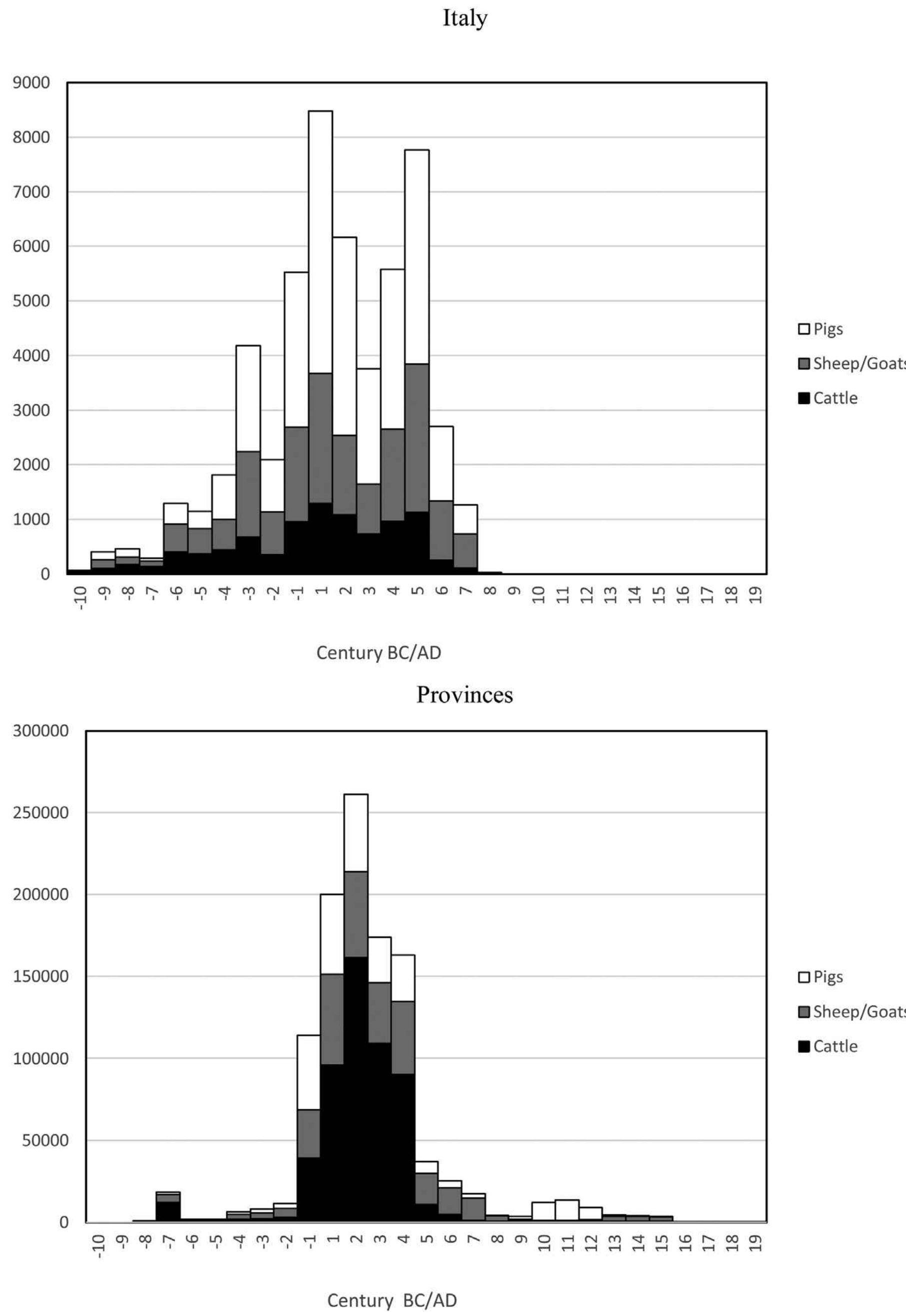


Fig. 9. Animal bone assemblages from Italy and the provinces by century Italy. Source Jongman (2007a).

shipwrecks per period as a proxy for long-distance shipping. Fig. 12 presents an updated version of Hopkins' graph by Andrew Wilson.

The Mediterranean not only made the Roman Empire a geographically integrated economy, but also created the first integrated disease regime. Moreover, in between this network of water transport, the Romans built an unprecedented network of roads. Originally primarily intended to move the legions, they quickly became a crucial part of an integrated network of sea, river, and land transport (Scheidel et al., 2019). Roman cities were all important hubs in this network. Economically this was all very good, and serves as an important part of the explanation for Rome's success. In health terms, however, the consequences were not necessarily that favourable. Roman cities had become the focal point of viruses and bacteria that all vectored in on them, to find a densely packed population (Scheidel, 2003). Historically, a declining biological standard of living under conditions of economic development and increasing economic integration is not unique, of course, see e.g. Coppola (2013).

So, in the end, the best explanation for the negative correlation between biological standard of living and material prosperity may well be that Romans paid a price for their wealth with a deterioration of their health.

5. Conclusion

We have presented here the first more or less comprehensive dataset of currently available skeletal data for the entire period of more than one thousand years of history of the Roman Empire (and a bit beyond that) and for its complete geographical extent. The dataset features fifty-year time periods and locational information. Unlike previous similar datasets we did not attempt to reconstruct total body lengths, but opted for trends in factor scores.

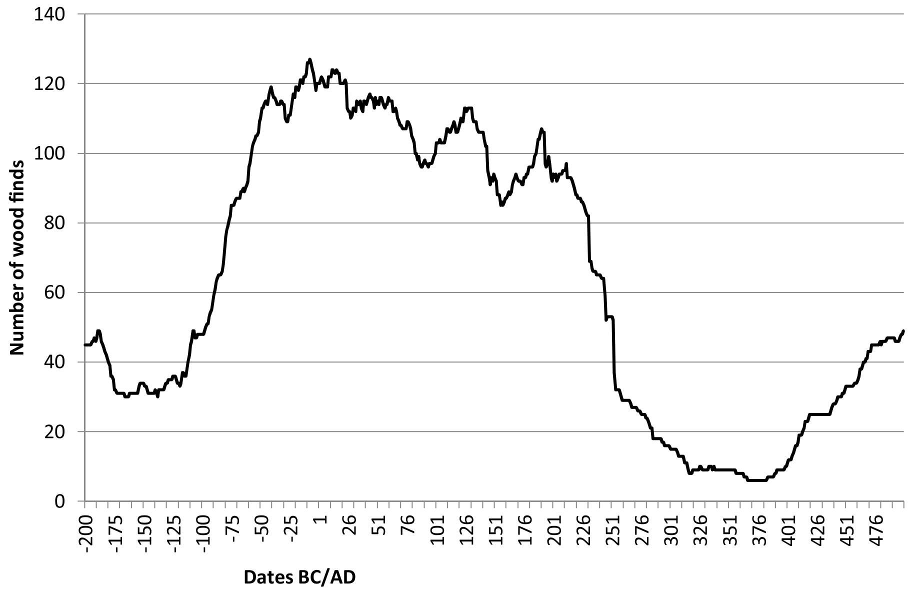


Fig. 10. Chronology of wood consumption in Western Germany. Based on Holstein (1980).

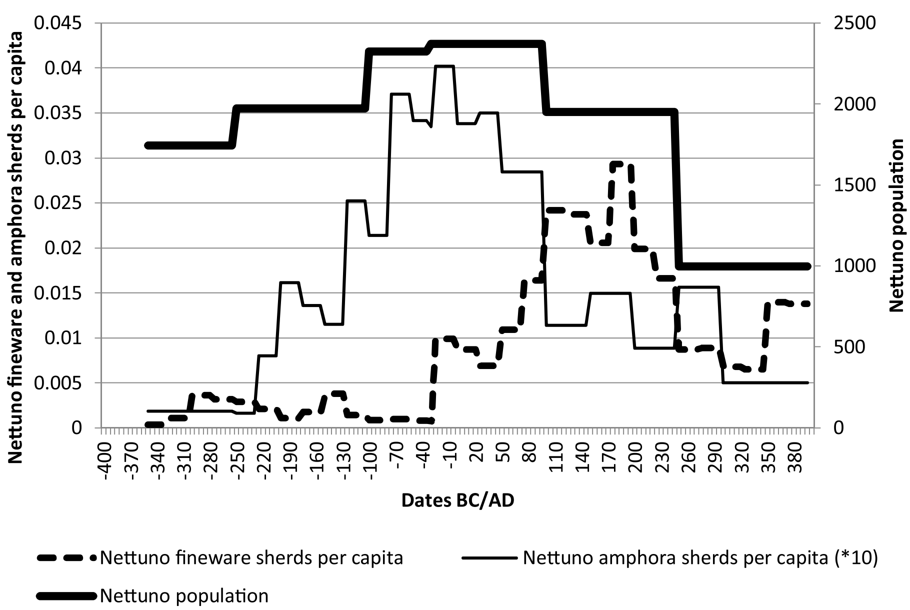


Fig. 11. Nettuno per capita consumption trends. Based on De Haas et al. (2011).

Table 5
Roman urban population from Hanson (2016).

Band	Number of estimates	Total size (ha.)	Proposed population density (p/ha)	Population
More than 400 ha.	5	4,323	500	2,161,520
400–350 ha.	1	399	450	179,510
350–300 ha.	2	647	400	258,980
300–250 ha.	4	1,134	350	397,009
250–200 ha.	12	2,670	300	801,015
200–150 ha.	33	5,634	250	1,409,262
150–100 ha.	60	7,344	200	1,468,232
100–50 ha.	172	11,951	150	1,792,461

We found a downward trend until the first century AD, after which the trend reversed and factor scores improved again, particularly after the fall of the Roman Empire in the West in the fifth century AD (the pattern in the East may have been different but is still badly known). This improvement in factor scores roughly coincided with a collapse in population and the decline of cities. Factor scores for biological standard of living moved in opposite direction to the tentative population trends that we have.

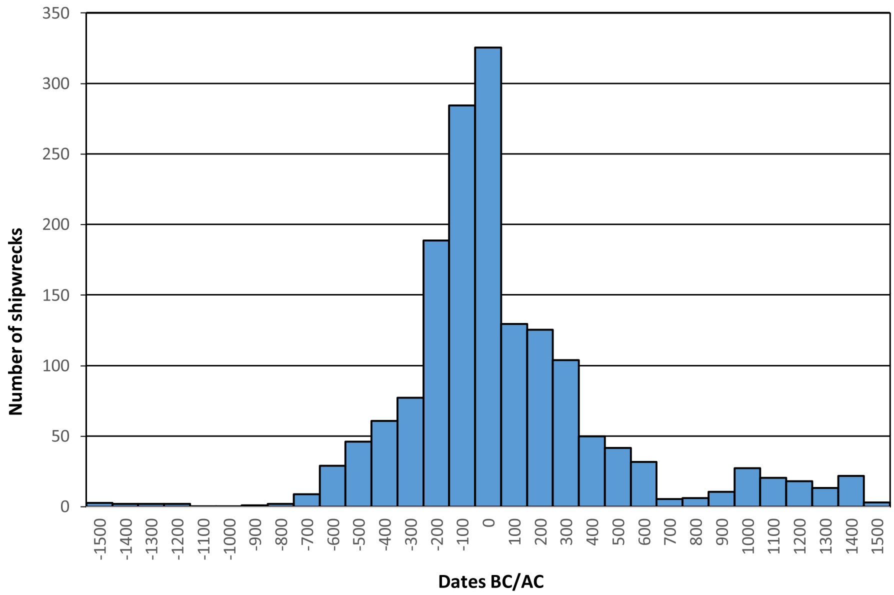


Fig. 12. Shipwrecks by century. Source: Wilson (2011, Figure 2.3).

The inverse relation between trends in population and biological standard of living suggests a Malthusian explanation. However, other independent data on trends in standard of living showed the opposite pattern from the trends in biological standard of living. Material standard of living including diet improved in tandem with population growth, and declined again when population declined. Biological standard of living, therefore, is not another measure of standard of living, but a rather different one, documenting a different aspect of past well-being. In the Roman case, and since the trends are opposite/inverted, biological standard of living, just like life expectancy, showed a pattern that we may call Malthusian, but it was not from poverty. We conclude that Romans paid a health price for their material wealth.

Our project also suggests that much further research is both necessary and possible. We may seem to have a large dataset, but the data are very unevenly distributed through time and space, and may be socially biased. All this becomes even more problematic if we want to look into regional differences in the trends.

We also conclude that there is an urgent need for better data on aggregate population trends. Here, the promise of archaeology is enormous, as the few examples of population trends from survey data already show (Fentress, 2009; De Haas et al., 2011; Zimmermann et al., 2009). Until now, however, that promise has not born fruit because the hundreds of surveys from over the last seventy years were done with diverse methodologies, and almost never published the underlying data. This is about to change with a Dutch, Italian and British project in which we have now for the first time successfully integrated three well-known high-quality datasets of surveys in the territory of the city of Rome, down to in many cases the level of individual sherds, something long called impossible. This will allow us to reconstruct trends in population, settlement structure, social relations and material culture, first for the hinterland of Rome. In due time and once this integrated dataset will have been extended with many more local datasets this should give robust data for many parts of the Empire and for a period of more than a thousand years.

As for Romans' food consumption and health, the rapid advances in scientific archaeology will give us far more detailed information of the kind we can often not even imagine right now, and could certainly not even imagine only recently (Scheidel, 2012; Harper, 2017). Stable isotope analysis of diet from skeletal material is advancing at breakneck speed, and so is work on infections (Salesse et al. in press; Mitchell, 2016). Here, we are at the threshold of a completely new historiography.

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