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**Agricultural Specialization and Height in Ancient and Medieval Europe**

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## **Abstract**

Land per capita was one important determinant of height in the Malthusian world 0 to 1800 A.D. A second factor was specialization in milk cattle agriculture. It had two positive effects on human stature: first, proximity to protein production resulted in a very low local shadow price of milk, as this important foodstuff could not be transported easily. Second, this low price resulted in a low inequality of nutritional status, whereas, for example, tradable pork contributed to nutritional inequality. For this study, we used a data set of more than 2 million animal bones to measure specialization in cattle and its impact on stature.

Anthropometrics, Agriculture, Cattle Farming, Very Long Run, Growth, Living Standards, Taphonomy, Archaeozoology

## **Agricultural Specialization and Height in Ancient and Medieval Europe**

Protein-rich milk and beef were major determinants of the biological standard of living of late-eighteenth and nineteenth century societies, with a high local supply of milk leading to better nutrition and taller stature. The shadow price of milk (especially after the milk fat was extracted) tended to be extremely low since this food item could not be shipped. The milk fat was extracted and made into butter, and this item was sold on urban markets (Baten 1999; Baten and Murray 2000). In this paper, we consider the “proximity-to-protein production effect” described above for ancient and medieval Europe. The influence of protein production on human height is traced quantitatively using a sample of 2,059,689 animal bones, based on data collected by King (1984, 1999a, 1999b) for the Roman Empire, as well as data for Northern and Eastern Europe. The share of cattle bones served *ceteris paribus* as an indicator of milk (and beef) supply, especially when available land per capita is taken into account. Furthermore, we compare information on the cattle bone share with height estimates from three European regions (the Mediterranean, the North-East, and the Central-West) for the first to the seventeenth centuries A.D.

### **Introductory Remarks**

Between 600 and 300 B.C., cattle as a share of livestock declined sharply in Mediterranean Europe, and remained very low during the remaining period of the Roman Empire. Poor and middle income groups consumed grain and vegetables, while the wealthier strata consumed meat (and esp. pork). The central point of this paper is that one can document

the cattle “deficiency”, so to speak, using archeological evidence on cattle bones; and, further, that this deficiency mattered in terms of net nutrition, which is reflected in mean height.

The empirical analysis in the paper begins with a discussion of data on animal bones collected by previous scholars (see fn. 1 for references).<sup>1</sup> We pay close attention to various selection biases involving excavation (which bones were found) and taphonomy (which bones survived to be found). We match up data on the cattle bone share with estimates of human height for three major European regions (Mediterranean, North-East, Central-West) for the first through seventeenth centuries, in the process discussing strategies for controlling for migration, social and regional composition, among other variables; along with a description of how the comparison of several regions yielded mutually corroborating evidence (Koepeke and Baten 2005). Lastly, we consider whether the meat trade played an important role during the Roman Empire.

## **Literature Review**

Most pre-industrial societies were characterized by a severe scarcity of high quality protein --especially, animal protein (Baten and Murray 2000). Furthermore, after the Neolithic agricultural revolution, the distribution of protein consumption became increasingly unequal (Armelagos 1990; Steckel and Rose 2002). Milk availability appears to have been an important “bottleneck” for health and longevity, given that milk is rich in high-value protein, calcium, and

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<sup>1</sup> Data on animal bones are drawn from King (1984, 1999a, 1999b), Benecke (1986), Becker (1980), Bökönyi (1955), Boessneck and Wiedemann (1972), Enderle (1975), Heinrich (1985), Hüster (1990), Johansson and Reichstein (1979), Luff (1982), Paul (1978), Reichstein (1990, 1991) and Reichstein and Pyrozok (1991).

vitamins.<sup>2</sup> Cows in particular provided a relatively high protein per capita supply in regions where cattle could be kept, whereas goats and sheep rarely reached sufficient numbers, except perhaps in the Western Balkans (Baten 1999).

For the eighteenth and nineteenth centuries, it can be shown that a good local supply of milk led to better nutrition and taller stature, and thus – *ceteris paribus* – to better health and longevity values, even in regions that were not otherwise “rich” (Komlos 1998; Baten 1999). However, it is not known whether the relationship between milk intake and height also holds for ancient and medieval history (Garnsey 1999). For example, can we explain the larger stature of Germanic tribesmen by their milk consumption?<sup>3</sup> A variety of ancient sources suggest that the autochthonic people of *Germania Magna*, beyond the borders of the *imperium Romanum*, used milk as their basic food – in sharp contrast to the Roman-Italian population.<sup>4</sup> The share of cattle bones among the the three main domestic animal species cattle, pigs, goats and sheep<sup>5</sup> - can serve as a proxy for two aspects. Firstly, population density tended to be negatively correlated

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<sup>2</sup> Milk is especially rich in vitamin D and an important source of trace elements, fat, and sugar: see Davis (1987: 155). Consequently, milk is of special importance for a good quality of nutrition.

<sup>3</sup> Lactose intolerance was probably not a decisive limiting factor in Europe. Crotty (2001) emphasized the importance of lactose intolerance in his bold attempt to explain the evolution of capitalism based on cattle farming patterns, arguing that lactose-intolerant people could not make sufficient use of cattle. Lactose intolerance implies that many people in the world have digestive problems when consuming large quantities of milk after age 5–7, because at that age, genetically lactose-intolerant people lose their ability to digest fresh milk without facing diarrhea and similar problems. Especially East Asians (east of Tibet and Rajasthan), American Indians and some African people have problems with lactose intolerance. For Southern Europe, the results are mixed – one study on Spain categorized the country into the lowest group of lactose intolerance (30 percent and less lactose intolerance), and a Greek study found Greece to obtain a middle position (30 – 70 percent lactose intolerance); whereas in Italy and Turkey, more than 70 percent were classified as lactose intolerant (see Mace et al. 2003). However, even lactose-intolerant people can digest modified milk such as Kefir, Lassi, and similar products. Moreover, all people can drink about one cup of milk per day if their intestinal bacteria adapt to live in a milk environment through careful training. Even many South Koreans consume some milk today, using this method of permanent training. We thank Barry Bogin, Anthropology Department of the University of Michigan/ Dearborn, and S. Pak, Seoul National University, for their observations on this issue.

<sup>4</sup> See for example Tac. Germ. 23; Plin. nat. VIII 179.

<sup>5</sup> Sheep and goats are commonly considered as one group in the literature, because the bones of these are difficult to distinguish.

with the cattle bone share in ancient times; extensive cattle husbandry was not possible where population was dense.<sup>6</sup> Secondly, the share of cattle bones was sensitive to climatic and landscape conditions since goats and sheep could be kept more easily than cattle in both dry and warm, and cold climates (Bökönyi 1974).<sup>7</sup> Cattle, by contrast, could not cope well with meager vegetation and in general needed to be in stables during winter (Nobis 1955; Reichstein 1972; Benecke 1986).

What were the effects of a high cattle share on humans? For pre-industrial times, a high value typically implied a substantial local supply of milk, because milk could not be transported unspoiled over more than five or ten kilometers (Komlos 1989; Baten 1999; Craig 2004). Apart from the direct effect of geographic proximity, an indirect advantage also occurred in terms of nutritional equality: the transport problem led to a very low shadow price of milk in remote milk-producing areas, which thus induced a relatively egalitarian distribution of high-value proteins. Therefore, even low-income groups could consume a healthy diet. By contrast, in large cities, only high-income groups could afford a protein-rich diet, which there would be based primarily on meat (and especially pork). As nutritional inequality tends to reduce average height due to the declining marginal effects of food on height, this second effect reinforced the proximity-to-nutrients effect on average height in ancient and medieval times (Steckel 1995; Boix and Rosenbluth 2004). Taking those two relationships together suggests that a higher cattle share should have been accompanied by higher average height (and perhaps lower inequality) in Europe during antiquity.

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<sup>6</sup> See Jongman (1988a). For example, Benecke (1986) argues for the Southern Baltic Sea region that the increasing importance of pig farming at the beginning of the early medieval period correlates with a population increase. Cattle need larger areas to graze, whereas pigs can be kept on smaller plots of land.

<sup>7</sup> Sheep and goats are undemanding when it comes to fodder; in addition, sheep are more common than cattle in the very cold areas of Northern Europe since their fur will protect them from the cold, making stables superfluous even in winter.

## Data on Animal Bones

In earlier decades, archaeozoologists mainly assessed the qualitative composition of diets, whereas more recently attention has been paid to the quantitative dimensions (including meat consumption) of human nutrition.<sup>8</sup> The findings from this recent research form the basis of our data set on animal bones. As noted earlier, these data consist of observations from various sites compiled by King (1978, 1984, 1999a, 1999b), Benecke (1986), and others. King collected a large body of evidence on animal bones from published reports and unpublished archival data.<sup>9</sup> His data were grouped according to the major domestic animal species: cattle, pigs, and sheep/goat (the latter were combined).<sup>10</sup> To ensure that animals were meant for daily food consumption, and not burial or other rituals, only civilian and military settlement sites were taken into account, none with a sacral background. Moreover, bone assemblages that obviously

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<sup>8</sup> See for example. Uerpmann (1972): all animal bones related to human activities in a settlement should be collected; accordingly, good preservation conditions for organic substances are important for drawing correct conclusions. One must also take care not to combine data based on different counting methods. In addition to the information on the quantitative proportion of meat in human nutrition determining an animal's age at butchering yields more precise insights into the composition of human food consumption. For instance, zoologists have found that a large number of cattle butchered at an older age is an indicator that the animals were not only used for meat production, but especially for milk production: see Jankuhn (1978). Furthermore, a high percentage of only a few days old cattle slaughtered, and especially bull calves, can be directly related to dairy-farming: see Reichstein (1991, p. 246). In addition, the longer the slaughtering could be delayed, the larger the animal and therefore the quantity of the meat obtained: see Reynolds (1995, p. 309). Kokabi (1988) came to the conclusion that (corresponding to its utility), cattle is the most widely represented (husbandry) animal among the existing bone material from the Roman provinces. However, his analysis implied that cattle was mainly employed as 'working animals' for field processing, this being indicated by the gender distribution of the preserved cattle bones, with ox and bull remnants being almost twice the amount of cow bones, followed by pig and sheep bone remains.

<sup>9</sup> King (1999b) includes data from Luff (1982), Lepetz (1996), Peters (1998) etc., thereby creating an overview for the entire Roman Empire. This evidence was recently used by Jongmann (forthcoming), who based his argumentation on the approximate completeness of the palaeo-zoological record for Roman antiquity.

<sup>10</sup> Furthermore, domestic fowl and some wild animals were consumed, yet these accounted only for a small amount of the total food supply and were therefore not included in the study. Fish consumption can probably not be estimated accurately using this method.

represented remnants of craft production were excluded. We will discuss questions of representativeness, bone survival and excavation probabilities in the following section.

We divide Europe into three large groups. The regions along the Rhine river – Benelux, Northern France, South-Western Germany, and Switzerland – together with Bavaria/Austria and the UK are grouped as “Central-Western Europe”.<sup>11</sup> “Northern and Eastern Europe” denote regions that had only little or modest contact with the Roman Empire and its provincial economy -- Scandinavia, North-Eastern Germany, Russia, Romania, and Hungary. “Mediterranean Europe” in our sample stands for Italy, Spain, and the French Provence.

We only considered the European sites recorded by King, neglecting Africa and the Middle East.<sup>12</sup> Because North-Eastern Europe is underrepresented in King’s data (due to his concentration on regions that were Roman provinces at some point in time), we enlarged our data set to include bone data from Sweden, Denmark, Hungary, Russia, and Northern Germany (collected by Luff (1982), Benecke (1986) and others).<sup>13</sup> Thus, our data set comprises animal data from 415 sites. Moreover, the sample covers the centuries between 400 B.C. and 600 A.D. satisfactorily for all regions (see Table 1). Before 400 B.C., however, only Italy is well-documented; after 600 A.D., this is only the case for North-Eastern Europe.

What are the major trends in our data set? First, the cattle share in the ‘major’ regions fell sharply between the tenth century B.C. and the seventeenth century A.D., especially in

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<sup>11</sup> Compared with population estimates for the Roman Empire, the number of sites in this group might indicate a somewhat larger amount of bones for the United Kingdom. However, as we are only using shares and not absolute numbers of cattle, only a slightly higher precision for regions with more data available would be implied by this.

<sup>12</sup> King recorded animal bone data from 533 excavation sites all over the Roman Empire, including some post-Roman sites. At the average site, 1867 animal bones were excavated, ranging from a minimum of four to a maximum of 366,507 animal bones. Overall, cattle bones were more frequent than sheep/goat bones, with pig bones being least common.

<sup>13</sup> In concordance with the height estimates, those data points were aggregated with King’s observations on Eastern Europe, as this region was only integrated to a limited extent into the imperial economy. For example, Northern Romania (for which reliable data exists) was *de jure* only part of the Empire for some 150 years.



Mediterranean between the eighth and third centuries B.C (from almost 0.40 to approximately 0.17, see Figure 1). After the first century A.D., the cattle share stagnated on a low level (at approximately 0.20 of the total mammal bone share) until the sixth century A.D.<sup>14</sup> Except for a small decrease between the fourth and third centuries B.C., trends in the cattle share in the Central-Western European region followed a different pattern: specifically, after a substantial increase from the third century B.C. onwards, the share of cattle remained relatively constant throughout the second and sixth centuries A.D. Then, however, a decline set in. Last, the cattle bone share in the North-Eastern European region displayed a less volatile pattern of change over time. Although a slight decrease became apparent over the centuries, this occurred ‘step by step,’ with long periods of constant values. Overall, the North-Eastern cattle share was consistently higher than the Central-Western one, with the share in Mediterranean Europe ranking lowest.<sup>15</sup>

When comparing the evolution of the cattle bone share with those of other domesticated animals by regions (not shown), we found that in all three parts of Europe, the pig and cattle

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<sup>14</sup> There was only very small variation in between: from the third to the first centuries B.C., the percentage increased slightly. In the eighth century A.D., the Mediterranean average reached its highest share (0.23).

<sup>15</sup> There were also some special developments which related to individual cities. For example, during the Roman Imperial period, large cities like Rome or Pompeii had a very small share of beef and milk consumption because cattle grazing was too costly. Therefore, beef was substituted with grain and vegetables – and pork was left to the richer strata of society to consume. In fact, the impressive cattle share of 0.28 for Rome (*Aqua Marcia* excavation) between the first century B.C. and the first century A.D. fell to 0.079 in the first and second centuries, and to 0 in the second and third centuries A.D. During the fourth century, the share was still negligible (0.006 on the Palatine). Only excavation at a fifth century site (*Schola Praeconum*) yielded again a substantial cattle share, after population density had decreased significantly and Germanic invaders had brought their agricultural system (and perhaps taste). Similarly in Naples, the share remained low over the first and third centuries A.D. (0.02- 0.06), becoming somewhat higher during the fifth to seventh centuries (0.06 – 0.09). Ostia and other excavation sites display a similar, but more mixed result. In general, the second to the fourth centuries A.D. were characterized by low urban cattle rates in Italy.

share developed more or less antipodally, whereas the sheep/goat share developed independently and was relatively stable overall.<sup>16</sup>

Differences in levels of absolute bone numbers do not invalidate the evidence which can be gained from considering shares. In other words, one could imagine that a lower share of cattle in the Roman diet could still imply a higher consumption amount in levels if the Romans ate disproportionately more other meat. However, this was clearly not the case. In fact, the diet of the Mediterranean region with its high population density was probably marked by much lower overall meat consumption. If we compare King's animal bone evidence for the Mediterranean provinces (Italy, Southern France, and Iberia) with the Central-Western European provinces (that is, those along the Rhine, in Northern France, in the Alps, and in Britain), in the Mediterranean, only one seventh of the Central-Western Europe bone number was found, for the first century A.D. For the second century and thereafter, the gap is even wider. Furthermore, the Mediterranean population was larger (37 million, as opposed to 32 million in the vast Central-Western territories). A part of this gap can certainly be explained by taphonomic distortions. Yet given a ratio of 1:7, it is unlikely that the Mediterranean population consumed more meat per capita than the Central-Western Europeans.<sup>17</sup> The difference in pig bone levels is much smaller (only 1:3 in favour of Central-Western Europe in the first century A.D., and about 1:4 in per capita terms), whereas that in cattle bones is almost 1:20.

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<sup>16</sup> Although the Romans substituted beef with pork, Jongman has argued that the overall meat consumption was still relatively high in the Roman Empire (albeit not necessarily per capita). Jongman (forthcoming), see also Jongman (1988b; 2006). We took a somewhat different focus in this study, arguing that cattle husbandry provided important advantages in terms of proximity to milk production. Unlike Jongman, we based our results not directly on meat per capita values.

<sup>17</sup> The Northeast is even a bit more difficult to compare in levels, as the bone data stem from another source, and comparisons over time are also difficult.

## Taphonomic Biases

Taphonomy is the sub-discipline of archaeology that studies the process of the decomposition of bones and, hence, survival probabilities.<sup>18</sup> Although this subfield has made considerable progress depositional biases are highly site-specific and time-variant and there are no overall valid formulae to estimate the original numbers (Nicholson 1996). Despite this, it is important to consider several possible sources of bias, as follows:

(1) Zooarchaeological *counting strategies*. In order to estimate the composition of the animal consumption of at least the three large animal groups (cattle, pigs, sheep/goats), two main concepts have been used, the “Number of Identified Specimens” (NISP) and the Minimum Number of Individuals” (MNI). The NISP (also called TNF for “Total Number of Fragments”) counts all bones and bone parts that can be attributed to a specific animal, which then may be weighted by a certain ratio of bone-to-meat or left un-weighted. Proponents of the MNI method consider only such identified bones which exist only once in a certain animal, and then construct the lowest possible number of individual animals comprising a given bone population. The principal biases of these methods are as follows: (a) the NISP tends to overestimate large animals with robust bones, as the likelihood of these bones’ showing in the record is higher. This relates in particular to an underestimation of small animals such as chicken, but in our case, underrepresentation might be the case for goats and sheep as well, albeit to a lesser extent; (b) the MNI, in contrast, seems to overestimate animals with a relatively small share at a given site or in a given region, as it only needs one bone element to

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<sup>18</sup> For an overview on taphonomy, see Lyman (1994), O’Connor (2000); for a list of non-cultural processes, see Behrensmeyer (1993: 345). For further critical discussions of interpretation possibilities, see Wilson (1996). A quantitative comparison of different methods is given in Hambleton (1999).

indicate the existence of this animal. To give a hypothetical example, goats in England (which were overall not so frequent there) could in principle be over-represented in our record (had we used this method, which we have not). Gilbert and Singer (1982: 32) report that the MNI does not perform well in simulation exercises: in fact, the NISP requires a smaller number of bones to arrive at approximately correct animal shares, as compared to the MNI method. Fortunately for our study (our sources were based on the NISP), the results of the two methods correspond broadly when the animal bone shares of the three large animal groups are studied (Hambleton (1999) 36), Figures 11a, 11 b).<sup>19</sup> In sum, the bias from zooarchaeological counting strategies should be relatively limited.<sup>20</sup> Overall, we follow the conclusion of the recent taphonomic literature that it is crucial to compare data in percentages of animal types, analysed using one homogenous method.<sup>21</sup> In contrast, the ‘real’ number of animals would be much more difficult to measure correctly.

(2) *Representativeness*. If we collect data on consumption patterns, we have to make sure that all animal bone remains are related to food consumption activities. Thus, data from ritual offerings in temples or sacrificial deposits in non-sacral contexts, as well as grave goods and workshops were not taken into account (see Lauwerier 2004). Firstly, ritual sacrificing may or may not have been combined with the regular human consumption of meat. To be on the safe side, it is thus reasonable to exclude such sites. Secondly, bones from specialized large slaughterhouses should be excluded. A substantial bias, at least on a local level, could stem from the special institutions that centralized the killing of animals; similarly, the separation of

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<sup>19</sup> Nevertheless, King deliberately excluded data based on MNI or ‘bone weight’ estimates; see the discussion in Hambleton (1999).

<sup>20</sup> The alternative “share of meat rich bone parts” has been severely criticized: is not suitable for interpretation, as these bones are the largest and most robust ones and therefore have the best chance to survive. Thus, it can be problematic to estimate the yield in meat based on the estimated average live weight per animal (see Doll 2003; compare Hanik (2005, 66) referring to Reichstein 1991 and others).

<sup>21</sup> See Amorosi et al. (1996, 138-139): “We cannot reconstruct direct counts of ancient stock whatever our method of quantification.... [bone assemblages should be used as an] altered proxy indicator.”

bone and meat could potentially bias the record. Fortunately, special slaughterhouses and sacrificial deposits were not very frequent in the samples available to us; otherwise, we would have needed to consider a counteracting bias arising from omitting them. In general, however, in order to minimize the bias, animal bone remains stemming from any such special ‘locations’ should not be taken into account, as they might distort the more realistic shares we can obtain from regular waste deposits (see, for example, Doll 2003; Lauwerier 2004).

(3) *Taphonomic factors*. During the post-mortem, pre-burial, and post-burial histories of faunal remains, various taphonomic factors influence bone survival. As far as it is known, these factors result in a corroded bone surface and perhaps fibre structure in most cases, but not in the total loss of the bones (Lyman 1994; Denys 2002)<sup>22</sup>. In general, at least some parts of a consumed animal are preserved and can be analysed.<sup>23</sup> In the worst case, the bones are comminuted.<sup>24</sup> In discussing possible bone destruction, biostratonomic (i.e. relating to the sedimentary history of the fossil) and especially diagenetic (i.e. relating to post-burial, chemical and mechanical alterations within the soil) factors are of interest which can affect a bone in a way that it is fully destroyed. Abrasion can be the result of various conditions:<sup>25</sup>

First, cooking may affect the degradation of the bone material due to its softening impact, as it makes the bone more vulnerable to later diagenetic conditions (see e.g. Nicholson 1996). It is not possible to quantify this aspect.

Second, different survival probabilities are based on the *soil type* in which the bone material is deposited. Soil type includes factors like sedimentation: different sizes of silt, sand,

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<sup>22</sup> Denys (2002, 469), for example, admits that “taphonomic processes” are “rather complex and still not fully understood.”

<sup>23</sup> Personal communication from Dr. Cornelia Becker, Free University of Berlin.

<sup>24</sup> Using the NISP, this could result in a bias towards cattle (and pork) as opposed to sheep/goat, because these animals are larger and therefore can be broken into a larger amount of fragments. But most of the taphonomic factors do not break the bones, except for trampling and the excavation method (see below).

<sup>25</sup> Naturally, all of these different factors might interact.

gravel and pebbles lead to various degrees of abrasion. Sedimentation is also related to another factor, namely the erosion of the surrounding soil which might be reinforced by intensive and special forms of agriculture. Already the medieval clearing of forests could have had such an effect. Erosion in turn can result in other factors like weathering. Also, root etching can be a factor if the roots stem from plants (and fungi) that excrete humic acids (Lyman 1994, 357). Furthermore, chemical soil parameters can affect bone survival, especially soil-pH or microorganisms.<sup>26</sup> In contrast to alkaline soils, soils with much acid (such as peat) destroy bones more quickly. However, the amount of microorganisms increases with higher pH-values, which can counterbalance the 'preferable' soil-pH. In alkaline chalk and limestone soils, a particularly large number of bones have survived. Can we find differences in soil structure between our three large regions of Europe, and over time? According to Zech and Hintermaier-Erhard (2002; based on the Reference Soil Groups of the World Reference Base of Soil Resources, WRB 1998) and the FAO (2006), the overall soil-pHs of the dominant soils in Europe differs not much. Yet local differences can be large, of course – and even variations in the composition of the soil depending on the strata – which cannot be quantified in an overview study.<sup>27</sup> Thus, in different soils, bones have a different likelihood of surviving over centuries and showing up in archaeological records. However, this should not have a major

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<sup>26</sup> Soil-pH is of special importance, because it has an impact on many further soil attributes: see Hillel (2005, 197); Scheffer and Schachtschabel (2002); Anderson and Kreitz (1997). In the literature, it is also discussed whether acidity itself has a significant impact or not; see Nicholson (1996, 523), versus Gordon and Buikstra (1981).

<sup>27</sup> It is problematic to reconstruct the soil-pH, because except for the basic conditions (soil composition), the soil-pH can vary 'micro'-locally and temporally - even by several units (see Scheffer and Schachtschabel (2002, 122). Differences in soil-pH arise from various natural factors as well as anthropogenic changes and burdens: like the type of vegetation (even similar soils can have a different concentration of pH and bacteria due to different flora), extension of the rootedness of the soil, emission and acid precipitation, intensity and kind of fertilization, drainage of fields and irrigation etc., or even changes in the CO<sub>2</sub> partial air pressure. It is important to bear in mind that except for short time variations, soils changed extremely over time due to nitrate wash out, and an increase in the concentration of pollutants.

impact on the share of the three types of large mammals. Certainly, cattle and pig, and probably also sheep/goat bones are similarly robust against soil acidity.

Third, we must consider bone destruction by *dogs and other animals*. Carnivore and rodent scavenging can affect a bone, but in general, it only modifies the bone surface in the form of tooth marks, so that the bone does not “fully” disappear.<sup>28</sup> Even after digestion, the specialist can still distinguish from which animal the bone stems.<sup>29</sup> Moreover, coverage with earth prevents the risk of access by scavengers (Lyman (1994) 144).

Fourth, trampling may be a factor, although this counts mainly for bone remains lying on the surface (Denys 2002, 475). However, as chemically altered bone breaks easily under large weight (Lyman 1994, 423), earth-covered bone material close to the surface may also be affected. In this context, the impact of modern agriculture should also be discussed. Over the nineteenth and twentieth centuries, agricultural techniques changed substantially, resulting in disruption due to today’s heavy vehicles and machinery moving much deeper into the soil, and thus destroying a considerable amount of bones and other archaeologically interesting material. Although this influence is substantial and it could be imagined that Western and Central Europe had much more intensive agriculture than the other two regions, we think that this should affect all three types of large animal bones similarly.

Fifth, there are other factors that may matter especially at individual sites, but less so in the three large regions into which we divided Europe. For example, variation in bone assemblage composition could be the result of punctiform building activities, or varying waste disposal practices for larger and smaller animals even within single sites (see Driver 2004). But if the overall bone collection for data analysis consists of material from a wide range of settlement types, this should not lead to a significant bias towards one particular species.

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<sup>28</sup> Personal communication from Dr. Cornelia Becker.

<sup>29</sup> Hyenas are the only exceptions.

(4) *Excavation density and method.* The total number of bones is clearly determined by the amount of interest archaeologists develop for certain periods and regions, and sometimes by the institutions that decide about excavations. Simply counting the total number of bones and then calculating the “animals consumed per capita” would be misleading in our view, as those periods and regions which are of predominant scholarly interest would automatically have higher numbers. Furthermore, excavation methods and post-excavation activities can also vary, resulting in different bone registration likelihoods – for example, some excavators might simply have left bones unrecorded if they were interested in other archaeological finds.

Three main arguments support our use of animal shares as important and more or less reliable evidence for ancient and medieval agricultural specialization: first, we consider only the shares of three types. The strongest taphonomic biases tend to affect the total number of surviving bones, and not so much the shares of large animal types. Second, if any of our three groups is more vulnerable, it is the sheep/goat category (given the smaller size of these bones). However, our account is driven by the ‘pig versus cattle bones’ argument, and those were of similar sturdiness. The strongest taphonomic biases (in all possible factors) refer mainly to small animal categories, such as chicken, fish, and other small animals (again, thanks to C. Becker for personal communication). This is also the reason why little is known about these species for the period under study (fortunately, the small amount of meat and non-existent milk suggests that their nutritional value is somewhat limited, except for fish in coastal locations). Thirdly, most of the literature on taphonomic bias refers to single excavation sites, whereas we consider three large regions of Europe, so that a substantial part of the measurement error averages out or has only modest influence in our study.

In general, we agree with Luff’s statement that “although we cannot accurately quantify the exact species changes through time, we can identify general trends and also differences in



species exploitation between sites” (Luff 1993, 54). Even if this statement refers to individual sites (whereas we are more modest here and average large European regions), we also think that some measurement error remains in our series, and that we can only interpret broad trends and differences between regions. However, we can still use the given bone material in shares to approximate husbandry strategies. Temporal and regional differences between the animal species percentages used here can thus be interpreted as a result of different consumption conditions, although the caveats mentioned above must be kept in mind.

## **Height Data**

Our height data stem mostly from archaeological excavations. This collection of evidence represents the largest collection of observations on Europe to date (see Table 2).

We again distinguish three regions (a) Central-Western (b) Northern and Eastern Europe and (c) the Mediterranean region (west of Greece). For the early Middle Ages, the data are quite abundant (Table 2). After the twelfth century, height data become scarcer, as bones in cemeteries were more often lost or mixed with bones from later epochs. From the seventeenth and eighteenth centuries onwards, archival sources provide much larger sample sizes, while at the same time posing additional selectivity and truncation problems (Komlos et al. 2003). Because the period from the eighteenth to twentieth centuries is relatively well studied, we focus mainly on earlier centuries here. Our sample consists of 2,938 female and 6,539 male height measurements, distributed more or less equally among all major periods. Only for the seventeenth and eighteenth centuries are an insufficient number of cases for women are

available.<sup>30</sup> A large proportion of the height measurements were aggregated by the excavators and original investigators. Wherever possible, we collected disaggregated figures. Thus, our final database is comprised of 2,972 different height measurements after discarding extreme heights (less than 145 cm or greater than 200 cm). When the dating was imprecise, we used the average of the earliest and latest date mentioned by the principal investigators, as the real date could have been both before and after the middle of a century. We experimented with estimation techniques granting smaller weight to imprecisely dated observations or discarded them completely, but the main results remained robust.<sup>31</sup> Because of these data limitations, our time unit of analysis is the century. We organized all heights by century of birth and discarded such individuals who were still in the process of growing (less than 23 years of age). Heaping and truncation did not play a large role as is illustrated by the approximately normal distribution of heights (see Figures 1a and 1b in Koepke and Baten 2005). We also performed Jarque-Bera and Kolmogorov-Smirnov tests for normality (by century of birth) and found that the distributions of well-documented centuries were all distributed normally, except for the eighth century (details available from the authors).

Our intention was to collect as much height data as possible, with the consequence of having to accommodate different types of height information. The majority of measurements were based on excavated long bones (see next section), but some information was also derived from complete skeletons; with such measurements, we relied on the original authors' judgement and adjustments (typically, for instance, 2 cm are added to cadaveric length in order to adjust for disappeared non-bone parts of the body, but none in the case of *in situ* measurements, as the *post mortem* stretch is compensated by missing skin (see Maat 2003).

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<sup>30</sup> The so-called primary deficit of females (smaller number of females in the case of patriarchally-structured societies) is typical for prehistoric and ancient populations (Mays 1995).

<sup>31</sup> The same applies to age estimates.

We also used heights that were estimated using armour from sixteenth and seventeenth-century Central and Eastern Europe. One might assume that the armours did not fit those wearing them perfectly, but that they were in fact slightly larger in order to allow for some mobility.<sup>32</sup> Fortunately, our data set contains a sufficient number of archaeological height measurements for those centuries, which can be compared to the armour. The average difference between armour height data and other height data was only about 0.3 cm for those periods and thus insignificant.

We used both weighted regressions (square root of sample size) and regressions with individuals only to estimate height trends first by gender, and then by European regions. The regression approach allowed us to control for migration and social status at least to the extent that we (and other scholars) were able to assess the influence of those factors on the basis of grave goods and similar information.<sup>33</sup> The resulting height time series is given in Figure 2.

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<sup>32</sup> Most armour originated from a time period when military technology had moved away from the horse-based knight armies which had proven so unsuccessful in the Hundred-Years' War. Our armour probably stem from males from all social strata, who were hired and received salaries as soldiers.

<sup>33</sup> Migration required additional assessment, since environmental circumstances during the first three years of body growth have the most lasting impact on adult height. Two points are important in this respect. Firstly, most migrants experienced a different environment during their first years of life, compared to the autochthonous population. For example, if they were born in a Northern or Eastern European agricultural environment and then migrated to the Mediterranean in their later life, we would expect them to be significantly taller. Secondly, if immigration was extensive enough, agricultural production techniques might have been transferred to the target region if they turned out to be sufficiently efficient in the new environment. We know that the most important migration streams moved from the Mediterranean region into Central and Western Europe between the first and third centuries A.D., while important Germanic (and other) migration took place from Northern Europe to Eastern, Central, and Southern Europe and later to the British Isles between the fourth and sixth centuries. Migrants from the Mediterranean region to Central Europe (especially Roman soldiers and officers, as well as administrative staff) turned out to be 4 cm shorter than the rest of the population. However, skeletons which could be identified as "Germanic migrants" were not significantly different from Eastern Europeans. Likewise not statistically significant, but economically meaningful was their coefficient in the "Mediterranean" regression: Germanic migrants who died in the Mediterranean region were 1.63 cm taller. It is furthermore important to control for migration because a number of anthropologists are still convinced that genetic height potentials play a determining role in this regard, whereas other anthropologists have doubts whether genetic height potentials can explain any variation in the average height of a population at all (in contrast to individual height, which is clearly influenced by genetic factors; see Bogin 1988; Mascie-Taylor and Bogin 1995). Social status is an important variable, since many studies of the eighteenth to twentieth centuries found height differences of

Overall, heights remained stagnant and indicated no real progress in European nutritional status until around 1800 A.D. However, there is considerable variation between the centuries, as, for example, in the fifth and sixth centuries when heights increased, or during the medieval warm period (eleventh and twelfth centuries A.D.).

In order to ensure that our estimates of height development would be reliable, a number of other factors had to be taken into account, since some statistical limitations naturally arose. For instance, although our sample was larger than in earlier studies, the number of cases considered remained small in comparison to data sets on more recent periods. However, this shortcoming is probably acceptable given the fact that height trends evolved in similar ways for separate European regions and genders, except where we expected them to diverge (Figure 3a and 3b). For example, we expected a decline of heights in Northern and Eastern Europe during the Little Ice Age (14<sup>th</sup> -17<sup>th</sup> centuries A.D.) because of the extreme impact of the climatic change on cattle farming and human nutrition. In contrast, conditions were more favourable in maritime Central-Western Europe during this period. In addition, Western and Central Europe performed much better than Northern and Eastern Europe, especially the Netherlands and the United Kingdom which took over economic world leadership during this period (on North-Eastern Europe, see also Steckel 2004). Female mean height is by nature always lower than male height. However, female growth can also be inhibited by the discrimination of females (Figure 3b). During the Middle Ages, female heights were even

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typically 2-4 cm among adults of the lower versus the middle and upper classes (Baten 2000). In our data set, we relied mostly on the classification schemes of the original studies. If skeletons were not of higher social rank, the excavation reports often did not find this fact worth mentioning. We therefore assigned dummy variables in cases of middle and upper class origin (leaving a “lower or unknown” group to the constant). This also means that we should not over-interpret the coefficient of this social status variable. However, this variable is not only important as such, but also serves to control for the social composition and potential social selectivity when analyzing height trends. Although the bulk of our measurements stem from burial sites which represent all societal strata, we wanted to exclude the possibility of social selectivity as a potential cause of height trends as much as possible. However, the latter was at best marginally significant anyhow.

relatively lower than male heights as compared to other epochs, whereas gender dimorphism decreased in the Renaissance period, as we would have expected based on the literature. For our study, we pooled heights of both genders and adjusted to male height levels, controlling for deviation with a dummy variable in order to make use of all available height estimation data points (see Koepke and Baten 2005).

Apart from the expected deviations mentioned above, height trends developed relatively similarly over the regions and genders suggesting that the underlying data are reliable. We also ascertain reliability by checking burial sites that were used for more than one century. If they shared the same trend with the corresponding larger region, we could be more certain that the height trends discovered by us were not mainly caused by a random regional composition effect. Regarding the larger samples, the majority of cases pointed indeed in this direction. Nevertheless, we must also stress the limitations of our height estimates, since some measurement error certainly remains in all three series.<sup>34</sup>

### **Determinants of mean height**

In order to test whether, and to what extent, the cattle bone share – as a proxy for protein intake – and various other determinants influenced average height in Europe until 1800 A.D., we applied panel data analysis at the level of the three European regions outlined

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<sup>34</sup> As we already admitted earlier, it is apparent that studies based on archaeological data can naturally not be based on a similar amount of cases as studies on written sources. In addition, they will always involve some uncertainty (concerning dating etc.). In spite of this, it is important to compile and collate all the information available and learn as much as possible from it – on further limitations, see Koepke and Baten (2005).

above.<sup>35</sup> Here, we discuss estimates with regional dummies (equivalent to fixed effects) and period dummies.<sup>36</sup>

Below, we will interpret a part of the “land per capita” effect as being caused by the often more favourable disease environment of low population density areas. Land per capita is simply calculated as square kilometers per inhabitant. It was included in logarithmic form to account for decreasing marginal product effects (or, inversely, increasing costs of population density).<sup>37</sup> We clearly need to control for gender, given that we constructed the data set from both male and female heights.

Which variables have the greatest explanatory power for the long-run development of mean height (Table 3)? In model 1 we included the cattle bone share variable, gender, climate, the regional and period dummies for North-Eastern Europe. The period dummy for antiquity was statistically significant (on the 5%-level, see Model 1 in Table 3), as well as the cattle

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<sup>35</sup> For as many centuries as were covered by our animal bone data. All time information refers to A.D. values from here.

<sup>36</sup> Most of the population data comes from McEvedy and Jones (1982). Data on population density for the period after the thirteenth century are based on Allen’s (2003) study on Europe. Colder winters and correlated weather extremes tended to make food production (and especially protein production) more difficult in Central-Western and North-Eastern Europe (Baten 2002). Thus, the impact of climate on human history was immense (Grove 2002; Pfister 1988). We reported in Koepke and Baten (2005) how we created a climatic index from tree rings, glacier movements, etc. One would expect that higher gender inequality *ceteris paribus* has a reducing effect on mean height, since Osmani and Sen (2003) have argued convincingly that female discrimination hurts both girls’ and boys’ height if their mother lives under unfavorable nutritional conditions. We measured this by century, calculating the gender differential of height (by centuries). On inequality in general, see Steckel (1995). We experimented with a “plague” dummy for the centuries of its most violent outbreaks but we were well aware that our height data can only measure heights with a time resolution by century. We hence decided not to give too much credit to the insignificance of the plague dummy in our model, and did not report it in the final regression table. The disease environment might have been the reason that heights in North-Eastern Europe in the fourth century were 3 cm shorter than expected. Although not much is known about this phenomenon, the arrival of the Huns in the fourth century A.D. might furthermore have spread new diseases which were brought from Central, North and East Asia – in addition to the population pressure and worsening conditions accompanying the very beginning of the ‘main’ migration of peoples. The decline of the Roman Empire and the wars of this century could have had an influence on Central and Western Europe, but it is unclear why they should have had any influence on Northern and Eastern Europe. To be on the safe side, we excluded North-Eastern Europe from our analysis of the fourth century.

<sup>37</sup> Moreover, the original variable was strongly skewed to the right, and the logarithmic transformation led to a more symmetric distribution. We thank a referee for this suggestion.

share variable, our indicator for specialization on milk and beef production.<sup>38</sup> In the second model, we included log land per capita, which was also individually significant, whereas the significance of “antiquity” vanished. This might actually indicate that the reason for the relatively short stature during Roman antiquity was the low land per capita values. After controlling for land per capita, the significance of the Roman antiquity period disappears. On the other hand, the regional dummy for “Northeastern Europe” is significantly positive in Model 2, which does not control for cattle specialization. Northeasterners might have seemed taller simply because the region was more specialized on cattle farming, providing the positive proximity and equality effects of untradable milk. Against the background of the older anthropological literature which assumed “racial” differences in height between different European populations, it is particularly noteworthy that the significance of the dummy for North-Eastern Europe disappeared as soon as we controlled for specialisation in cattle farming.

In Model 3, we included both core variables, land per capita and cattle share. They in fact remained both statistically significant with only modestly smaller coefficients. Finally, we were curious whether those two variables remained robust after removing the period and region dummy variables, and climate. In fact, the significance of the two determinants of human heights was quite robust. The size of the coefficients is smaller, if period dummies are not included. Even the adjusted  $R^2$ s remained at 0.41, and the explanatory power was in general quite high in all models.

As hypothesized above, land per capita represents two main causal links: high land per capita values allow greater specialization on milk cattle agriculture, which affects heights on the one hand, but on the other hand, a low population density (which is simply the inverse of land per capita) has a direct positive effect on heights through a more benign disease

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<sup>38</sup> The reference value is ‘Central-Western Europeans living in the early Medieval Age’.

environment. How large is the economic significance of those two variables? If we multiply the two coefficients of our preferred Model 3 by the standard deviations of the underlying variables, we obtain positive, but slightly different effects: an additional standard deviation of cattle share implies 0.98 additional centimetres in height and one additional standard deviation log land per capita gives 0.68 additional cm (calculated only for those 25 cases for which all information is available; the standard deviation for log land per capita is 0.54, and for the cattle share, 0.14). An additional centimeter of height is quite substantial, as it has been estimated that it corresponds with 1.2 years of additional life expectancy (Komlos and Baten, 1998). It also represents about two thirds of the standard deviation of height, whereas the effect of land per capita accounts for about one half (see Table 4). We conclude that the effect is composed of two valid components, of which the cattle share is apparently the stronger one. The other component (land per capita, or its inverse: population density) can be related to (a) the more benign disease environment, and (b) Malthusian declining marginal product forces. Thus, we can quantify the potential contributions of the protein proximity effect as being somewhat larger than the potential effect of the disease environment.

### **Discussion: Milk consumption and alternative cattle product use in ancient times**

We claim that changes in the relative composition of cattle bones reflect milk consumption. But is this so? After all, cattle could have been used for meat rather than milk. In effect, cattle were certainly used for both milk and meat, but milk has a stronger influence on regional human nutrition. In general, it is clear that cattle farming was always multipurpose (“kept for meat, milk and/or traction,” Crabtree 1996), or at least for dual use (Bartosiewicz et al. 1997; Luff 1993; Seetah 2005). The question remains, however, whether milk was the most



important component in the output. We cannot quantify this fully for the ancient period, but some considerations allow at least a rough judgement regarding relative importance. Most of the literature views the primary use of cattle as somewhat less important than secondary use (milk, traction, fertilizer), as will become clear in the following. Greenfield (2005) even argues that predominant primary product use was rarely practiced, except, as he puts it, “under unusual circumstances, such as in developed market economies.” Urquart (1983) postulates that the secondary products, which can be obtained from cattle were actually the ‘trigger’ for domestication.

The primary use of cattle (meat, hide, bone) is, of course, only possible once in the life cycle of cattle. Secondary use for milking is possible more often. Thus the latter has the decisive advantage over meat consumption in that it uses resources much more efficiently: milking yields four to five times the protein of meat production, even if milking is admittedly more labour-intensive (Sherratt 1981, Davis 1987). Milk production results in a higher energy output than meat production because in the ancient economies, the latter required a substantial input of milk: 10 kilograms of milk had to be fed for gaining one kilogram of meat (see Foley et al. 1972). This implies an exchange ratio of 4:1 in energy values (Legge 2005) - 6,500 kcal of food energy in milk for 1,600 kcal of food energy in meat.

Can we measure when and where dairy farming was practiced? Evidence on milking practices of cattle comes from archaeology (pots, tools), historical sources, art (depiction of milking on friezes, vessels etc.), and the age structure of male and female cattle (see below). Moreover, recent mass spectrometric analysis has made it possible to identify milk fats (as distinguishable from meat fats) in excavated pots, because milk fats display a different signature ratio of carbon isotopes than meat fats (see Bower 2003; Copley et al. 2003; Craig et al. 2000). This recent chemical research shows that the use of cattle as a dairy supplier was

dominant over the use of cattle as a meat supplier in North-West European prehistory (Copley et al. 2003; Privat et al. 2004).

The most important and commonly used possibility to find out about the dominant use of cattle is zooarchaeological demography. Zooarchaeologists can detect differences in cattle husbandry by studying the sex and age structure of the kill-off patterns:<sup>39</sup> firstly, if the emphasis of cattle use lay in milk production, the bone assemblage consists mostly of remains from female adult cattle and male calves, but of very few older male cattle for reproduction (Maltby 1994; Locker 2000). This results in the highest possible output of milk available for human use (Legge 2005).<sup>40</sup> Secondly, if the emphasis of cattle use was on meat production, the animals slaughtered were mostly bulls of full meat-bearing potential; 2-3 years of age (approximate time of the 3<sup>rd</sup> molar eruption) is commonly regarded as the optimum meat weight age (Reid 1996; Locker 2000). Thirdly, the emphasis could also have been on traction, especially for grain production. In this case, bulls and cows, and especially oxen, all older than prime meat age, can be found in the bone material (Crabtree 1996).<sup>41</sup> Although to a lesser degree, ‘worn out’ joints can also be normal signs of old age (traumatic lesions), draught animals can be identified by sub-pathological deformations (Hugonot et al. 1991, Bourdillon 1994, Bartosiewicz et al. 1997; Groot 2005).

These are the archaeozoological methods for obtaining information on regional and temporal differences in the use of cattle in Europe. Habicht (2004) gives an overview of the use

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<sup>39</sup> On the methods, see also McCormick (1992); for an overview of the literature, see Wilson (1994).

<sup>40</sup> In contrast to the general view that a kill-off pattern with many calves is a hint towards dairy production, see McCormick (1992): in his opinion, cows in former times needed to have their calves around to stimulate their milk production. On the other hand, Peters (1998: 65) among others states that due to the rather small milk output of the cows of the Teutonic tribes, the culling of the calves had to be carried out during the first weeks of life if the aim was to obtain any milk. The contemporaries had methods for stimulating the milk flow even if the calf was killed.

<sup>41</sup> Because castrated animals are especially suitable for the use of plough pulling because they are sedate (Hugonot et al. 1991). Furthermore, their growing span is prolonged due to the later closing of the epiphyses because of castration (Hanik 2005), which results in higher stature.

of cattle in the whole period of our study, and other studies provide further details: at excavated prehistoric sites, the predominant part of the stock are adult cows (in correspondence to the importance of milk for ‘barbarians’ mentioned below, see also the ancient literature, e.g. Tacitus Germ. 23, Caesar Gall. 6, 22,1., Strabo 4,4,3). Only at some sites, bones displayed lesions indicating a degenerative joint disease resulting from the traction use of some cattle (Telldahl 2005; Murphy 2005).

When Central and Western Europe became a Roman imperial province, more cattle was used for traction power, because grain agriculture grew. Research opinions diverge on whether cattle was used predominantly as draught animals (Junkelmann 1997) or whether milk production was still dominating in the North-Western provinces (Rothenhöfer 2005), but meat was apparently not the primary or secondary, but rather a tertiary aim of keeping cattle. Still, meat animals to supply the urban population and the army also played a role (Groot 2005). It is important for our study that Romanization might have meant a movement towards more dominant draught animal use, from the previous clear milk orientation.<sup>42</sup> Peters (1998) argues that cattle were primarily used for traction power in the Northern Roman provinces. Others argue that cattle in the Northern and Western provinces were mainly used for the purpose of obtaining milk, meat and skin (Fellmeth 2001). Especially in the (former) Gallic and Teutonic regions, dairy production was most common because the autochthonic population was used to it. Some sources also report a high cultural appreciation for milk production there, whereas the Italians of the Roman Imperial period considered cow milk consumption as something for barbarians (Tuffin and McEvoy 2005). However, we can never know whether such statements

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<sup>42</sup> This would fit with the breeding efforts towards an increased capacity of cattle in Roman times, which was only secondarily aimed at a higher meat and milk production. More working power was needed to reach increased efficiency in intensified sowing for producing more grain to feed the increasing population numbers.

about taste and cultural preferences are truly exogenous, or perhaps partly determined by economic and climatic factors.

After the Roman Empire broke down, female cattle dominated again in medieval Central Europe (Doll 2003); the main function of husbandry was breeding and milk production. Different types of settlements show heterogeneous patterns (see Thompson 2005; Driver 2004), but the general pattern seems to hold. From the end of the thirteenth century, treatises on husbandry in England survived which allow us to infer the importance of the attainable yields of dairy products from cow milk, as well as investment in those products (Thompson 2005). Based on the material overviews of kill-off patterns from different sites, separate and detailed information on the sex and age at death is published very rarely (e.g. Hugonot et al. 1991 - but the number of observations is rather small). In the high to late medieval society, the nobility again increased their pork consumption strongly, in contrast to peasants, farmers, and the urban poor (see Doll 2003, Ervynck 2004, Pigiere 2004).

Overall, it is possible to conclude that the consumption of bovine milk and meat was more prevalent in the regions outside the *imperium Romanum*, as seen from the archaeological and historical sources (Fellmeth 2001). By contrast, traction power was the main motivation in the heartland of the *imperium Romanum* – and after Romanization, perhaps also in some of the Northern provinces. In principle, we might even have given less weight to the cattle share in Roman times, as orientation towards traction use meant less milk and therefore protein, but we think that this effect is already captured in the lower cattle share and land per capita values. For the provision of the army and the provincial cities, meat also played a role, but it is difficult to quantify its importance. In fact, as we already mentioned in the beginning, the relative importance of meat and milk is not too important for our approach because we argue that milk

was the component which had the strongest regional impact, and had the egalitarian effect observable in the regression (having a positive impact on height).

### **How important was the trading of cattle meat?**

Given the scarcity of cattle meat in the Mediterranean, one wonders whether trade could have played a role. Of course, cattle meat was always stored and to a certain extent also traded.<sup>43</sup> However, when considering quantities, trading of meat must have been somewhat limited because of the modest transport technology of the time. The value of cattle meat was limited compared to its weight; hence, its transport was not very profitable. It is true that the *imperium Romanum* was known for its relatively developed transport system; however, long-distance trade on Roman roads was mainly for army purposes, as the dispersion of barrel and amphorae finds demonstrates (Junkelmann 1997, 58). Also, the imperial Roman import/export potential of long-distance trade goods was dominated by grain and luxury foods (for example, oysters). Even taking living animals to Rome or other big cities was costly, as they needed vast trails that could not be efficiently used for other agricultural purposes (and if driving cattle herds would have been the strategy, the bone shares would have reflected consumption patterns in the region of consumption; hence, this does not create any bias in our measurement). Only from the sixteenth century onwards are large cattle imports from Hungary to Austria and Germany a proven occurrence (there are some earlier exceptions: see Seetah 2005). In sum, long distance trade in meat products was not the regular way to provide for the

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<sup>43</sup> For example, Schweissing (2004) demonstrated that even in Roman times, live cattle was traded over long distances: this was the case for longhorn cattle, traded from the Hungarian region to Upper Austria. However, the long distance trade of meat products is proven only in few cases, like for the Latène period when pigs and salted sheep meat were traded especially with Greek traders (Mollenhauer (1995)). In one ancient source (Varro, rust. 2,4,10) the import of ham and bacon from Gallia to Rome is reported.

average population in the ancient economies.<sup>44</sup> In general, we can assume that animals were consumed where their bone remains are excavated. Therefore, the animal bone material of a region does provide evidence on the composition of the nutrition of the people of in a given region, as we have claimed.

## **Conclusion**

Important shifts in agricultural specialization shaped the economic history of Europe over the period 1000 B.C. to 1800 A.D. As population density and urbanisation increased on the Apennine peninsula, agriculture switched from an initial specialization in cattle and goat breeding – which implied a relatively high and egalitarian protein supply – to a completely different system. During the Roman Imperial period, pork was a prominent food of the urban high-income strata of society, whereas the poorer ancient Roman population consumed primarily vegetarian food (Souci, Fachmann, and Kraut, 1994).

We tested the hypothesis that protein-rich milk and beef were major determinants of the biological standard of living in early history just as today, and considered the effects of cattle farming on health by using anthropometric techniques, based on a sample containing information on more than 2 million animal bones. A number of taphonomic factors were taken into consideration which had an impact on the zooarchaeological quantification. We constructed indices of specialization for three regions of Europe for the period of approximately the first millennium B.C. to the second millennium A.D., with some gaps remaining in between. The share of cattle bones turned out to have been a very important

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<sup>44</sup> Preserving meat might not have been an unsurmountable problem for meat trading, even if all strategies of ancient meat storage also led to a certain loss of nutrients; especially heating results in a vitamins loss, salting in a protein loss. On preservation, transport and nutrition administration over time: see Mollenhauer (1995); Peters (1998), Fellmeth (2001).

determinant of human stature (correlating with health and longevity), being *ceteris paribus* an indicator of milk (and beef) supply. Secondly, land per capita (which comes with low population density) had an impact via productivity per agricultural worker and the benign disease environment of low population densities.

Since earlier scholars did not take the milk/beef indicator into consideration, the fact that the Germanic, Celtic, and Slavic populations of Northern and Eastern Europe were taller than the Mediterranean populations was hitherto solely attributed to genetic reasons. When we controlled for this indicator, however, statistically insignificant dummy variable coefficients resulted for North-Eastern Europe. Hence, autochthonic Germanic people in *Germania Magna*, beyond the borders of the *imperium Romanum*, were taller than in the core-land of the Empire because they produced and consumed more milk and beef.

Although certain limitations of our estimates cannot be denied, we are convinced that the approach presented in this paper could generate interesting findings in other contexts as well. If we are to study the economic history of the very long run, anthropometric and archaeozoological techniques do provide indispensable insights into some of the central aspects of human life.

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**Table 1**

REGIONS COVERED BY OUR DATA SET: NUMBER OF ANIMAL BONES

Source: see text

Century	Central-Western Europe			North-Eastern Europe		Mediterranean			Total
	Germany/ Austria	Gaules	Britain	Danube prov.	Barbaric um	Italy	Provence	Spain	
-10	.	.	.	.	.	81			81
-9	.	.	.	.	.	516			516
-8	.	.	.	.	.	457			457
-7	.	.	.	.	94	477			571
-6	.	.	.	.	27836	1471			29307
-5	.	.	.	.	94	468			562
-4		326		.	94	1559			1979
-3		260		.	94	3473			3827
-2	13142	4446	143	256	596	2016	104		20703
-1	289848	10801	3410	.	8235	2989	33		315316
1	64230	16385	35787	10533	18264	5005	10730	508	161442
2	176613	13641	51275	16956	18684	3779	9860	1392	292200
3	111473	9811	55417	11173	18684	2041	895	718	210212
4	32436	15601	61328	932	18352	3431	513	924	133517
5	1623	4060	11434	1198	36910	5567	1368	376	62536
6	33		5694	1077	23280	2654		392	33130
7	33		149	.	33884	1267		156	35489
8			149	.	41882	32			42063
9	.	.	.	1217	102623	.			103840
10	.	.	.	391	106360	.			106751

Century	Central-Western Europe			North-Eastern Europe		Mediterranean			Total
11	.	.	.	391	175154	.	.	.	175545
12	.	.	.	391	102906	.	.	.	103297
13	.	.	.	.	96470	.	.	.	96470
14	.	.	.	.	93795	.	.	.	93795
15	.	.	.	.	18821	.	.	.	18821
16					15169				15169
17					2093				2093
	689431	75331	224786	44515	960374	37283	23503	4466	2059689

**Table 2**

AREAS COVERED BY THE HUMAN HEIGHT DATA SET

(NUMBER OF INDIVIDUALS)

Century	Central-Western Europe				North-Eastern Europe		Mediterranean	Total
	Bavarian/Austrian region	Northern Rhine region	Southern Rhine region	UK	Eastern Europe	Northern Europe	Mediterranean region	
1	21	21	14	2	36	72	95	261
2	56	6	210	711		14	11	1008
3	16	95	24	184	37	46	50	452
4	361	1	26	227	65		4	684
5	3		113	9	68	5	164	362
6	338	208	380	2	99	7	35	1069
7	146	35	456	2	218	5	7	869
8	225		20		179			424
9	78	5	36	164	135	251	12	681
10		49	24		1	133		207
11	1		14	4	229	823		1071
12	1		18		20	440	125	604
13	3	12	9	174	29	53		280
14		113	3	4	6	547	7	680
15		55			6	11	29	101
16	73	55	314		17		3	462
17	21	19	39		39	41		159
18		103						103
	1343	777	1700	1483	1184	2448	542	9477

Sources: see [www.uni-tuebingen.de/uni/wwl/twomillennia.html](http://www.uni-tuebingen.de/uni/wwl/twomillennia.html)

**Table 3**

FOUR REGRESSIONS: DETERMINANTS OF HEIGHT IN A PANEL OF EUROPEAN REGIONS  
AND BIRTH CENTURIES

	Coeff.(1)	<i>S.E.</i>	Coeff.(2)	<i>S.E.</i>	Coeff.(3)	<i>S.E.</i>	Coeff.(4)	<i>S.E.</i>
Constant	86.21	<i>52.50</i>	154.90**	<i>53.9</i>	148.0***	<i>50.50</i>	172.1***	<i>2.97</i>
Cattle share	10.83*	<i>5.15</i>			7.01*	<i>3.92</i>	3.23*	<i>1.92</i>
Log Land per cap			1.53***	<i>0.51</i>	1.26**	<i>0.51</i>	1.08**	<i>0.50</i>
Gender inequality	0.10	<i>0.77</i>	-0.63	<i>0.58</i>			-0.27	<i>0.49</i>
Climate warm	8.37	<i>5.81</i>	2.25	<i>5.85</i>	2.23	<i>5.31</i>		
Mediterranean	2.68	<i>1.85</i>	0.12	<i>0.70</i>	2.29*	<i>1.32</i>		
North-East. Eur.	0.66	<i>0.66</i>	1.08*	<i>0.52</i>	0.68	<i>0.52</i>		
Antiquity	-1.85**	<i>0.79</i>	-0.48	<i>0.57</i>	-1.24*	<i>0.60</i>		
High-Middle-Ages	-0.84	<i>0.77</i>	0.67	<i>0.78</i>	0.21	<i>0.72</i>		
Adj. Rsq	0.58		0.66		0.69		0.41	
N	25		25		25		25	

Standard errors in italics. \*\*\* p<0.01, \*\* p<0.05, \* p<0.10

Constant refers to a hypothetical height value for the Early Middle Ages and Central-Western Europe. For descriptive statistics, see Table 4.

Definitions: the cattle share is defined between 0 and 1 (1=100% cattle bones). Land per capita is defined as the log of land (in square km) per inhabitant (sources: McEvedy and Jones 1982, and Allen 2003, see also text). Gender inequality is the difference in cm between male and female height. Climate warm is an index which is explained in detail in Koepke and Baten (2005). Mediterranean and Northeastern Europe are regional dummies, and Antiquity and High-Middle-Ages are period dummies.

**Table 4**

## DESCRIPTIVE STATISTICS

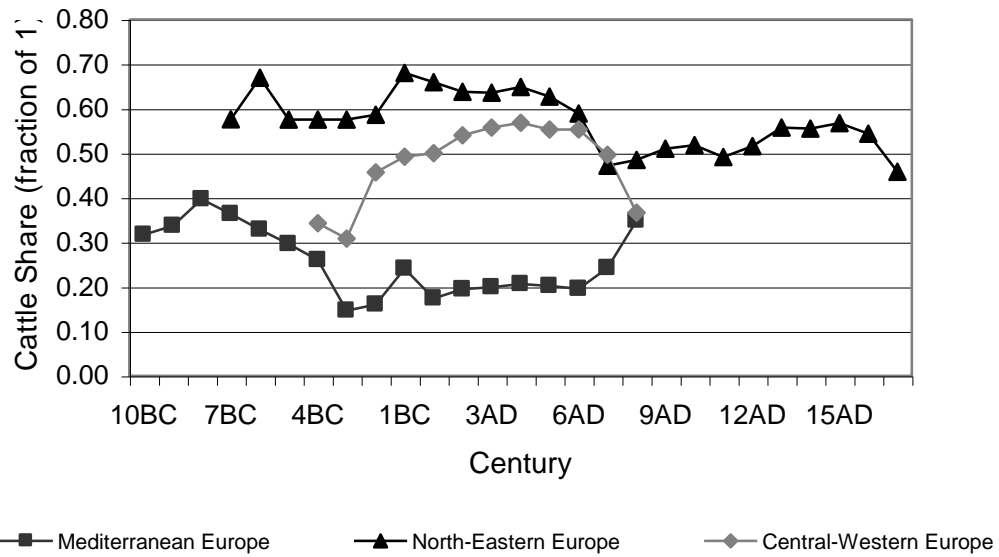
1	2	3	4	5	6
	N	Minimum	Maximum	Mean	Std. Deviation
Height	25	167.65	172.74	169.9626	1.404193
Cattle share	25	0.17	0.66	0.48	0.14
Log-land per capita	25	-3.52	-1.32	-2.01	0.54
Climate warm	25	9.20	9.40	9.32	0.05
Gender inequality	25	4.69	6.11	5.41	0.48

Note: the standard deviations for only the 25 cases using the regressions above are reported in the text. The 25 observations for which sufficient height and bone data, plus values for all explanatory variables were available, are: Centre/West: 1<sup>st</sup>-8<sup>th</sup> century; Mediterranean 1<sup>st</sup>, 3<sup>rd</sup>, 5<sup>th</sup>-6<sup>th</sup> centuries; North/East 1<sup>st</sup>, 3<sup>rd</sup>, 5<sup>th</sup>-14<sup>th</sup>, 17<sup>th</sup> centuries.

**Figure 1**

DEVELOPMENT OF CATTLE SHARES IN THE THREE 'LARGE' EUROPEAN REGIONS

Source: see text

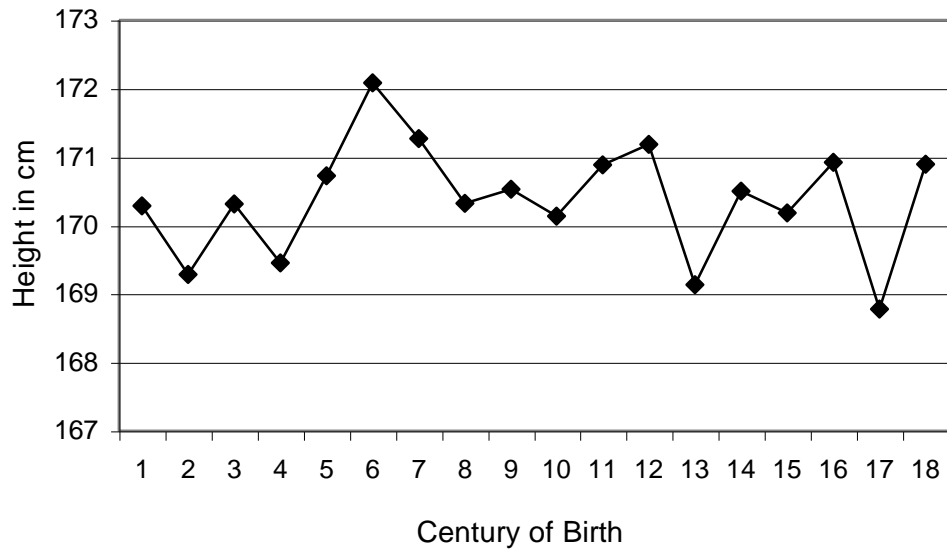




**Figure 2**

**HEIGHT DEVELOPMENT, 1<sup>st</sup> TO 18<sup>th</sup> CENTURY A.D. (IN CM, MALE AND FEMALE)**

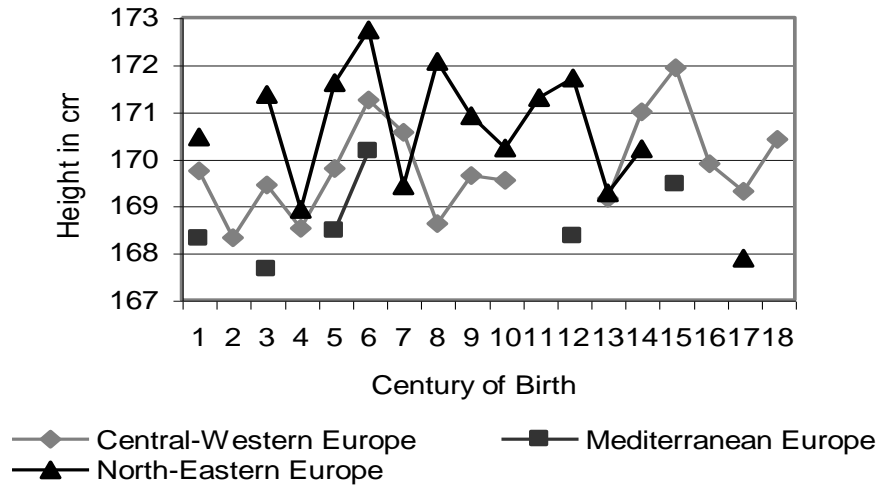
Source: see [www.uni-tuebingen.de/uni/wwl/twomillennia.html](http://www.uni-tuebingen.de/uni/wwl/twomillennia.html). The level of heights was adjusted to male heights of average Europeans (using the regional coefficients and weighting them with sample weights).



**Figure 3a**

**HEIGHT DEVELOPMENT BY MAJOR REGIONS (IN CM)**

Source: see Figure 2



**Figure 3b**

TWO-AXIS-DIAGRAM

HEIGHT DEVELOPMENT BY GENDER, 1<sup>st</sup> TO 18<sup>th</sup> CENTURY A.D. (IN CM)

Source: see Figure 3a

