Regional Differences and Temporal Development of the Nutritional Status in Europe from the 8th century B.C. until the 18th century A.D.

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„WICHTIG IST, DASS MAN NICHT AUFHÖRT ZU FRAGEN."

A. Einstein, zit. von W. Miller, in *Life* 2. Mai 1955

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PREFACE

In the present study the nutritional status of humans is used as an indicator for welfare, in terms of the biological standard of living, being examined for pre- and early historic Europeans.

The mean height of the population is used as a proxy for the nutritional status. For the heights physical anthropological measures of skeletons from archaeological excavations serve as main data source. Based on these data, temporal development and regional differences in the quality of the nutritional status are determined. Possible determinants of the different development in nutritional status and altered circumstances are studied using econometric methods. The utilized statistical methodology is novel for the study period: It is the first time that anthropometry is employed for a long run study on pre- and early European history. And this, although the anthropometric approach is of particular suitability for these periods, since only very few written ancient sources on nutrition and welfare development exist, which are furthermore of questionable reliability due to the specific intentions of the writers, and therefore not usable.

All the data used in the study, the dependent variable – means all height data – as well as the explanatory variables were collected, compiled, and (re)estimated personally by the author as important part of the present study. The data set is the largest of its kind compiled for this study period and region so far. Hence, in contrast to studies on recent periods, the necessary extensive investment has to be emphasized.

To study the nutritional status of populations of early-historic periods, an interdisciplinary approach is necessary: all height data and most data on its determinants stem from excavations and archaeological work, whereas the econometric methods come from applied economic research.

During the data collection it turned out that various models had been applied by different authors to reconstruct height from excavated bones. Because these models result in different estimations, it was necessary to develop algorithms to enable the use of as many data as possible, and to guarantee a reliable, homogeneous evaluation of the data. This method for unification of the results of the various models, which is also of interest for future researchers, is part of this thesis.

With the present work the first approach is presented to fulfill the long outstanding desideratum of a very long run study in the nutritional status in pre- and early historic Europe.

The PhD-Thesis focuses on questions such as: How has the nutritional status in European developed in the long run? Are there differences in the development between the different European regions? Do gender effects make a difference? Is mean height affected by, for example, changes in agricultural specialization, changes in population density, or by Roman 'civilization'?

1. GENERAL INTRODUCTION

Based on the concept of the biological standard of living various authors were able to elucidate the development of the living standard in the course of the recent three decades in economic historic research (for example, Baten 1996; 1997; 1998; 1999; Komlos 1993; 1995b; 1998; Steckel 2007; and most recent the works presented in the journal of "*Economics and Human Biology*"). The informative value of mean height as indicator for health and nutrition also became further established in medical science and palaeo-medical research (see e.g. Cohen 1989; Armelagos 1990; Czarnetzki 1996; Larsen 1997; Grupe 1990).

The utilization of mean height of a population as indicator for nutritional status is based on the finding of biologists that chronically insufficient nutritional status during childhood and adolescence suppresses growth, and therefore results in lower adult height. Final height is the output of the cumulation of factors concerning living conditions during the whole growth period.

Obviously, this anthropometric approach, the determination of nutritional status by mean height, is especially appropriate for study periods for which no sufficient quantitative data on any aspect of living standard exist. Therefore, this methodology of utilizing mean height is the ideal way to study 'archaeological' periods.[1] For the long run study presented in this thesis excavated bone material is used, because it is the only quantifiable source for mean height and nutritional status.

[1] Additionally to the uniqueness of height data as information source for archaeological periods, where no other adequate sources are available, the use of mean height as proxy for nutritional status has further important advantages: primary sources are available, and the data provides good comparability possibilities between centuries and regions (the creation of an exact good basket can be avoided – this anyhow would have been impossible for the present study).

Wing and Brown (1979, 87) already stated that "stature estimation (of fairly complete skeletal populations) can be used to examine long-term changes in resource availability and nutritional intakes, and to test the possibility of status differences within a population". However, up to now scarcely anybody employed this ideal possibility in order to study living conditions in Europe in the very long run to learn about pre-modern periods.[2]

Already Garnsey (1989, and 1998) formulated the utilization of mean height as "exigence". Presumable reason, which kept others from complying this desideratum could be the extreme work and time expenditure required to compile the data on all the variables. Furthermore, the need to make the height data comparable may have hold former researchers back in conducting a long run study.

But in this thesis, finally the conditions of pre-historic, ancient, and early historic, up to early-modern Europeans are studied.

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[2] By now a great number of studies were conducted which deal with modern times, especially the pre-industrial and more recent periods. All of them emphasized the informative value of mean height as proxy, and detected an interaction with various economic conditions (for example technical progress in agriculture or medicine, or free trade: Baten 1999). However, on the contrary no extensive regional and temporal – means several periods over-spanning, long-term overview – anthropometric study of the nutritional status in pre- and early historic Europe was conducted by now. The only few existing works mostly focus on osteological-anthropological aspects, and cater for single regions or periods (Huber 1968; Cohen and Armelagos 1984; Bennike 1985; Gilbert and Mielke 1985; Grupe 1986; Haidle 1997; Kunitz 1987, Schutkowski and Grupe 1997; Jäger et al. 1998; Lalueza-Fox 1998; Schröter 2000; Waldron 2001; Brothwell 2003; Maat 2003; Steckel 2003; deBeer 2004). Furthermore all of them are based on a small number of observations only. Lalueza-Fox (1998) even compared data reconstructed by different models. For example, Steckel (2003) studied Scandinavian data finding a considerable decrease in mean height since the Middle Ages. Maat (2003), and Brothwell (2003) recently confirmed this finding for the Netherlands. Antiquity was hardly considered by now in an overview (see Jäger et al. 1998); if at all single cemeteries are analyzed in terms of nutritional status (see Bisel 1988; Farwell and Molleson 1993). Exception was provided by Angel (1984) with his work on Greek regions in ancient Roman times, for which he found decreasing mean height. The only long-term study of a dimension comparable to the present study was rendered by Steckel and Rose (2002) for the Americas from pre-historic times onwards.

1.1. INITIATION AND OBJECTIVES OF THE STUDY

Activating 'trigger' for this PhD thesis was our special interest for regular living conditions in Roman antiquity. The reason to choose as the study period the pre-historic, and early historic centuries, from Iron Age until modern pre-industrial times, and to choose Europe as study region underlies in our fascination for both, the overall archaeological period as such, and the possibility to learn more about it in a new, interdisciplinary way. This includes the possible verification of older hypotheses by employing the interdisciplinary approach. That is, for example, to clarify the impression of a contradiction in terms of a positive impact of Roman imperialism and occupation.

In particular, we were interested whether the opinion that a positive effect of Romanization – which one gets mediated studying Roman archaeology – is correct. It seems that the idea of the positive impact of Romanization was accepted by archaeologists directly from the ancient literature. The "ultimate Other is the 'barbarian', the man or woman from outside the frontier, subject to conquest and enslavement as well as to Romanization" (Fantham et al. 1994, 385), and thus becoming 'civilized' and therefore positively affected.[3] Based on this common idea the question arose in which direction, and to what extent the ancient Roman imperialism actually had an impact on the core region, perhaps different to the occupied regions.[4]

Another key question was whether the image of the comparably 'Dark Ages' in medieval times, which is presented in the written sources, can be confirmed or not.

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[3] see Fantham at al. 1994, 386: "These are the figurations of the separation between inside and outside, between civilization and its opposite … Roman historical texts and images tell… us less about 'barbarians' than about the Romans themselves. The most familiar visual type is the mourning 'barbarian' woman on coins and reliefs … She recurs as the emblem of defeat … Until the emperor reaches out to raise her up and transform her into the personification of a happy province".

[4] Of course, one has to have in mind, that periods do not really end or begin exactly in one century, and that 'flows' in development can hardly be captured accurately.

Overall question was how the nutritional status developed with time, over approximately 2500 years, and for different regions in Europe. Until now, no overall quantitative study was conducted to clear up these questions.

The main questions of the study are: What was the overall development of nutritional status? Which were periods of ameliorated conditions? How did conditions develop in different European regions during pre-, and early history? And what are the determinants causing differences?

But how to challenge these questions for periods for which an adequate amount of reliable written, quantifiable sources is missing? “Soliciting” tool is the anthropometric approach. We apply the concept of the biological standard of living (Komlos 1985) – using mean height as proxy for the nutritional status of a population – and studying its interdependence with environmental, political, economic and social developments.

“Archaeological human skeletal finds constitute a valuable empirical source for a better understanding of daily life in the past. In contrast to many written records, art and artifact, which often have a symbolic meaning, information on the living circumstances of the individuals are available from the bone” (Grupe 2003, 293).

To study the nutritional status of populations of early-historic periods, an interdisciplinary approach is utilized: All data (height data, as well as data on its determinants, and dating purposes) stem from excavations and archaeological work, whereas the econometric methods come from applied economic research.

The study starts with the eighth century B.C. and covers the centuries including the 18th century A.D. The whole period under study (800 B.C. – 1800 A.D.) belongs to the later Holocene, which means that no extreme climatic changes occurred; however, the Little Ice Age, and the medieval warm period are considered. Of special importance are the centuries prior, during, and after the period of the *imperium Romanum* in order to examine changes in nutritional status in connection with Roman occupation and foundation of provinces, and break down of the empire, as well as to study further development during the Migration Period and the Middle Ages.[5]

Europe, as the study region mentioned in the title was separated in three major regions[6]: into a Mediterranean, a Central-Western and a North-Eastern part (see Figure 1). The regional classification is based on the initial idea of subsuming regions in terms of their occasional "pertinency" to the Roman Empire.[7] In terms of data origination, the first part refers in particular to the Italian region, and France. The second part is geographically quite comprehensive: Central-Western Europe includes Britain, Benelux, South and Western-Rhine Germany, North-Eastern France, Switzerland, and Western Austria. The third part 'consists' chiefly of Scandinavia, Eastern Germany, Poland and Hungary.

The focal point of the study is the mean human height, which is directly based on the nutritional status (that is comprised by quality and quantity of diet, health conditions, and work load). Therefore, it is the ideal indicator for nutritional status respectively the biological standard of living.

The separation into three major European regions allows, on the one hand, the study of nutritional status in different regions in comparison to one another during each

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[5] Please note, in this study the labeling of the centuries is done the following way: starting from year 0 (standing for the Nativity) in each direction (B.C./A.D.) those years, which would – according to the order of numbers – come first, are subsumed as one century that is (as "generic term") labeled by the next highest number in a classical enumeration, means for example 99 - 1 B.C. is classified as the first centuary B.C., and 200 – 299 A.D. as the third century A.D.

[6] For more detailed information which modern countries are subsumed in each of the there main European regions see chapter 4.1.

[7] Hungary only in small parts; see for example Visy 1985.

of the centuries, and on the other hand the temporal development in the course of the centuries within each region.

FIGURE 1
MAP OF THE THREE MAJOR REGIONS IN EUROPE AS SUBSUMED IN THE DATA

The value of the study is the use of the quantifiable source “mean height” (based on the novel source of bone remains) as indicator of nutritional status to describe the development of the biological standard of living in Europe over 2500 years. In addition, it is the creation of variables to analyze the reasons for the development for the study period, which had not been studied (that way) until now. The data that have been collected for this purpose result in the biggest set on pre-modern Europe (see chapter 4.1, Table 3, for comparison to other studies). Other than data stemming from most written sources even for the last centuries, the skeletal remains have the advantage that not only information on males, but also on females, is given in a representative amount. This enables us to study also gender-specific inequality.

1.2. OUTLINE OF THE THESIS

The thesis is based on four, in parts already published, papers, which are combined in chapter 4. In order to embed these results the work starts with two incipient chapters: To illustrate the background, chapter 2 presents a review of the research fundamentals that are the basis for the study, including the description and discussion of the interrelation of nutritional status and mean height. In addition, possible determinants of nutritional status, as well as the complex interrelations of these various factors are illustrated. This part of the thesis ends with a sub-chapter giving a historic outline – providing a brief overview of important events and developments that might have influenced European living conditions and its potential determinants (and vice versa).

In the next chapter, description and discussion of the employed data are given – of the sources and their informative value – and an overview on the methods applied for the study; including a sub-chapter about the newly developed algorithms.

Chapter 4 starts with an overview of the main topics and results, followed by the presentation of the detailed sub-studies conducted in the mentioned different papers. The four sub-chapters concentrate on different questions on European nutritional status and its determinants. We test different hypotheses, like the positive effect of proximity to high quality protein production, the negative impact of rapid urbanization without sufficient sanitation and public health that is among other aspects accompanied by greater exposure to vermin and pathogens, or the impact of climate change. In chapter 4.1., we study the development of mean height, from the first century until the 18th

century A.D, and several determinants, such as population density, social status, and temperature development. In chapter 4.2. the same centuries are covered; however, in terms of explaining variables the central focus lays on the changes in agricultural production and the effect of animal protein. For the subsequent chapters the data set was expanded for the centuries already studied, and in particular data for the centuries back to the eighth century B.C. have been added. In chapter 4.3., emphasis lies on the effect of Romanization, besides the various other potential determinants. In chapter 4.4., we study the gender dimorphism in the course of the pre- and early European history.

The thesis closes with the general discussion of the main findings and conclusions. An appendix displays the algorithms that had been developed in order to harmonize the different models for height reconstruction in the literature.

2. NUTRITIONAL STATUS AND MEAN HEIGHT

Fundamental basis for the thesis is the existence of a close correlation between the mean height of a population and its nutritional status or net nutrition (see, for example, Schofield et al. 1991; Baten 2000 et al.; Harris 2000; Leonard 2000; Scott and Duncan 2002; Moradi and Baten 2005; Li et al. 2007; Schwekendiek 2008). Therefore, mean height is a good proxy for nutritional status during growth, and thus for (biological) well-being of a population. The why and how will be illustrated in the following.

Growth in humans, and thus final mean height, is on the one hand influenced by endogenous factors like genetics, and hormones. On the other hand, it is influenced by exogenous factors such as nutrition, disease environment, and physical activity. All of these interacting factors "are influenced by the [ecological] environment they are embedded in and by changes in this environment" (Curtis et al. 2005). If an individual suffers from under-nourishment this results in growth retardation or even occasional growth cessation and reduced final height (Floud et al. 1990; Mays 1995b; Rey and Bresson 1997; Wahl and Kokabi 1999), which in summation is manifested in mean height of a population.[8] Thus, the exogenous factors determine in how far the genetic height potential can be reached (or the attaining is prevented), and therefore mean height is a sensitive indicator for wellbeing and living environment (Waldron 2006, 255).[9]

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[8] We know from studies on modern times that Europeans are genetically quite homogenous; that this is the case can also be seen if one compares penrose-distances: for example early medieval skeletal series of Franks, Saxonians, Bajuwaric and Alamannic people are nearly identically (Roth 1984, 183). For a study such as this thesis a genetically homogenous data is necessary, of course.

[9] For a genetically homogenous population Silventoinen (2003) found that approximately 20% of the variation in height is caused by environmental differences; she presumes that under worse environmental conditions the percentage is probably even higher. Correspondingly, many studies point out the

Nutritional status is defined as the counterbalance of a positive effect of nutrient consumption (quantity and quality), and the negative effects of exposure to parasites, disease stress, and work load (McKeown 1983; Al-Dabbagh and Ebrahim 1984; Scott and Duncan 2002; Ulijaszek 2006). The nutritional status is adequate if the quality and quantity of diet is sufficient (or even exceed the needs) to compensate any possible negative effect resulting from the other main factors.[10] But any of these four main factors is of crucial importance in comprising nutritional status. Correspondingly, inadequate or sufficient living conditions have a detrimental or beneficial impact on mean height.[11] Moreover, often risk factors that have a negative effect on the outcome in mean height occur together or cumulatively, with concomitant increased detrimental

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importance of environmental changes for temporal and regional differences in mean height as opposed to genetic changes: for example the extreme upward trend within only a couple of years all over the world in modern decades if economic and health conditions develop positively (see for example Steckel 1995; Floud et al. 1990). Especially impressive is the mean height increase in Dutch recruits, starting from being (with 165 cm) the shortest Europeans in the mid-19th century A.D., and becoming the tallest today (see van Wieringen 1972). The importance of nutritional status is also verified by occasionally occurring decrease in mean height reverse to the course of positive secular trend (Malina 1990; Baten 2007). Variation in mean height hardly can be explained by genetics, because it is to be supposed that a Darwinistic evolution does not modify the genetic growth potential substantially within a few centuries (Eveleth und Tanner 1976); and moreover the experience of different height gains between sub-groups of a genetically homogenous population like the Europeans (Garcia and Quintana-Domeque 2007). Correspondingly, people of higher social status have comparably a taller mean height than people of lower class (Huber 1968): Living conditions for members of the higher social classes are often comparably good, and thus beneficial for reaching full genetic potential (Floud et al. 1990), whereas malnutrition, infection, and poor living conditions result in a vicious circle producing a net negative response in growth and development (see for example Saunders 1992; Larsen 1997). Correspondingly, in isotope analyses pre-industrial Europeans of higher social status were found to be better nourished in terms of high-quality animal protein (e.g. Grupe 1990; Schutkowski 1993).

[10] In addition, also further aspects like psychosocial status can have an impact.

[11] Growth failure ranges from retardation to complete stunting. Waterlow (1972) introduced the term ‘wasting’ to denote acute malnutrition (i.e. low weight-for-height), and the term ‘stunting’ to label chronic under-nutrition (low height-for-age). Stunted individual’s stature is defined as height, which is below two standard deviations of mean height for age of the corresponding population.

impact on the growth development potential (Walker et al. 2007b). Consequently, mean height of a population can be used as proxy for its nutritional status (that allows to deduce the Biological Standard of Living); see for example Komlos and Cuff 1998; Steckel 1995).[12]

2.1. IMPORTANCE OF ADEQUATE NUTRITIONAL STATUS AND MEAN HEIGHT AS PROXY

Nutritional status is very important for any population at any time because it is in close interaction with welfare: On the one hand, living conditions (and thus welfare) determine the determinants, which shape nutritional status. On the other hand, if nutritional status is insufficient, it can result in important negative consequences for the body and its activity function, and thus in turn has an impact on welfare:

Adequate nutritional status is most important for a body, and its physically and mentally functions to develop and perform well. An adverse nutritional status has vast, far-reaching effects, because it results in immediate consequences for health during childhood, and also can lead to negative upshots later on in life constituting "severe and costly physical and psychological complications in adulthood" (Bogin 1996a, 21).[13] Chronic malnutrition leads to reduced growth during fetus-, childhood and youth, to enable the maintenance of basic body processes. Thus a full attaining of the possible genetic height potential is suppressed, which results in lower adult final height (see for

[12] Mean height is (even) used as indicator for nutritional status for today's populations (WHO 1995; De Onis and Habicht 1996), as well as historic populations all over the world, pronouncing the importance of this proxy (Fogel et al. 1983; Komlos 1985 ff.; Steckel 1995; Floud and Harris 1997; Steckel and Floud 1997; Baten 1999 ff.

[13] See Hamilton (1982, 135 f.) with an overview on possible results especially of deficient diet.

example Henry and Ulijaszek 1996; Cameron 2002).[14] Moreover, lower adult height was found to be an unfavorable basis for several aspects in life (beginning with matchmaking success up to chances in the job market: Holden and Mace 1999; Nettle 2002).

Furthermore, inadequate nutritional status during growth has an impact on morbidity also later in life, for example on cardiovascular, bronchial and respiratory, or cholesterol and diabetic disease susceptibility in adulthood (Uljiaszek 1996). And in the worst case, malnutrition leads to higher mortality rates and lower life expectancy (for example Rotberg 2000; Baten and Fraunholz 2004; Gluckman and Hanson 2004a).[15] Also, the formation of physiological, physical and cognitive body functions depends on nutritional status during growth (for example Grantham-McGregor et al. 2007; Walker et al. 2007a): this means reduced ability and motivation to be physically and mentally active (what, for example, abates the ability to learn, which subsequently can result in adverse adult living conditions).

Nutritional status influences welfare, because it affects both height outcome and human capital (Gautschi and Hangartner 2006), which in turn have an impact on nutritional status again, via e.g. working capability (see for example Stinson et al. 2000).[16] As a consequence, nutritional status can affect productivity and human capital accumulation. As a negative outcome this may result in an “intergenerational

[14] In case of prolonged nutritional deficiency, somatic growth can be permanently impaired. But more temporary mis-conditions can be compensated by so called catch-up growth; however, to enable this development substantial improved nutritional status is the basic requirement (Whitehead 1977). And still, in general, retarded growth in infancy is connected with small height in a child, and, usually, in small final adult height (despite possible catch up growth: see for example Li et al. 2003).

[15] Increased mortality often is not only caused by ‘pure’ starvation, but by inadequate diet in combination with diseases that are sometimes also conditional on nutrition quality.

[16] For example Robert Fogel won the Nobel-prize stressing the relevance to combine biomedical and economic analyses, which makes it possible to consider the impact of improved nutrition on the secular trend in health and life expectation, on labor productivity, and on economic growth.

transmission of poverty" (Thomas and Strauss 1992).[17] Correspondingly, higher social status in pre-industrial developing countries regularly has a positive impact on final height. Often this effect can be 'translated' to overall national economic development and the interaction with mean height of a population (for example, Arcaleni 2006; Fogel 2004; Komlos 2007). Nonetheless, this does not mean that economic growth always can be associated with overall beneficial biological well-being, as, for example, the 'Industrial Growth Puzzle' circumscribes (Komlos 1998). Factors like 'urban height penalty', increased inequality, and inadequate or unequally distributed food availability can result in stagnating or decreasing mean height despite national economic increase (Steckel and Floud 1997; Baten 2000; López-Alsonso and Condey 2003; Haines 2004; Łaska-Mierzejewska and Olszewska 2007; Chanda et al. 2008).

Permanent malnutrition seems to result in adaptations of the body, which "may permanently alter adult metabolism in a way that is beneficial to survival under continued conditions of malnutrition …, but detrimental when nutrition is abundant" (Scott and Duncan 2002, 137). This adaption of the body is realized by lower height.

Which is the predominant age period of final (mean) height determination? Growth of humans develops not continuously, but in different 'propulsions': during the intrauterine, and the post-natal period, infant and weaning childhood, and the adolescent growth spurt cumulatively final adult height is comprised.[18] Correspondingly, under-

[17] On the relationship of mean height and productivity, see for example: Margo and Steckel 1982; Spurr 1983; Fogel 1994; Strauss and Thomas 1998.

[18] Different recent studies indicate that early nutrition has significant consequences for later life (see Stinson 2000, 457 f.; Koletzko et al. 2005). Environmental conditions during growth of the suspected mother determine body proportions of the gravida, that way also the placenta, whose size is related to foetal, and infant growth (Leiarraga 2002; Hindmarsh et al. 2008). Poorly nourished gravidae tend to give birth to small babies, "which tend to show poor growth in … height over time. The cycle of poor nutrition, poor health, and unsanitary living conditions repeats itself" (Gopaldas and Gujral 1995, 226). Moreover, preterm birth (with additional negative effects on the child) is related to low maternal pre-

nutrition of a child can even start with malnutrition of the mother.[19] However, of special importance, is nutrition during infancy – the lactation period as well as the weaning period. This is, because then the growth velocity is the highest[20], which results in especially high nutritional requirements (Poskitt 1999; Scott and Duncan 2002). The first years in life are the most critical, and therefore the most decisive period for the attainability of the growth potential, and thus for the determination of final height (Eveleth and Tanner 1976; Tanner 1981; Bogin 1988; Baten 1999; Baten 2000; Stinson 2000).

It can be assumed that the conditions, which are relevant for the growing up part of the population can be transferred to the contemporary living adults. Therefore, mean

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pregnancy body-mass index (Merlino et al. 2006). On the other hand, foetal growth depends on the current nutritional status of the mother during pregnancy, which in turn affects postnatal (and even later) height and health outcome (De Onis et al. 1998; Wu et al. 2004; Langley-Evans and Carrington 2006; Mericq 2006; Martin-Gronert and Ozanne 2006; Roseboom et al. 2006). A breastfeeding mother needs extra calories to provide complete food for healthy infants, and "mothers in communities suffering from malnutrition, … may be unable to produce sufficient quantities of good quality milk to satisfy the requirements of the growing infant" (Scott and Duncan 2002, 151).

[19] During the lactation period nutrition and nutritional status of the contemporary population is of special importance, because maternal nutrition influences lactational performance. Firstly, in pre-modern, underdeveloped societies not only mother milk per se is of special importance for 'backing up' adequate nutritional supply and protection against infections (see for example Brown et al. 1998), and, in addition, a breastfeeding mother needs extra calories to meet complete diet requirements for healthy infants (see above). Secondly, furthermore, adequate nutrition of the mothers enables prolonged breastfeeding, which has both, an important impact on the infants' health and stature, and results in stretched birth intervals, which mean support for ameliorated maternal health during the next pregnancy (Scott and Duncan 2000). In the following weaning period high quality and quantity diet is of particular importance, because the dietary change makes the individual all the more vulnerable (Motarjemi et al. 1993; Marino 2007).

[20] A second period of pronounced growth increase is puberty, but it is less decisive because the human body is less sensitive then. Nevertheless, gaining final height can be delayed or prolonged until an age of 23 or even up to 25 years (Tanner 1981; Komlos 1985; Moradi and Guntupalli 2004) due to environmental and socio-economic determinants resulting insufficient nutritional status (Eveleth und Tanner 1976).

height of a ‘birth cohort’ can be used as indicator for the nutritional status, and welfare of the whole population.

As we have seen, nutritional status defines mean height of a population. Therefore, the correlation of nutritional status and welfare, and thus the importance of nutritional status have long been accepted (Shepard and Pařízková 1991; Scott and Duncan 2002). Consequently, mean height of a population is the ideal proxy, and thus allows to reconstruct the nutritional status of a population (as was it done for example, by Lopez-Blanco 1995; Steckel 1995; Komlos and Cuff 1998; Li et al. 2007).

Correspondingly, it is possible to define changes in environmental conditions as indicated by changes in mean height. Especially for archaeological periods for which no adequate written sources are given, this is an essential method to analyze living conditions. This possibility is employed within the scope of the present study for the first time to give an overall, long run overview for pre-and early historic Europe.

2.2. MAIN FACTORS DETERMINING NUTRITONAL STATUS

Nutritional status is ‘brought about’ by a wide range of different determinants. UNICEF (1990; 1998) differentiates three levels:

- basic determinants, which are the potential and economic structures,
- underlying determinants, chiefly the resources for food, care and health, and
- immediate determinants, the individual dietary intake and health status.

Anyhow, it is difficult to separate the effect of the different levels, because they are interrelated. For example, the population density is, among others, a result of the economic structure, but also influences food and health as resource, and vice versa. Therefore, in this thesis, the determinants are discussed independent of any level.

Nevertheless, one can differentiate two 'types' of determinants. Direct determinants (having an immediate effect) are the main factors defining nutritional status by definition: disease environment, parasite exposure, work load, and, most essential quantity and quality of diet. Indirect determinants are environmental (natural, cultural, socio-economic etc.) factors, which have mediate influence on nutritional status, by affecting the direct determinants.

2.2.1. Direct Determinants

2.2.1.1. Disease Environment

The disease environment is decisive for the nutritional status due to different factors.

The interrelation of disease and diet consumption can be a vicious circle, and in particular infection and malnutrition have a "synergistic and cyclical relationship" (Rosenberg 2007, 348). On the one hand, diseases can cause a reduction in ingestion due to inappetence, and some diseases can harm absorption and utilization of nutrients, and both result in decreased nutrient intake quality. On the other hand, resistance against infections is related to quality and quantity of nutrition[21], and therefore frequency of infections, but also severity, duration, as well as recovery (for example, Lunn 1991; King and Ulijaszek 1995; Scrimshaw 2000; Stinson 2000). Furthermore, some diseases are also the direct, immediate result of inadequate diet itself: for example measles, diarrhea, and respiratory diseases were found to be heavily dependent on quality and quantity of nutrition. Overall, "there is a bidirectional influence in which

[21] Even if a disease is not directly affected by inadequate diet, debilitation of the body and thus susceptibility to an infection (and due to deficient annealing because of inadequate diet vulnerability to further diseases) can be promoted.

malnutrition may predispose to infection or increase its severity, while infection itself results in nutritional abnormalities." (Scott and Duncan 2002, 279). Correspondingly, for example, Checkley et al. (2003) found chronic diarrhea being closely related to height deficits in Peruvian children. Nelson et al. (2001) suspect that nutritional deficiency may even give rise to epidemics by contributing to the emergence of additional viral strains.[22]

Therefore, often conditions giving rise to malnutrition and infection are frequently associated. This may result in a vicious circle, with malnutrition predisposing to infection, and infection leading to malnutrition, with an exacerbation of both.

Several ancient writers mention disease and their detrimental impact on the population. But this information is not quantifiable, of course. Hitherto in some cases researchers do not even know exactly which epidemic is described in each case, however, that they were of pandemic proportions.[23] In palaeo-pathological research methods were developed to determine diseases in the skeletons (see for example

[22] Discussing the complex interaction of disease environment and inadequate nutritional status it should be noted that recently Beard and Blaser (2002) presented the hypothesis that any change in mean height (including the secular trend) was induced by a change in heliobacter pylori distribution, and the changing degree of exposure to and transmission of gastroinal microbes. This explanation seems rather bold, since various studies found direct correlation between overall nutritional status and mean height (see above). However, one can proceed on the assumption that in the course of military and economic expansion of the Roman Empire the previously existing overall relatively constant epidemiological disease pool became altered "through progressive contact with significant disease pools in at least three other regions, namely neighboring Mesopotamia…, the Indian subcontinent … and China" by soldiers and traders (Retrief and Cilliers 2000, 270). But by now it is not possible to control for this effect quantitatively. Later mass migration could also have had a negative impact on disease environment by promoting the spread of previously locally restricted communicable diseases.

[23] For example, it is still not clear, whether the Antoninian plague was a smallpox pandemic, as the disease is most often identified, or if it has been anthrax (Fears 2004).

Roberts and Manchester 1995; Mitchell 2003). But by now bone remains were not analyzed in comparable extent to be usable for this study.[24]

Thus, within the realms of this long-term study it is not possible to measure the actual disease conditions. Generally, tuberculosis, typhus, leprosy, malaria and other diseases were certainly always present (see Arcini 1999; Sallares 2002). And some of the 'large-scale' epidemics are mentioned in the historic accounts. These are, for example, the "great plague" under Marcus Aurelius Antoninus' reign (the so-called Antoninian plague), and also the Justinian plague. For these particular cases, various written sources exist, and effects can also be seen in production breaks in coin minting, and in manufacturing (Duncan-Jones 1996; Fears 2004; Haas 2006).

For the thesis a 'plague-dummy' was created in order to check the effect of epidemic-periods on mean height (for details please see chapter 4.1. and 4.3.). In terms of mean height of a population, the effect of epidemics could work in both directions: It could have been harmful, or have had a positive impact, because more food became available for the surviving people due to better land-labor-ratios.[25]

2.2.1.2. Exposure to Parasites

Interconnected to diet on the one hand, and disease environment on the other hand, is the exposure to parasites. Infectious diseases caused by infestation rank among the most

[24] It should be mentioned in the present context, that a great substantia is 'arising' for future osteological study on living conditions in pre-, and early historic populations by DNA analysis. However, up to now data are not available in an usable amount for an overview. The method provides new possibilities, because by now only those few diseases could be determined, which result in morphological changes in the skeleton at all (tuberculosis, leprosy). For example, plague is one of these diseases, which are impossible to be identified morphologically; the only possibility to identify definitely this disease is by identifying the ancient Yersinia pestis DNA (Nuorala 2004). Same is the case for diphtheria. But these data are not available at all by now.

[25] Because this could mean that in the beginning a negative impact is affective, whereas a positive effect follows after the reduction in people, we controlled for by half centuries (see chapter 4.1.).

common diseases in human beings (Frauendorf 2001; Oberhelman et al. 1998). Various species exist that can transmit diseases (for example malaria[26]: Sallares 2002, 141).[27] But also parasites as such have a direct important negative effect, especially various kinds of worms derogate nutritional status, harming health and (thus or even directly) growth.[28] "Poor hygiene and inadequate sanitation augment the favorable environmental conditions to enhance proliferation of the organisms." (Lunn 1999, 1515). Of special danger is the 'malnutrition-diarrhea-cycle', especially for weaning toddlers (Scrimshaw et al. 1968; Molla and Molla 1999), which can be amplified by exposure to parasites (Motarjemi et al. 1993; WHO 1993; Marino 2007). Diarrheal diseases can be caused by inadequate sanitation, water supply, and food preparation under unhygienic conditions. Correspondingly to modern developmental countries (WHO 1993), in pre-modern periods contaminated diet certainly were major causes of malnutrition, due to the bad quality of drinking water and sanitation, missing refrigeration, et cetera. Moreover, people's assessment and lax attitude towards these aspects presumably did its bit. Particularly in Roman times, a lack of awareness of even most basic hygiene amongst people is known. Instead special caution should have been exercised because of the wide-spread trade and military connections bringing new parasites (and diseases) in and in particular due to the extreme increased population density.[29] Latrines (in the Roman

[26] This disease also cannot be identified by any distinctive pathological changes, but research on DNA brings first results.

[27] Although most common in warm and wet conditions, many species are distributed worldwide.

[28] For example round worms inhibit diet utilization, whipworms produce diarrhea, and the dangerous types of tapeworm erode the host's body (Mehlhorn and Pierkarski 2002).

[29] The disparity is emphasized by Jackson (1988); correspondingly see Scobie (1986); Thüry (2001): Sewage and latrines were often located near to wells, or even the kitchen. This resulted in a widespread coverage of parasites (esp. round worms and wip-worms, flies, and also bacteria). Furthermore, commonly used public latrines 'contributed' the rest in spilling over bowel diseases into vast parts of the population (even though those were equipped with running water, they nevertheless consisted of a collective 'bench' and they were provided with brushes to share: see excavation Housteads).

case even public) – sometimes due to geologically given circumstances even with ‘contact’ to groundwater – and the custom to manure the field with human faeces ‘generate’ infection circles (Sczech 1993). According to Jackson, the frequent mentioning of dysentery and diarrhea by ancient medical writers indicates that these diseases “must have been endemic in most places” (Jackson 1988, 53).[30]

The problem is to measure the effect of parasites on pre-industrial Europeans. Vermin or worm infestation can be measured by the analysis of coprolite remains (mineralized or desiccated excrements). But so far these kind of studies were conducted only rarely (although started comparably early, see for example Aspöck et al.1973; Herrmann 1985), and therefore are not adequate for the long run study. So we cannot create a direct variable on parasite exposure. However, it is to be supposed that conditions were worse in urban environment (see for example Jackson 1988; Weeber 1990; Herrmann 1987), and thus this effect will be incorporated in the urban rate-dummy, which we created as a proxy-variable in order to test for all urban effects (see chapter 4.1. and 4.3.).

2.2.1.3. Work Load

People doing hard physical work have a higher metabolic rate compared to less physically active individuals. If people are not supplied with adequate food quantity and quality to equalize the physical stress this has a detrimental effect on the energy balance. For children the consequence of excessive child labor could be retarded growth (Baten 1999). It is to be supposed that average pre-modern girls began household chores at early childhood. This was found for modern India at an age of five years (Gopaldas

[30] One can assume that hygienic conditions did not ameliorate until the 17th century AD, when use of soap and use of clean water became common features. This could be one of the basic factors inducing an overall smaller mean height until the phasing in secular trend. Similarly, McKewon (1979) found the introduction of hygienic and health care as important determinant.

and Gujral 1995); in particular fetching water from a public well in distance from home causes drain in energy. Similarly, children certainly were appointed in agricultural work.

In adult skeletons the degree of physical work load can be assed for example by bone abrasion. But in general these information 'subsumes' whole life conditions, and are not directly transferable to childhood conditions. Only in very rare studies work-related symptoms in children were analyzed (Capasso and Di Domenicantonio 1998).[31] The discerned lesions show that "children, even of the youngest age, [were] engaged in heavy manual labor".

Except for direct effect of work load on the body, the growth of a child could also be influenced by an indirect effect of work load: Based on the fact that a breastfeeding mother needs extra calories, for an adequate energy balance one would expect hard working women to give less and subsequently poor milk. Therefore, the lactational performance could depend on maternal work patterns. However, an example that this effect is not so important is given by Prentice and Prentice (1995), who found the milk output of Gambian mothers to be reduced 'by only 10% during the annual hard field work season'. But this result stands in contrast to tests with rats (Scott and Duncan 2002).[32] Anyhow, the interruption of the usual demand feeding patterns result in higher infection levels, and will also result in reduced nutritional intake of the infant (with impact on growth and later life).

For the region and time of the study, no direct information on work load can be given, because also adult data on physical stress are scarce. A plausible assumption is

[31] But hopefully in the near future also on this topic more detailed information will be available, as for example most recent research draws on the analysis of bone's microstructure (mechanical loads caused by activity patterns affect the compact bone cross section: see Doppler et al. 2006).

[32] Moreover, in contrast to hard factory work, field work can bring the advantage to get additional protein by consumption of maggots and worms (Kalka 1995).

that it was more or less equal over all periods, and in all regions. It is to be presumed that the only difference will be between persons of different social status. However, this assumption could be tested only to a very rough extent, because too few data on certainly assessed individuals of high status were available for the bone material used for the study (see chapter 4.1.).

2.2.1.4. Quality and Quantity of Diet

Of particular importance is the diet consumption itself, because if diet is adequate, it 'makes up' the factor in the nutritional status-'balance sheet' that counterbalances possible negative effects. Insufficient diet – studies found particularly protein-deficiencies to be important for mean height[33] – is not only equal to any scarcity in protein and energy.

One focus of the thesis is the effect of consumption provision with quality diet on the development of mean height. The access to high quality food is of special importance to 'equalize' the detrimental effect of stress: thus, for example the "access to high quality animal foods … is a strong predictor of early childhood growth and nutritional status" (Leonard 2000, 303). In particular, cow milk intake stimulates linear growth in childhood, and also youth (Hoppe et al. 2006; Wiley 2005).[34]

Additionally of importance to the "content-quality" of diet, is also that food quality can be affected in terms of health, which is related to hygienic conditions. Here,

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[33] Studies found deficiencies in diet to be of three types: protein and energy deficiency; protein deficiency alone in the presence of an adequate energy intake; lower quality protein in the presence of an adequate quantity of both protein and energy. That implies the importance of protein quality if the quantity is reduced. Besides the 'protein'-question vitamin deficits cause deficiency diseases, which in turn affect nutritional status, such as scurvy, resulting among others in heavy diarrhea, and fatigue (Brickley and Ives 2006).

[34] Moreover, Olsen et al. (2007) found that cow milk consumption in gravidae is directly associated with large-for-gestational age birth length in their children, due to the content of growth-promoting factors in the milk.

the presumably most important factor is drinking water (Smith and Haddad 2000; Maron 2007). The inadequate food preservation in ancient times certainly had a significantly negative impact on the quality of diet. Different types of food poisoning are recorded in ancient sources (Jackson 1988, 37 and 188, fn38.).[35] Additional to food 'spoiledness', for example, contamination of crops by *secale cornutum* resulting in ergotism was frequent in medieval times. This affected people on the one hand directly, by infecting them;[36] on the other hand, people presumably were also affected indirectly via the infection of the livestock, because ergotized barley (*claviceps purpurea)* causes agalactica in cattle (Al-Tamini et al. 2003).

Contamination with pathogens, and resulting food-borne infections can even have dangerous long-term effects on nutritional status: "the resistance of infants suffering from nutritional deficiencies is suppressed, leaving them wide open to infectious diseases, particularly those causing diarrhea, which further reduces their ability to fight diseases. They then become progressively more malnourished" (Motarjemi et al. 1993, 80).

However, the most important factor is the availability of food, and "within" in particular its protein quality. In order to estimate whether quantity and quality of diet were sufficient, different determinants were utilized in this study, such as climate, population density, urban rate, quality protein availability (cattle share), gender dimorphism, and impact of Romanization.

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[35] The common use of strong species in ancient recipes (esp. meat and fish) indicates the whish to cover up bad taste and odor.

[36] Affected people suffer from vomiting and looseness.

2.2.2. Indirect Determinants

All the direct determinants defining nutritional status of a population – and consequently possible differences within a population – are somehow determined by resources, production, redistribution, allocation, sharing, and final consumer behavior. In turn, all these factors are determined by various further aspects (especially socio-economic and cultural ones).

Mean quality and quantity of diet are influenced by natural basic conditions – such as climate and soil quality –, which, for example, determine the type of agriculture or husbandry in use, as well as the produced outcome. Additionally, a wide range of – often mutually conditional – socio-cultural, economic, and political determinants, including factors such as land *per capita* or distribution of welfare (esp. wealth) in a population, have an impact on diet consumption supply conditions. In the case of agriculture these determinants would have had an affect by stipulating the specialization in use, affecting the rights (and thus freedom of choice in specialization) of the farmers, the sizes of the fields, and infrastructure up to irrigation. Moreover, socio-cultural, economic, and political determinants influence allocation of food both on the whole society level as well as on the intra-household level (Thomas and Strauss 1992). Some factors can have a detrimental or beneficial impact: for example, increasing trade can improve the supply situation in a region, but also can reduce diet quality in formerly isolated populations (Komlos 1989); and it bears the danger of new and epidemic disease.

Furthermore, commonly, risk factors affecting the outcome in mean height negatively occur concurrent (poverty, crowded living conditions, and malnutrition increasing infection risk etc.), interacting cumulatively, and therefore resulting in concomitantly increasing detrimental effects on the growth development potential

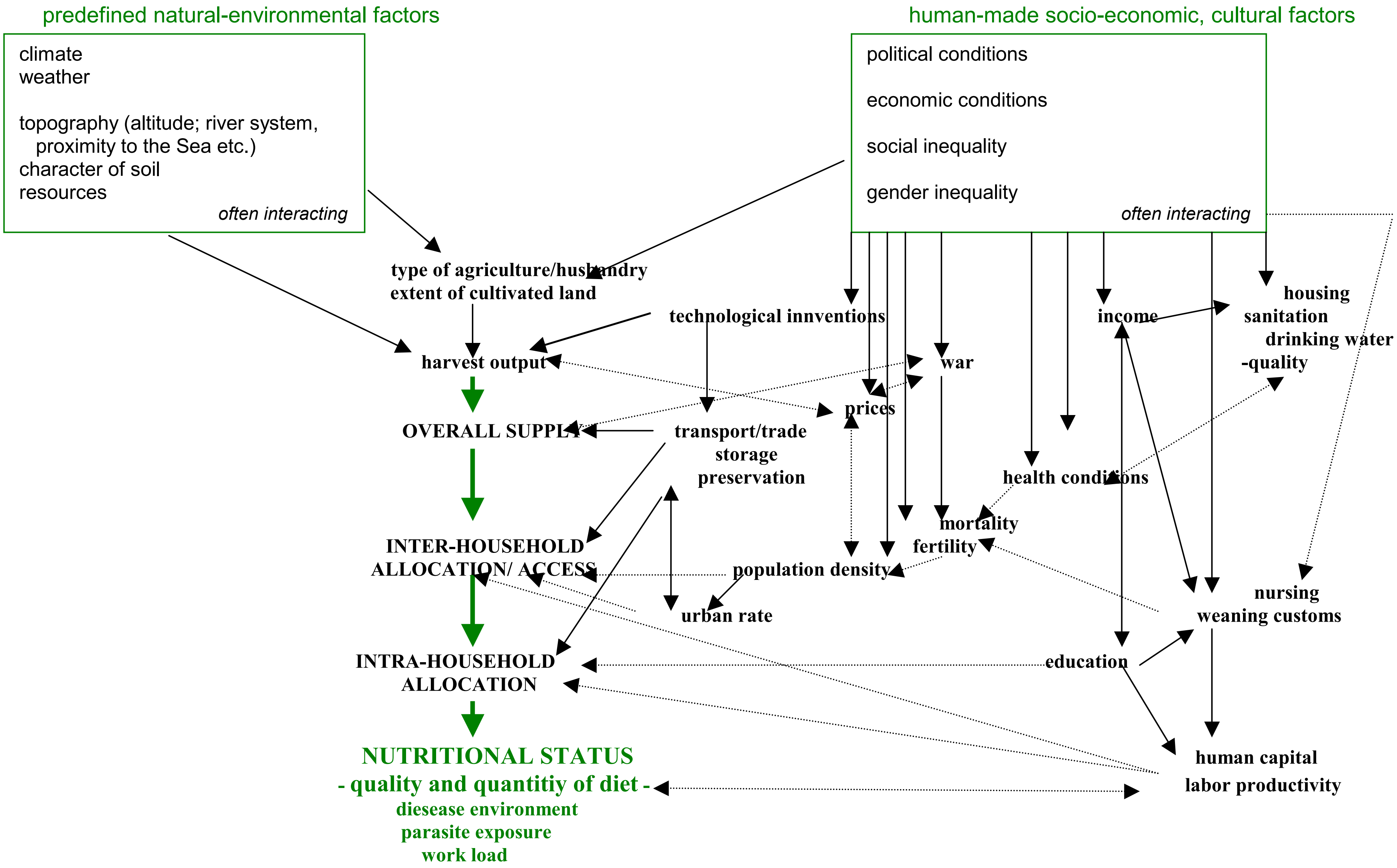
(Rosenberg 2007; Walker et al. 2007b). Disease as well as parasite environment depend on natural conditions, including different regional exposedness, and also on society made factors like pollution, or temporal varying protection possibilities due to medical inventions, or often class oriented differences in sanitary and hygienic conditions, housing situation (air quality, heating possibilities).

In figure 2 we show the many-layered nature of the interrelation between the innumerable natural-environmental, bio-cultural, and social-economical indirect determinants influencing the direct determinants of nutritional status via several steps such as overall supply situation up to the complexity of intra-household allocation. Social inequality or gender inequality, conditional on cultural factors, will result in unequal allocation between the concerned groups, and within the concerned groups (household allocation) for all the main determinants of mean height. The effect may vary in different populations. For example, Sen (1984; 1990) found that extreme under-nutrition often occur despite aggregate food supply not being less adequate than normal. In those cases, malnutrition is due to the missing access to food of a sub-group of people. Correspondingly, – despite the presumable fact that food poverty is the most evident reason for food deprivation – many people are malnourished in households, which could afford to provide all their members adequately (DeRose et al. 1998).

Some of the further determinants can be assumed as not significantly differing between the regions, or changing in the course of the study period, like schooling; similarly exogenous changes in the health situation presumably did not take place. Many of the determinants cannot be studied in detail in archaeological context. Nevertheless, various factors at least subsumed in testable variables, like for example, exposedness to parasites or endogenous diseases environment within urban rate-dummy.

FIGURE 2

SIMPLIFIED INTERRELATION OF SEVERAL 'LAYERS' OF DETERMINANTS OF NUTRITIONAL STATUS, with emphasis on the factor 'diet'



For the investigated long run overview it is not possible, of course, to check in detail the impact of these factors, which presumably influence nutrition, because information on most of the potential determinants is not available. Since this is the case, we utilized variables on which different aspects are 'combined'. Those potential explaining variables have been checked, which can be tested because quantifiable information is available. These variables, which are partly relevant for and related to various further aspects somehow determining nutritional status, are discussed in detail in the different papers in the result part of this thesis (chapter 4).

2.3. HISTORIC SETTING

Since the study covers a period of 2500 years, from B.C. 800 until 1800 A.D., a short overview on the historic development in Europe will be given in the following, focusing on the aspects about how events might have been of relevance for the nutritional status.[37]

For the three major European regions the development over time is roughly congruent, although up to the medieval ages the civilization progress, for example with iron use or written documents, started in the Mediterranean region and moved West and North.

The time from 800 till about 300 B.C. belongs to the Iron Age, were subsistence economy was practiced, the population density was low and the agricultural methods were simple.[38] During the later part of this period Hellenic colonies were founded in the Western Mediterranean, but more essential, the Roman Republic was created.

[37] For detailed overview see Menghin (1980), Ploetz (2003), Menghin and Planck (2005).

[38] Baitinger (1999); Bérenger (2000).

The time of the Roman dominance in large parts of Europe up to about 400 A.D. is marked by nearly permanent warlike operations (in- and outside the country) with spread of diseases, on the one hand, and the spread of Roman law, breeding and cultivation methods, on the other hand. The different wars, with a lot of men active in fighting, probably had negative influence on nutrition. And the same holds for the population in the colonies that increased strongly due to Roman occupation, however, due to soldiers and administrational personnel, which are not involved in food production. The extremely increased population resulted in the founding of many cities and for the first time in European history, some parts of the population did not live in subsistence economy, but had to be fed. Also the urbanization increased, with more people living close together, which resulted in negative effects due to bad hygiene. Positive effects on food security probably are the inclusion of Egypt, serving as "granary", stable conditions in the provinces due to Roman right (*pax Romana*)[39] and improved trade connections.

During the reign of the emperor Augustus (in the decades around the Nativity) Rome was lead away from the crisis. But already after a comparably short time of approximately 80 years, the empire erupted into a major civil war again, already in the "year of the four emperors" (69 A.D.). The overall stable conditions allowed further expansions, again probably with consequences on the nutritional status.

The decisive disaster of the c*lades Lolliana* ("Varrus-Schlacht") against Germanic tribes in 9 A.D. restricted the Roman expansibility to regions in North-Eastern Europe. But during the period until the end of the third century A.D. Rome shaped the conditions in the largest part of Europe.[40] However, during this time repeated phases

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[39] Although discussion is going on whether or not, the whole population benefited from the upswing, or more the upper class (Malitz 2000).

[40] Kühlborn and Bérenger (1995).

with vivid conditions were followed by muddled conditions under incompetent emperors, which, for example, resulted in military revolts. Some stabilization might have brought a law (212 A.D.) that gave Roman citizenship rights to all free men born in the empire, but in the same time "soldier emperors" and "contra emperors" resulted in frequent political changes, inducing violent riots. Hence it follows that from historic facts a decision about positive or negative effects on nutrition cannot be given.

In the mid of the third century A.D. the first wave of the Migration Period started, which jeopardized the Roman Empire. This Migration Period, which lasted about four hundred years till about 700 A.D., brought important changes. On the one hand, battles and moving should have had negative influence on nutritional status, but on the other hand agriculture moved back to subsistence economy, the population density was reduced and urban rate declined. Living conditions might have been stabilized in the forth and fifth century, since different smaller empires were established, especially in Southern Europe. In the eighth century A.D. the Iberian Peninsula is invaded by the Arabs, with their expansion stopped by a period of battles again. But also this incident may have had both positive and negative effects on nutrition, due to positive effects from new cultural ideas and negative ones due to occupation. In any case, the time was too short and the region too small, to really see effects on nutritional status in the analyzed data.

In the Middle Ages the situation stabilizes on a low level. Feudalism replaced the Roman administration, Central Europe split into small feudal states, destabilizing the Holy Roman Empire. After some increase of the number of small urban settlements subsequent to their remarkably decrease during the Migration Period, the number decreased again now. During the subsequent time until 1000 A.D. growth of feudalism was accompanied by gradually rising land rents and production, as well as by exploitation of military market power against peasants.

In a couple of decades around 1000 A.D. Normannic tribes attacked Northern and Western Europe, and as far south as the Mediterranean. They conquered and even settled; however they seem not to have dramatically changed the life in the affected regions. The same holds for the plunderer campaigns of the Hungarians in central Europe, which were only short-lived. Nevertheless, they could have brought new diseases.

In the 11th century trade increased again, beginning on the Apennines Peninsula, leading to economic and cultural growth, but it is not clear what the consequences are for the lower class people. The same question holds for the Crusades, which resulted in additional far distance trade, from which especially the Italian cities benefited. At the same time conflicts started between secular and clerical authorities (Investiturstreit) and competition between monarchy, aristocracy and the church resulted in the establishment of nation states like England, France and Spain. During the High Middle Ages the population increased and from the 13th century onwards the towns flourished again, and around the town's agriculture and husbandry supply belts were developed. Due to an ascending ”bourgeoisie”, art, science and economy improved and advances in the jurisdiction (“Magna Carta” in England and “Sachsenspiegel” in the German Empire) might have brought some consolidation in living conditions.

But from about 1300 onwards Europe undergoes a severe crisis: The Hundred Years War and in the middle of the century the “Black Death” killed approximately one third of European's population. With respect to nutritional status again two aspects may have converse influence: destruction of economy, and reduced population.

In the course of the 14th century the Hanse League became important, increasing trade and supporting the growth of Eastern European States; invention of printing accelerated the dispersion of knowledge;[41] the discovery of America induced new expansion possibilities; and the “Reichsreform” induced the end of traditional feudalism in the German Empire. All these aspects can be assumed to have a positive effect on welfare for European population. However, during this period falls the Protestant Reformation in Western Europe, resulting in various wars animated by religion but also by the ambitious monarchs successfully aiming at the purpose to become more powerful. Within, and between the states, religious orientation was abused in making war.

In the following century again positive and negative aspects may balance and it is difficult to formulate an expected welfare-level of the population in general. Positive could be the cooperation of the states on the Italian and the Iberian Peninsula, the end of the War of the Roses in England, and the treasures of the Inca Empire, which were brought to Spain by the South American conquerors. Negative could be the wars which took place again and again and affected basic security.

The various wars did not impede European states from conquering vast parts of the world. The 17th century was marked by the Thirty Years War, in which large parts of Central and Northern Europe were involved, and during which large areas were destroyed and depopulated. Moreover, further wars took place in this century, like a further war between England and the Netherlands, and the separation of Portugal from Spain

The 18th century is characterized by further increase of tax burdens of the working class and increasing land rents for large land-owners, especially in France where it

[41] Baten and van Zanden 2007.

ended in the French Revolution. The following French Wars presumably resulted in detrimental conditions for the population. But during the 18th and 19th century industrialization began, which in the long run enhanced living conditions remarkably.

This short overview shows that it is nearly impossible to describe overall welfare development and nutrition status for the common population from historic data and events. Positive and negative aspects can occur in parallel. Therefore, it is necessary to use other information sources to get information on the (overall) effect of the various historic contexts and the actual nutrition status in the past.

3. MATERIAL AND METHODS

To study the nutritional status of populations of early-historic periods, an interdisciplinary approach was necessary: All data – both, the height data, as well as data on potential explaining variables – stem from 'somehow' archaeological research. The reconstruction of the height data, which are based on human bones from excavated cemeteries, needed the employment of physical-anthropological methods. For the final analyses several econometric methods were applied.

3.1. SOURCES

In contrast to studies on modern times the main source for the pre-modern study period is physical-anthropological data, because no adequate written sources are available.[42] Furthermore, no quantitative information on aspects like literacy level or infant mortality[43] is available for pre-modern times, which could be used to investigate overall welfare. For the long run study period it is not possible to measure welfare by the 'conventional' way, using economic data, like GDP (only exception are the rough GDP-estimates by Maddison 2001) or real wages. Moreover, no reliable data on aspects like fertility rate or infant mortality exist.

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[42] Those few ancient sources, which give at least any numbers on production or consumption of food, provide not really usable information, because they are small-regional specific (like marks on ostraca). Moreover, written sources are problematic since texts by ancient authors or on inscriptions exist only sporadically, and in general cannot be taken as objective due to the antique writers' usually intentional formulations.

[43] Data is not representative because of the bad preservation conditions of neonatal and infant bones (Kölbl 2004).

However, in the archaeological data some non-anthropometric sources are available, which are helpful to employ.

3.1.1. Non-anthropometric sources

Using archaeological non-anthropometric data it is possible to gain some information on aspects concerning especially diet consumption[44]: These are in particular archaeo-botanic and -zoological data.

The archaeo-botanic remains stem from pollen layers in lake sediments, and also from food remains located in settlements. However, they have been studied only to a limited extent, with a concentration on single local areas (Teuteberg 1992; Küster 1994; Schwarz 1995; Willerding 1996). This does not allow the reconstruction of interregional and inter-temporal differences and changes in consumption as desired for this long run study. At least this information can utilized in order to capture agricultural changes in the course of (pre)history.[45]

But what can be used to study regional and temporal differences in food consumption, and thus living conditions are archaeozoological data. They stem from food stocks and alimentation garbage, and are present to a reasonable quantifiable extent. These comprehensive data were used intensively in the course of this study (see chapter 4).

[44] Approximations concerning single individuals are studied: for example, the preserved stomach content of bodies found in bog or ice is analyzed (for example Spindler 2000; Caselitz 1979). But this information cannot be extrapolated to the whole population, of course.

[45] Of interest is that Roman strata show the highest percentage of grain pollen in comparison to both, previous and following strata, which indicates maximum tilth farming during this period. And this confirms other sources (see White 1995).

As a consequence, to get information on the overall nutritional status in pre-, and early times we need another source. These are the skeletal height data as will be shown in the following.

3.1.2. Anthropometric Source: Human Bones

In populations of today various neurological and physical symptoms indicate nutritional deficiency (see for example, table 1 in Meguid and Laviano 1999, 1376 ff.), but these are naturally impossible to measure in archaeological data.

The main sources to indicate nutritional status of pre- and early historic people are human bone remains. In the case of pre- and early historic times, recent palaeo-pathological research give different measures being stress markers[46]: for example, harris lines[47] as indicator of non-specific stress, dental enamel hypoplasia[48] as further indicator of growth disruption due to health and nutritional stress episodes during growth, porotic hyperostosis[49] and cibra orbitalia[50] as indicators of iron deficiency anemia (owing to nutritional derivation), or DISH (diffuse idiopathic skeletal hyperostosis)[51] as indicator of obesity and diabetes, and latest methods as the

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[46] For an overview see for example Cox and May (2000) or Waldron (2001). Additionally, stable nitrogen isotope analysis allows the direct measure of past human diets (Müldner and Richards 2006). It even allows determination of weaning age; but in this case also only very few data are available (Dittmann and Grupe 2000; Grupe 2003). Also ancient literature, and archaeological findings – from depictions (for example on grave stones) and micro rests in pots, to waste deposits, as well as coprolite, and disposed animal and plant remains in latrines (for example Wiethold 2003) – give an idea how former human diet was composited.

[47] Transverse lines of increased radio-opacity; only in non-adults.

[48] Linear enamel defects.

[49] Overgrowth of the spongy marrow space of the skull.

[50] Accumulated occurrence of porosis in the eye orbits.

[51] Fusion of (at least four) vertebrae.

measurement of carbon and nitrogen isotope ratio in bone collagen, and even polymerase chain reaction allows study of DNA.[52] But on the one hand the interpretation of such findings is still under research discussion (Alfonso et al. 2005). And on the other hand, by now data based on the different techniques that would bring exact additional information – like isotope analysis – were collected rarely, and for a few sites only (Grupe 1986; Schutkowski et al. 1999; Czernak et al. 2006; Müldner and Richards 2006). Thus they do not provide the possibility to prepare an extended regional long run overview on European nutritional status, as it was conducted here.

Height data are available to a much better extent, because they can be derived more easily from bones, and the generalized measuring of bones started much earlier in research history. Moreover, other than the solely single periods 'describing pathological measurements, final height has the advantage that it is the output of the subsumed (factors concerning) living conditions during the whole growth period, including possible catch up growth. Final height as proxy has the advantage that it is a "cumulative record of the nutritional and health history of a person or population" (Bogin and Keep 1999, 333). Moreover, this novel source brings another advantage: Other than data sources on early-modern, pre-industrial periods (which are dominantly recruit records, and thus provide none or only limited measurements on females), the height data from excavated skeletons are given in a representative amount for both, males and females. This means information on the whole population, and moreover the possibility to analyze gender effects, and gender-specific inequality (see chapter 4.4.).

For the present study height data were taken solely from adult human bones, because in case of pre-adult body remains an exact age assessment and sex

52 For example, also dental abrasion status is used to analyze quality of nutrition; but this can be problematic, because especially the degree of abrasion can be the result of factors like age also.

determination – adequate for reasonable analysis – is impossible (see below). The height data were acquired mainly from excavation reports on various cemeteries; additionally, few data on harnishes measures were included in the data set (for detailed description of the data set see chapter 4.1.). When compiling archaeological data, an important aspect is that a skeleton need not to be completely preserved to be analyzable; charred bones can also be determined in terms of sex, age, and height (see chapter 3.2.2.). Therefore, the height determination also is successful for periods in which mostly the custom of cremation was practiced.[53]

The final data base of this study consists of 18502 individuals from 484 sites. Therefore, the data set is the largest of its kind compiled for this study period and region by now (see Table 3). Table 1 displays the basic descriptive statistics of the final data set. For a more detailed description of the data set see chapter 4.1, and 4.3.

TABLE 1
DESCRIPTIVE STATISTICS OF MALE AND FEMALE HEIGHT
IN THE FINAL DATA SET

	$O_{riginal}$	minimum height	maximum height	mean height	std. deviation
males	11965	150,66	185,00	169,36	4,62
females	6537	145,00	179,00	161,29	4,07

[53] This custom of cremation was common during the Latène period and especially popular during the Roman imperial period. Additionally, to the data from cremations, data from Roman imperial inhumations were included in the data set, because it was found by recent research, that people in these special-graves also belong to the “normal average population” in terms of nutritional quality (Witteyer 2000).

3.2. METHODS

Two different methods are needed to carry out this study: First, the bone material has to be analyzed osteologically, to make this source "usable". Secondly, statistical methodology has to be applied on the compiled data to perform the promising anthropometric approach.

3.2.1. Osteological Methods I: Sex and Age Assessment

Basic requirement to reconstruct height of an individual correctly is the knowledge of sex and age at death, as naturally females and males differ sex-specifically in height, and the individuals have to be fully grown. Moreover, within this study the age of the individuals is also of interest in order to reconstruct the temporal development of nutritional status: the analyzed individuals have to be assigned to a certain century, which we did by using the dating of the graves and the determined age.

Usually sex determination and age determination are based on morphological diagnosis (see for example İşcan 1989; Cox and May 2000; Feneis and Dauber 2000; Waldron 2001).[54]

Correspondingly, the bone material has to be of rather good preservation quality to make the determination reliable. As a consequence, in the case of mediocre conditions this results in an uncertain diagnosis. However, we only considered 'quite definitely' sex assessed data in this study.[55]

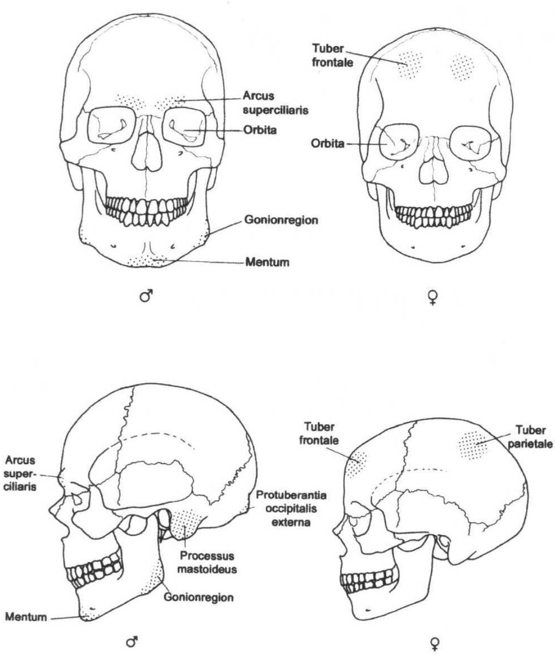
[54] Recently DNA-analysis was introduced for sex determination; but this is not commonly used by now.

[55] In the case of archaeological findings the ideal indicator is whether (or not) the epiphyses of the claviculae are finished.

3.2.1.1. Sex Determination

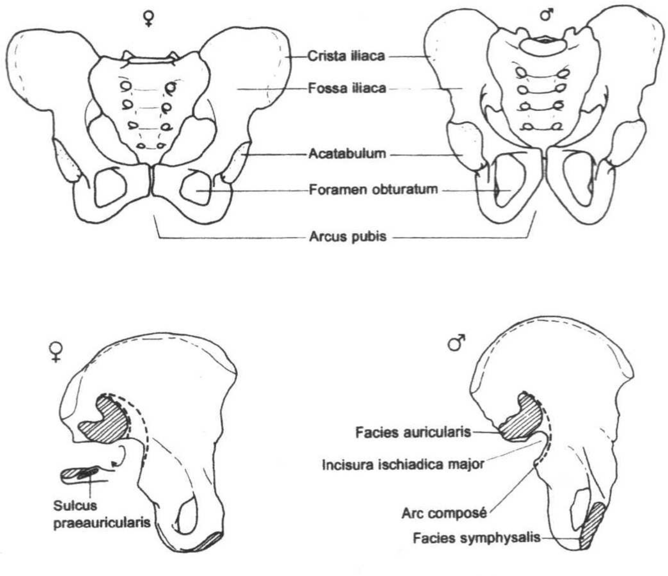
Sex is assessed by morphological and metrical criterions in the skull (Figure 3), and especially various features in the pelvis (Figure 4), because in the latter sex differences are most apparent due to its sex specific varying function (Acsádi and Nemeskéri 1970; Cox 2001). In the pelvis, for example, features which allow a reliable sex determination are among others: the regular female pelvis is lower in height, and wider in size than the male one; the female pelvic brim is about traverse-oval in contrast to kind of cordate in the male version; the greater sciatic notch (*Incisura ischiadica major*) generally is broad in females, and narrow in males; the female pubic arch is approximately twice the angle of the male one.[56]

FIGURE 3
SCHEMATIC REPRESENTATION OF THE
FEMALE VERSA THE MALE CRANIAL FEATURES
(Herrmann et. al 1990)



[56] Whereby as an auxiliary for the investigator one can employ the fact that the male arcus pubis has an angular measure similar to the angle between spread forefinger and middle finger – friendly information from M. Schweissing, Anthrop. Staatssammlung Munich.

FIGURE 4
SCHEMATIC REPRESENTATION OF THE
FEMALE VERSA THE MALE PELVIS FEATURES
(Herrmann et. al 1990)



Commonly the 'combined method' by Acsádi and Nemeskéri (1970) is used, in which different criteria are combined for sex assessment (see also Søjvold 1988; Herrmann et al. 1990 for an overview). The more indicators are combined, naturally the more assessment accuracy increases. Each feature is classified in the literature as well as in our data set as (A) definitely, (B) rather/quite definitely, (3) by tendency male/female, or (4) indifferent (non-determinable), and these classifications are 'subsumed' for the final assessment.[57]

For the conducted data set only those individuals were included, which were at least regarded as 'quite definitely' sexed in the final assessment; additionally 'tendentially' sexed individuals were included if for these cases also information on gender specific grave goods were given, which fitted together with the physical

[57] For example, in the male case – from excellent to impossible sex determination degree – in tables often marked as: m, m?, m??, ??.

anthropological sex determination. An ‘uncertain sex’-dummy was coded to mark these not definitely sexed individuals (1 stands for not definitely sexed; 0 stands for definitely sexed). To record each individual’s sex a male and a female dummy were created.[58] These dummies will allow measurement quality-weighted regressions (assigning lower weight to imprecise measurements), and robustness checks by removing those cases.

3.2.1.2. Age Determination

Individuals are classified in age groups (see for example Grupe et al. 2005):

age 0-6 years:	*infans I*: early childhood (with subdivision in ca. years 0-1 neonatus; years 1+ infans)
age 7-12 years:	*infans II*: late childhood
age 13-20 years:	*juvenis*: youth
age 21-40 years:	*adultus*: adult
age 41-60 years:	*maturus*: maturity
age 61+ years:	*senilis*: senility

In this study, only individuals of final height, means of adult or older age are of interest.[59] It is possible to differentiate different ages at death in these age range by means of age-related changes of the skeleton.

In order to categorize an individual’s age (for classification in the categories of full-grown age) commonly the so-called ‘complex method’, as introduced by Acsádi and Nemeskéri (1970), is employed for European data: it means a combination of different age indicators, evaluating mainly four different structures according to their

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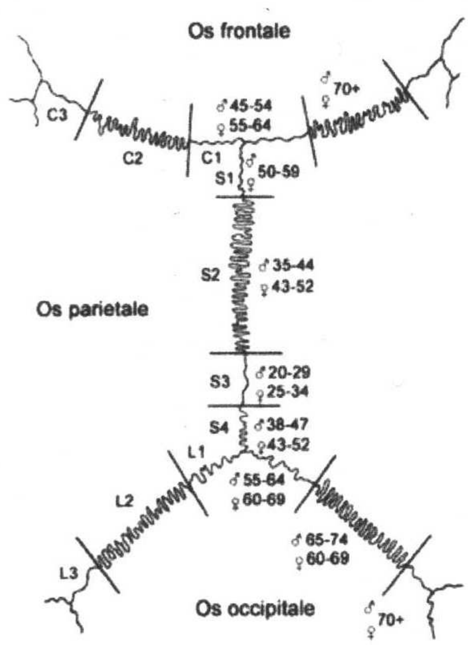
[58] In cases where only one mean height value for a whole cemetery population was documented in the compiled sources it was taken care that individuals of both sexes were not mixed in these values. We disregarded cases were no definite information was given on the topic of sex.

[59] As the shrinkage of senile individuals happens mainly due to deteriorating (inter)vertebral discs, but height reconstruction is based on simple long limb bone length, this age group can be included – We thank Rick Steckel and Barry Bogin for friendly communication.

age specific stage. The most reliable indicator/feature is the ossification status (or obliteration degree) of the cranial sutures (see Figure 5).

FIGURE 5
SCHEMATIC REPRESENTATION OF THE SCULL SUTURES
WITH THE OBLITERATION DATES

numbers give age span in years
(Szilvássy 1988)



This indicator is usually combined with the assessment of the modification of the pubic symphyseal surface (*facies symphysialis*), the changes in the proximal humerus epiphysis, and the proximal femur epiphysis.[60] For each feature the specific stage is assessed, which indicates an age, and finally these stages provided by the features are used to calculate the age at death by taking the mean value. This way it is

[60] One has to keep in mind that these morphological age determination strategies (including indicators like tooth abrasion) in general depicts the biological age, because adverse environmental conditions, and nutritional status (inadequate diet, diseases, and physical work) can make a body 'dilapidated'. Only recently – and therefore not in use for most of the data available for the current study – histological ageing techniques were developed, which allow the determination of the actual calendar age by counting the yearly increase in the dental cementum (incremental lines in the microstructure): Kagerer and Grupe (2001).

possible to reconstruct age; but this is still rather rough. Overall, in comparison to sex assessment of adults, the age determination is not so precise. However, for this study, which concentrates on centuries of birth, it is only necessary to be sure that an individual reached final height before death. This can be done by considering the complementation of the epiphysis of the claviculae (collarbones). This assessment possibility is of special interest, because due to under-nutrition, individuals can grow longer than the officially appointed starting point of adultness at age 18 (see Komlos 1985; see for example Moradi and Guntupalli *forthcoming*). For those individuals for whom an exact age quote was reconstructable, correspondingly, those individuals specified as having no completed claviculae at the time of death were not taken into account in the data set in order not to record a possible bias. Therefore, in the case of a categorization of a skeleton in the "early adult"-group (age 21-30) a mean value of 25 years was used, and the individual was coded as 'uncertain aged', because of the possibility that the specific individual was not yet completely grown at the time of death.

In order to assign the individual to be born in a certain century we made additional decisions if for an individual an age range was given (one age group, or a subgroup: for example "adult" or "late adult"). Then we took the mean value of this range as age quote: The individual's age was coded as the respective mean value (for example in the mentioned case 30 or 35 years). Those cases were attributed as "certain age" (coded as 0 in an 'uncertain age'-dummy), in order to have a control possibility of a possible bias when studying the collected data. If the given age specification was only 'full grown' the specific individual was coded with an age of 40 years (as the mean value from beginning adult to senile age), and assigned to the group of individuals of "uncertain age" (coded as 1 in the 'uncertain age'-dummy).[61]

3.2.2. Osteological Methods II: Height Reconstruction and Conversion of Measurements

In order to reconstruct height from skeletal material, various different methods exist. Because in archaeological material in most cases only a few bones are preserved, the so called "mathematical method" has been derived. This enables the reconstruction of height, using linear regression between height and long bone length.[62] Over 40 different

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[61] In the same way the age classification was handled, if only a mean height value for a group of individuals of one sex was given in the literature; but in most of these case the age structure is given in detail – then the mean age was calculated, but also assigned to the group of individuals of "uncertain age", because generally a much larger number of individuals can be age determined than their height reconstructed.

[62] Even single bone parts – and hence bone remains stemming from cremations – can be used, if the bone head survived, because the diameter of the long bone ends is closely correlated to the long bone length (May 1997; Rösing 1977; Herrmann et al. 1990; Gehring and Graw 2001: Shrinkage has to be considered). Even though the standard error is naturally higher in reconstructed heights based on cremations in comparison to reconstructed heights based on inhumations the R^2 for the used regression models by Rösing amounts to approx. 0.7 (friendly communication F. Rösing/Ulm). Only disadvantage of cremations is that naturally little bone material survives for analysis (Dokládal 1970). Also for cremated bones a range of methods exist to estimate height: more than 20 different models exist (for an overview see for example Wahl 1982; Heußner 1987). The height estimation based on the bone heads (diameters), especially of the caput femoris (and here f18 'vertical diameter of the femur head': linear distance of the highest to the lowest point of the caput femoris) is the most proven method (Herrmann et al. 1990, 274). Thus, the formulas by Rösing are in common use. The resulting values of this technique have additional advantage that they can be directly compared with the heights reconstructed using the formulas by Breitinger and Bach (see below). Only if the skeleton survived in situ (undisturbed, in original position) in outstretched posture it is also possible to determine stature by direct measuring of the skeleton length. Nevertheless, one has to take into account cadaverous stretching: a living person's stature and its corpse length differ by about 2 cm (Kurth 1954; Schott 1963; Herrmann et al. 1990; deMendonça 2000; Maat 2003).

models were developed by different authors for each long bone, and are in use in current research. Rösing (1988) gave an overview on the large amount of common methods.[63]

Thus, a direct use of the height data from different sources is impossible for a long run overview. Therefore, a part of this PhD-thesis is the development of equations that harmonize the heights reconstructed by the various initially utilized methods.[64] The processing of those algorithms for a recalculation and standardization is presented in the following.

3.2.2.1. Basics for Algorithms to Transform Height Estimations

Basic idea of height determination of pre- and early historic people is the phenomenon that the length of a long limb bone represents an approximately constant proportion of height (Verhoff et al. 2006).[65] Therefore, regression formulas have been developed, which differ for females and males, of course. As the length of a bone can be measured in different ways[66] for unification of the existing regression equations, one has to ensure

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[63] However, those are rarely in common use in osteology, instead mainly taken for modern populations in forensic science.

[64] Naturally a comparison of the mere long bone lengths would be more accurate then to calculate heights as no danger of additional estimation error occurs, but for a better common understanding interpreting stature is more feasible. The economic interpretation focus on differences over time and between regions anyway, less so on the interpretation of height levels.

[65] Even the length of each bone type of both body halves can vary. But this minor asymmetry can be ignored for stature reconstruction (Byers 2002, based on Trotter and Gleser 1952; Rösing 1988). In case that two separate measurements of a pair of bones was available for an individual we used the mean of the two long bone lengths to reconstruct height.

[66] Various possibilities to measure a bone were defined by Martin and Saller (1957). Interpretating mean height one has to have in mind, that the reconstructed values display merely an approximative character, because reconstruction cannot be perfect due to different preservation conditions (for example kind of soil, duration of deposit, kind of rediscovering). For all reconstruction models one has to remember that the estimation error is relatively high for an individual. But this value is negligible for the transformation as for a population solely the mean is of interest.

that the various reconstruction methods in work are based on the same bone measurement.[67]

Of all the bones in a skeleton, the femur (thigh) gives the best approximation to reconstruct human height.[68] To reconstruct height of inhumated individuals from bone measurement, mostly femur measurement f1 is in use that is largest length of the bone (proximal extremity with the femur in a physiological position); some methods instead utilize femur measurement f2 that is the 'whole length' of the long-bone (distal extremity).

Fortunately the femur is the most frequently preserved bone; in many cases it is even the only preserved long-bone (in addition to sculls, which allow sex and age determination). Thus, in the following, the focus lies on models using femur length, and here especially f1-measures, as this measure is mostly used in the formulae of the most commonly used regression models.

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[67] Rösing (1988) noticed that in many publications on height estimation it becomes not clear, which is the underlying bone measurement. An additional element of uncertainty results in the fact that often only the estimated height is given in the literature, but not the long bone length on which the estimate is based on respectively, whether the estimate is based on one or more bone measurements. Therefore, for example, Werdelin (1985) appeals for the publication of the single bone lengths on a regular basis.

[68] Already Beinhauer (1985) stated this. Still the hypotheses was popular that apart from the femur the humerus results in a smaller measurement error than radius and tibia (for example Wurm 1986, 157); in contrast to this recently researchers came to the conclusion that normally the long bones of the lower extremities give the best approximation (Herrmann et al. 1990, 93 f.). See on the use of the tibia: Duyar and Pelin (2003). Furthermore (even) in recent studies estimations based on small bones for example from the foot were developed (see Byers et al. 1989; Holland 1995); but these are not in common use. Waldron (1998), and similarly Gehring (2001) again came to the conclusion that the femur (and here especially measurement f1, maximum length of the femur) is correlated best with stature.

3.2.2.2. Recalculation and Standardization – Algorithms to Transform Height Estimations

The most commonly used methods in general height reconstruction, and correspondingly utilized for the observations compiled in the thesis data set (more than 90 %) to reconstruct height are the following, see Table 2.

TABLE 2
MOST COMMON RECONSTRUCTION MODELS FOR INHUMATIONS
in the compiled data set (final compilation)

Method	**N** $_{\mathbf{original}}$
Breitinger and Bach	6588
Manouvrier	2924
Trotter/Gleser[w]	2749
Pearson (incl. Wolanski)	2656
Others[69]	1983

note: the remaining data that complete the compilation are *in situ* measurements, individuals with given femur length, for cremations Rösing etc.

Given in Table 2 are the numbers of data that were compiled for the current study, separated for the different reconstruction methods: Breitinger (1932, for males) together with Bach (1965, for females); Trotter and Gleser (1952, for whites), as well as Pearson (1899) (respectively Wolanski 1953); and Manouvrier (1893). For these models the transformation algorithms are presented here, which are used to get an uniform data set.

We used Breitinger and Bach (B&B) as the 'basic' default model to determine the algorithms to convert the data, due to several reasons: firstly, B&B represent the largest part of the data set – and in order to minimize recalculation error, it is preferable to use the calculation method that most initial investigators employed. Furthermore, B&B

[69] "Others" are merely Dupertius and Hadden (1951), Trotter (1970), and Søjvold (1990).

gives the most accurate results (lowest mean of differences in stature) for the relevant spectrum of centimeters[70]: For the height range 164 – 178.9 cm for males Formicola (1993) arrives at the lowest estimation error for Breitinger, whereas the Trotter/Gleser and Pearson methods[71] are less efficient. A third argument for B&B is that Trotter/Gleser result in higher, and Pearson at lower height estimates, whereas B&B estimates fall between them. Therefore, B&B estimates are normally close to a "compromise" estimate "averaging" these three most commonly used methods.[72] Moreover, the B&B estimations are the best to compare with estimations after Rösing (for cremated bones)[73], which cannot be converted, because the reconstruction formulas are based on different parts of bones.

The methods to derive the human height, which are used here, all are based on the femur bone length. Based on this presupposition, the transformation algorithms that we derived for unicfication of the measured heights, are based on the femur length f.[74] We recalculate the femur length from the height H_X, by inverting the height formula for which it is known that it has been used by the author X, and use this value in the height equation by Breitinger respectively Bach, which we decided to be the default method. In the equation

$$H_B = m_X * H_X$$

[70] Compare Formicola (1993). But note that, if the height of especially small individuals (males below 160 cm) is reconstructed Pearson might be more efficient.

[71] He does not include Manouvrier's method due to the uncertainties mentioned above.

[72] In our case about 90% of both, the female and the male observations fall into this range.

[73] According to J. Wahl the stature estimates with the Breitinger/Bach method comes nearest to the Rösing estimates. Because we want to compare Rösing values, it is best to use Breitinger and Bach measures. – We thank J. Wahl, University of Tübingen and Landesdenkmalamt (Bureau of ancient heritage and monuments) Baden-Württemberg for his kind personal communication.

[74] Used as femur length is measurement f1 after Martin and Saller (1957).

m_X is the transformation factor that converts the known height value H_X, reconstructed using method X (for example, H_{TG} would be the height after Trotter/Gleser) to the height value H_B, estimated using the method by Breitinger (for males) resp. Bach (for females).

Breitinger, Bach, Pearson, and Trotter and Gleser use as femur length f the values f1 (after Martin and Saller 1957). The height estimation method by Manouvrier (1893), which is still in use for the study of most cemeteries from the French and Italic region, instead is based on f2 values with the consequence that in the transformation to heights after Breitinger and Bach firstly f2 has to be transformed into f1. To do this, we calculated a conversion factor Δ f % = (f1given- f2 given)/f2 given * (1/100) for each sex, using sample individuals[75] for which both, f1 and f2 values, were given.[76]

Since the algorithms are different for males and females, also the transformation equations are separated.

(A) Transformation factors for males (transformation into height after Breitinger)

(1) Femur length f1 from height after Breitinger (1937)

$$H_B = 1.645 f + 94.31$$

$$f = H_B / 1.645 – 57.33$$

(2) Transformation factor for height after Pearson (1899)

$$H_P = 1.88 f + 80.0$$

$$f = H_P / 1.88 – 42.553$$

$$m_P = 0.875 + 24,308 / H_P$$

(3) Transformation factor for height after Trotter/Gleser (1952) for white man

[75] The plotting is based on 170 female, and 204 male observations from the collected data.

[76] For analyses it is reasonable to mark those height values which initially were reconstructed on the bases of Manouvrier as uncertain for the data analysis.

$H_{TG} = 2.58\ f + 52.5$

$f = H_{TG} / 2.58 - 20.349$

$m_{TG} = 0.0.638 + 60.834 / H_{TG}$

(4) Transformation factor for height after Manouvrier (1893)

f2 is recalculated from H_M based on a nomogram, resulting in

$f2 = H_M / 3.92$ if $H_M \leq 153.0$ cm

$f2 = H_M / 3.9$ if $153.0\ \text{cm} < H_M \leq 163.05$ cm

$f2 = H_M / 3.8$ if $163.05\ \text{cm} < H_M \leq 166.1$ cm

$f2 = H_M / 3.7$ if $166.1\ \text{cm} < H_M \leq 169.15$ cm

$f2 = H_M / 3.6$ if $169.15\ \text{cm} < H_M \leq 177.6$ cm

$f2 = H_M / 3.5$ if $177.6\ \text{cm} < H_M \leq 183.0$ cm

$f2 = H_M / 3.53$ if $183.0\ \text{cm} < H_M$

The femur length f1 that is needed for the Breitinger algorithm is recalculated from f2 using Δf% and named f_M for Manourvier

$f_M = f1 = f2 * \Delta f\%$

Since f2 is based on a nomogram and not on a regression, a simple equation for a transformation factor Manouvrier can not be given and height after Breitinger is calculated directly using f_M

$H_B = 1.645\ f_M + 94.31$

(B) Transformation factors for females (transformation into height after Bach)

(1) Femur length f1 from height after Bach (1965)

$H_B = 1.313\ f + 106.69$

$f = H_B / 1.313 - 81.257$

(2) Transformation factor for height after Pearson (1899)

$H_P = 1.95\ f + 71.66$

$f = H_P /1.95 - 36.72$

$m_P = 0.673 + 58.48 / H_P$

(3) Transformation factor for height after Trotter/Gleser (1952) for white woman

$H_{TG} = 2.47 f + 54.1$

$f = H_{TG} /2.47 - 21.903$

$m_{TG} = 0.532 + 77.932 / H_{TG}$

(4) Transformation factor for height after Manouvrier (1893)

f2 is recalculated from H_M based on a nomogram, resulting in

$f2 = H_M / 3.87$ if $H_M \leq 140.0$ cm

$f2 = H_M / 3.9$ if $140.0 \text{ cm} < H_M \leq 146.25$ cm

$f2 = H_M / 3.8$ if $146.25 \text{ cm} < H_M \leq 156.2$ cm

$f2 = H_M / 3.7$ if $156.2 \text{ cm} < H_M \leq 160.35$ cm

$f2 = H_M / 3.6$ if $160.35 \text{ cm} < H_M \leq 171.5$ cm

$f2 = H_M / 3.58$ if $171.5 \text{ cm} < H_M$

The femur length f1 that needed for the Bach algorithm is recalculated from f2 and named f_M for Manouvrier

$f_M = f1 = f2 * \Delta f\%$

As for man, asimple equation for a transformation factor in this case can not be given, thus height after Bach is calculated directly using f_M.

3.2.3. Statistical Methodology

The aim of this thesis is, on the one hand the development of the human mean height as function of time and region; and on the other hand to study the reasons for the development. In order to do so statistical anthropometric methodology was applied in this study on pre-modern periods for the first time in econometric research. Using regressions potential influences and interrelations of various exogenous variables and their significance are studied. This method allows taking account of possible multi-dimensional impacts.

We performed multiple linear regression analysis to check for the impact of several different independent variables. The regression model bears mean height of a population MH_p as dependent variable, changes in it being explained by independent variables $EC_{i,p}$.

$$MH_p = \beta_0 + \sum_{i=1}^{I} \beta_i \cdot EC_{i,p} + \varepsilon$$

The extents to which the mean heights of different sub-groups vary indicate the degree of varying independent environmental conditions. More details are provided in chapter 4. For the purpose to study the data by regression analysis we used SPSS 12.0 for Windows, and STATA. The coding of the explaining variables is described in detail in the different papers in the main part of this work (chapter 4).

3.3. POSSIBLE RESTRAINTS AND CAVEATS

Studying pre-modern, archaeological periods is naturally exposed to some restraints in comparison to the studies on modern times. This, of course, also holds for the European nutritional status in the real long run, analyzed here.[77] Thus, for the present study possible uncertainties could arise concerning both the dependent variable and the

[77] Thinking of further aspects of biological standard of living, the impact of decrease in mean height on mortality could not be studied within the frame work of the present study, because given age determination is to vague for this kind of analysis. In single, specific studies with more exact age determination the authors found indicated a relationship of taller height and higher age at death, being not 'necessarily' causal, but coincidentally caused by environmental circumstances (see Gunell et al. 2001; Kemkes-Grottenthaler 2005).

explaining variables. In case of the dependent variable, mean height, uncertainties could arise from measurement errors on bone lengths and height reconstruction. However, these are unlikely because the collected bones' length have been measured by trained archaeologists. Furthermore, the varying burial customs might distort the data, because height reconstruction based on cremated bones can be less accurate than height reconstruction based on complete bones (due to the "double step"-regression). Thus, these cases were marked as uncertain in a corresponding dummy, in order to control for possible mis-distribution. Fortunately, the in-/exclusion of those observations did not make an important difference in the results.

Another problem is that dating is difficult; accordingly, it is only possible to allocate the data in birth centuries. Only some graves include small finds which can be dated definitely in half a century. However, often a grave can even only be associated to a range of centuries which circumscribe a period. Thus, only those cases were included in the data set, which can be dated reasonably well – means, in not more than span of two centuries. We controlled for it with a further dummy. Also in this case, the in-/exclusion of these cases did not make an important difference in the results.

In the case of the explaining variables – due to the limited sources spectrum of archaeological time – it is naturally only possible to study a small section of the potential determinants. In addition it is often possible to study a determinant only to a small extent, like the measuring of social status of an individual due to the often missing small finds. Moreover, different influencing factors have to be combined in one available determinant, such as urban rate standing for various aspects like parasite exposure, food supply et cetera. It is unfeasible to control for the entire range of possible determinants for which data are given on modern populations, like information on prices and price development[78], calorie consumption behavior, degree of education. No adequate data is also available on longevity of the mean adult population or infant mortality in a long run study. Moreover, it is of course impossible to study actual determinants on household level; but it is possible on a macro level. Furthermore, the reconstructions of potential determinants cannot be taken as completely certain, because for archaeological times those numbers are approximations.

However, we can state that basic requirements for a scientific investigation are fulfilled, due to the large amount of data collected for this study, and the algorithms used to harmonize heights based on different reconstruction methods. Moreover, the utilized height data can be seen as representative, as they were randomly collected; they originate from a large range of cemeteries from all over Europe, and without concentration on a social level (see chapter 4.1.). A possible distribution bias due to different excavation centroid etc. is not relevant.

Obvious caveats of our data set, as it was possible to compile by now, are the temporal and regional resolution, which reduce the possibilities for more detailed study of the determinants of the nutritional status. The same holds for the missing detailed

[78] For example, an important determinant as indicator for supply conditions would be prices of diet goods, because these 'incorporate' information on the scarcity of goods. But by now no adequate data is available, because historic sources on prices are either temporarily or regionally restricted. Rare references are given on single aspects in ancient or medieval sources (for example, Szaivert and Wolters 2005). It is impossible to find information on a homogenous, everywhere consumed good that could have been used as numéraire. Moreover, although rough ratings are possible (Allen 2007) numbers like the ones from Diocletian's price edict are problematic to analyze, because the numbers represent inflicted restrictions; or are only valid for single small regions (for example the indications on ostraca). Furthermore, the adequate consideration of the inflation in the course of the first millennium A.D. is problematic. For the purpose to study the effect of price development (with considering the complexity of inflation, comparability of 'good basket') only very recently a large venture has been started ('Cologne Tableau'), which one time will solve also this complex topic. It was started with a DFG-project on 'Econometrics of the Central European Neolithic'.

information on relative age at death development in order to countercheck the relative height movement.

Despite these restraints it is of special interest to study archaeological periods. The results may show a lower significance than perfectly exact data for modern periods, but we have to face the fact that “In the country of the blind, the one-eyed man is king”. The data enables us to get insights which have not been possible before “although skeletal data are scant and scattered, their study can contribute powerfully to the elucidation” of general former living conditions (Cohen and Bennett 1993, 288). Moreover the data certainly are adequate enough to draw reasonable conclusions, to check hypotheses, whose accuracy could not be controlled for before.

4. RESULTS

The two main questions of this thesis – can the development of mean height be used as indicator for nutritional status? And what were its economic determinants? – were studied with varying foci. In several sub-chapters the results of the study are presented belonging to different research priorities.

In chapter 4.1., the first anthropometric estimates on the nutritional status in ancient Europe ever conducted are presented. The data are concentrated on the two millennia A.D., showing no large scale progress in European nutritional status in the course of the centuries A.D. Not even for the time between 1000 and 1800 a decisive increase could be found, a period for which recent GDP *per capita* estimates diagnose an increasing development (Maddison 2001). On a more detailed level, we find that heights stagnated all over Europe during the Ancient Roman Period, while astonishingly increasing in the fifth and sixth centuries. Remarkably is the synchronicity of height development in the three major European regions. According to the regression analysis of height determinants, population density turns out to have been economically negative (but not statistically). This indicates some relevance of decreasing marginal product theories for the centuries A.D. Moreover, climate was found to be of marginal positive significance, social inequality and absolute gender inequality were found to be of marginal negative significance.

In sub-chapter 4.2., we concentrated on the question, whether in the long run nutritional status was decisively influenced due to changing emphasis in agricultural production from cattle to swine, resulting in lower animal protein consumption. Basic hypothesis was that protein-rich milk and beef were major determinants of the nutritional status in early history just as in (early) modern times (Baten 1999; 2000;

Moradi 2007), and considered the effects of cattle farming on health by using anthropometric techniques.

Agricultural specialization was documented quantitatively for the first time in this study by utilizing a sample of more than 2,000,000 animal bones; taphonomic factors of possible impact on the zooarchaeological quantification were taken into consideration. The share of cattle bones turned out to have been a very important determinant of human stature (correlating with health and longevity), being *ceteris paribus* an indicator of milk (and beef) supply. We rejected the hypothesis of earlier scholars who interpretated height differences between North-Eastern Europeans and Mediterranean Europeans as genetically caused, without taking the milk/beef indicator into consideration. 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 for the centuries A.D. The newly created milk/beef indicator (the share of cattle bones), land *per capita*, and a set of other variables (such as gender inequality, climate, regional dummies etc.) are able to explain 69% of the height differences for the period 0 to 1800 A.D., a relationship which also holds when region fixed effects are considered.

In the last two sections of chapter 4 the study was based on an enlarged data set with over 18500 individuals from the eight century B.C. until the 18^{th} century A.D.

In 4.3., for the first time in anthropometric research also prehistoric data were analyzed in a long run overview on Europeans. This allowed studying in particular the question, whether Roman occupation had a decisive influence on nutritional status. Until now a discussion was going on to what extent the Central-Western autochthonous population was positively or negatively affected by the Roman expansion. It is known that the Roman occupation North of the Alps was a well prepared enterprise (during the summer of B.C. 15), apparently with only little resistance. But uncertainties remain whether there was a region wide settlement hiatus, or whether the autochthonous Celtic population was decimated in particular during Roman occupation (by killing and abduction), and after the occupation by recruitment of the indigenous men to prevent rebellions, as Cassius Dio (54,22,5) wrote. Settlement continuity is only ascertained in a few cases; recent research 'speaks for' a reduction in the population density during the first century B.C. before the Roman occupation; for example pollen diagrams of the time shortly before the Roman occupation, show for the region North of the Alps that fields were uncultivated, and the woods expanded (Smettan 2005; interestingly after the Roman occupation mainly these regions were cleared again). All the more the – due to the settling of soldiers, traders and crafts men, as well as colonizing farmers – extremely increased population numbers in the aftermath of the Roman occupation, in combination with the before unknown people being no self-supplier, should have a significant negative impact on the nutritional status – if not the supply organization was adjusted.

Overall, the results of sub-chapter 4.1. are confirmed by the much larger data set in 4.3.: There was no general trend in mean height, but variation between centuries, indicating that there was no large-scale progress in European nutritional status prior to industrialization in the long run of the approximately last three millennia. Additionally to a 'Roman bath&technology'-dummy representing Roman occupation, further decisive determinants in influencing mean height are the degree of cattle share, and urban share. Controlling for cattle share the former finding is confirmed that no significant regional differences exist between the European major regions if husbandry was present, and thus basic human needs were met comparably well. Testing the impact of increasing urban rate the hypothesis of a negative impact for pre-modern times is confirmed (Steckel 2004a; Haines 2004). The set of endogenous variables in use can explain up to 61% of the European mean height development. The fact that the land *per capita*-determinant has no significant effect in the very long run could be explained by Malthusian, as well as by Boserupian effects; however, it cannot be decided which is the better explanation due to the low temporal resolution of the data set in this study.

In 4.4., the focal question are gender specific disparities – differences in the survival rate as well as height differences due to cultural, gender constrained practices – in pre-historic to early modern Europeans. Employing the anthropometric approach for the first time an overview on the development of female discrimination in the long run in pre-historic, ancient and early historic Europe was compiled, which allows to verify the vague picture of the relative status of females one gets analyzing solely archaeological and historic written data. Remarkably no significant change in gender effects took place in the course of pre-historic to early modern periods. In the course of time Mediterranean females lost in their relative good status, whereas overall North-Eastern and Central-Western females could strengthen their status in the long run over the eighth century B.C. until the 18th century A.D. Nevertheless, overall Mediterranean women did comparably well; the gender effect there is statistically significantly lower in comparison to the rest of Europe.

4.1. The Biological Standard of Living in Europe during the Last Two Millennia

4.1.1. Main Questions

How did the standard of living in Europe develop in the very long run? In this study, we distinguish the biological standard of living (which includes important elements of the human utility function such as health, longevity, and quality of nutrition) from purchasing power-oriented standard of living components.[79] For our analysis, which covers (mostly skeleton-based) height measurements from 9477 individuals, adult stature was used as a proxy for the biological components stated above. Out of these individual measurements, however, some were published in aggregated form by previous investigators and excavators, with each aggregate figure comprising between one and 360 individuals. Thus, the total number of height estimates available to us was 2974.

Our data were collected from 314 sites all over Europe. In this article, we find important deviations between the biological and purchasing power-related components of living standards over the past 2000 years. For instance, contrary to the widely accepted view that purchasing power should have increased during the period of the Roman Empire due to "Smithian Growth",[80] we find that mean stature stagnated. Another remarkable finding is that heights did in fact increase during the fifth and sixth centuries, after the breakdown of the empire in the West.

This chapter is based on an article published in the *European Review of Economic History*: Koepke and Baten (2005a). The concept for the paper was developed jointly, the analyses and writing was equally shared.

[79] Komlos (1985) was the first to use this term.

[80] Growth which is mostly stimulated by trade and comparative advantage, as opposed to Schumpeterian growth which is driven by technological change, see Mokyr (1992).

A related study by Steckel (2004) found a substantial decline in Scandinavian heights from the Middle Ages until today.[81] In a similar vein, Cohen and Armelagos (1984), Cohen (1989), and Armelagos (1990) have stressed the detrimental influence of civilization on human health and nutritional status over the millennia (until the late 19th century). Maat (2003) has recently confirmed this view for the Netherlands. However, the number of observations covered by these studies is very limited, especially for the periods up to the Middle Ages. Our study, in contrast, will take into account a substantial number of sites and observations in order to trace the biological standard of living in Europe over the last two millennia. Thus, the number of cases covered by our study compares favorably with earlier research (Table 3).

After describing the sample characteristics and discussing the limitations of our sample and methods, we will - in a first step - estimate a general height trend as well as more disaggregated trends for three regions of Europe. This will be followed by a more detailed analysis of the second estimation's time series, regressing it on population density, climate, social and gender inequality, and similar variables (the latter with substantial measurement error, however). Finally, we compare our height trends with purchasing power estimates.

[81] Richard Steckel and his co-operators have started a research project (Steckel 2003) in which they will investigate height and a number of diseases (as far as they can be traced with bone material).

TABLE 3
STUDIES FOR COMPARISON: SKELETAL DATA

Author	year of publication	Dating (approx cent.)	Region	N cases	N underlying heights	comment
Steckel/Rose	2002	B.C: 5500 – 0 A.D.	America	33	1106	
Steckel/Rose	2002	200 A.D. – 1800 A.D.	America	14	5188	
Steckel	2004b	B.C. 900 – 1900 A.D.	Scandinavia & GB	23	6531	incl 2 sites also included by Maat
Maat and DeBeer	2003 and 2004	0 A.D. – 1800 A.D.	Netherlands + Island	391	391	different height reconstruction models mixed (Maat)
Angel	1984	B.C. 3000 – 100 A.D.	E-Mediterranean	974 ?	974	
Angel	1984	100 A.D. – 1800 A.D.	E-Mediterranean	254	254	
Jäger/Zellner	1998	B.C. 5000 – 2000A.D.	NE-Germany	45	2130	
Haidle	1997	B.C. 5000 – 1900A.D.	S-Germany & N-Switzerland	488	488	
This paper		0 A.D. –1800 A.D.	Europe	2974	9226	without harnesses (251 cases)

Notes: grey-shaded are studies which focus exclusively on the same period as our article (0 A.D. to 1800 A.D.), while other studies include earlier millennia. DeBeer uses 41 cases in addition to Maat. We distinguish between number of cases including averages and individual data, and the underlying number of height measurements. For example, Steckel (2004) considers 23 averages from the excavation literature, which averaged 6531 individual heights.

4.1.2. Data and Regional Characteristics

Our height data stem mostly from archaeological excavations and represent the largest collection of observations on Central and Western Europe (see Table 4), covering contemporary Germany, Benelux, Austria, Northern France, Switzerland, and the UK.

TABLE 4
AREAS COVERED BY THE DATA SET (NUMBER OF INDIVIDUALS)

Century	Central-Western Europe				North-Eastern Europe		Mediterranean Europe	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 Bibliography part 1

The number of cases included in our sample is sufficient to subdivide the Central-Western region further into the regions along the Northern Rhine area (Benelux, Northern France, and Western Germany), the regions around the Southern Rhine (South-Western Germany, Switzerland, and Eastern France), Bavaria/Austria, and the UK. The category of "Northern and Eastern Europe" refers to those regions which had only limited contact with the Roman Empire and its provincial economy: Scandinavia, Poland, Northern and Eastern Germany, and Hungary, the latter being included here because the large region east of the Danube was not fully integrated into the Roman imperial economy. Northern and Eastern Europe constituted the least densely settled region in our sample, and it probably featured the highest *per capita* milk and beef consumption in Europe, since a high land ratio facilitates *ceteris paribus* a large number of cows and therefore a nutrition which is based on high-quality proteins (on the role of high-quality proteins (such as milk) for pre-industrial nutrition and health, see Baten 1999; Baten and Murray 2000; and many others).

These regional characteristics require further substantiation. Recent research on archaeozoology sheds some additional light on our assumption that milk and beef consumption was high in Northern and Eastern Europe. King (1999) and others have analyzed the share of cattle bones, pig bones and other bones (sheep, goats) drawn from excavations of ancient towns, villages, and other civil and military settlements. A high share of cattle bones was typical of Northern and Eastern Europe during the Roman period, whereas a high share of pig bones was typical of the most urbanized part of the empire, especially the Mediterranean region with its large cities (incl. Rome and the bay of Naples), until approximately the end of the fourth century A.D. The cattle bone share can be taken as approximating the cattle share – King reports no evidence on systematic bias from selective preservation or excavation. A high cattle share is plausible foremost in locations with low population density, since due to ancient technology, a large amount of land was already taken up by agriculture, while even more land was required for grazing. Pigs, in contrast, could be kept in locations with less land-intensive modes of production near large cities, and often be fed with side-products from other lines of agricultural production; in the case of Rome, for instance, even imported fodder was used (in addition to semi-spoiled grain and other foods). Hence, the cattle share might serve as a proxy for the consumption of beef and especially milk, which was of great importance for the protein-supply of low-income groups in pre-industrial societies. What is more, Peters (1998) points out that cow milk was not commonly used in the Mediterranean during Roman times, while bovine milk served in fact as the staple food of some populaces in Central Europe, like a number of tribes in *Germania Magna*. Von den Driesch and Peters (2003) explain the missing depiction of udders on a Roman stone relief showing a cattle herd by the fact that dairy-farming was of no importance for Roman husbandry-farmers during the imperial period. In addition, they also mention that Germans preferred cow milk. Ancient sources such as Tacitus and Plinius (Tac. Germ. 23; Plin. nat. VIII 179) emphasized this as well. Hence, we conclude that milk and beef consumption was considerably higher in North-Eastern Europe, and much lower in the Mediterranean already in Roman antiquity. We therefore need to control for those differences in the analysis. Even today, Scandinavians (and Dutch) rank highest in *per capita* milk and dairy product consumption, with East Asians ranking lowest. Western-Mediterranean dairy consumption was extremely low between the year 0 and ca. 1950 (in parallel to heights), but increased strongly thereafter (Quiroga Valle 1998; Bisel 1988). Milk consumption also increased after 1950 – thus, lactose intolerance was probably not a decisive limiting factor in Europe (on Asia, see Crotty 2001).[82]

[82] Crotty (2001) emphasized the importance of lactose intolerance in his bold attempt to explain the evolution of capitalism based on cattle-farming patterns. Crotty argued that lactose-intolerant people could not make sufficient use of cattle. Lactose intolerance means that people have digestive problems when drinking large quantities of milk after the age of 5–7, because at that age, genetically lactose-intolerant people lose their ability to digest fresh milk without encountering diarrhoea and similar problems. Especially East Asians (east of Tibet and Rajasthan), Native Americans and some African people suffer from lactose intolerance. For Southern Europe, the results are mixed – one study included Spain into the category with the highest degree of lactose tolerance (70 % and more) while the study put Greece in a middle position (30 – 70 % lactose tolerance). In Italy and Turkey, however, less than 30 %

The "Mediterranean" region of our sample includes Italy, Spain, Portugal and the Balkans. Obviously, the small number of observations in Table 4 indicates that more work is to be conducted on the Mediterranean region in the future. For the early Middle Ages, the data available are quite abundant.[83] After the 12th century, height data become scarcer, as bones in cemeteries were more often lost or mixed with bones from later epochs. From the 17th and 18th centuries onwards, archival (written) sources are available which provide much larger sample sizes, while at the same time posing additional selectivity and truncation problems (see Komlos 2003). Lastly, because the period from the 18th to the 20th century is relatively well studied, we focus mainly on earlier centuries here.

Our sample consists of 2938 female and 6539 male height measurements which are rather equally distributed among all major periods. [84] Only for the 17th and 18th centuries, an insufficient number of cases for women is available (12 and 0, respectively). A large proportion of the total 9477 height measurements were aggregated by the excavators and original investigators. Wherever possible, we collected disaggregated figures. Thus, our final database is comprised of 2972 different height measurements, after discarding extreme heights (<145 cm, > 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

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were classified as lactose tolerant (see Mace et al. 2003). Yet 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 they train their intestinal bacteria to live in a milk environment. Even many South Koreans today consume some milk, using this method of permanent training. We thank Barry Bogin, Anthropology Department of the University of Michigan/ Dearborn, and S. Pak, Seoul National Univ., for sharing information on this.

[83] Koepke (2002) extensively discussed the estimation of height from cremated bones for the period of ancient Rome.

[84] 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: see e.g. Mays (1995a).

middle of a century. We experimented with estimation techniques granting smaller weight to imprecisely-dated observations or discarding them completely, but the main results remained robust.[85] Because of these data limitations, our units of analysis are restricted to entire centuries. We organized all heights by century of birth and discarded such individuals who were still in the process of growing (< 23 years).[86] Heaping and truncation did not play a large role, as is illustrated by the rather normal distribution of heights (Figures 6 and 7). 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.

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

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[85] The same applies to age estimates.

[86] We also discarded old individuals (> 59 years) and included an "age 51-59 "–variable in the beginning, because one earlier commentator pointed towards a possible selection bias due to osteoporosis, as this could have the effect that bones could be less likely to survive over the centuries (but this would be a minor effect). We therefore used a dummy variable to control for any potential bias, but it turned out to be insignificant and is therefore not reported in the table. In contrast to data based on living heights, however, by using long bones we do not have to take into account the biologically determined shrinking process experienced by older people, since bodies shrink due to the compression of the disks between the vertebrae (as well as poor posture), while the femur does not change significantly with age. Some compression of joints occurs in the lower half of the body as well, but the length of the femur does not change enough to make a difference: Almost all of the age-related loss in height is derived from the collapse of the intervertebral disks, and the collapse of the vertebral bodies in the case of some individuals. Changes in femoral length terminate with the fusion of the epiphyses. The only way to achieve changes in length thereafter would be through a remodelling of the articular surfaces, or by bending the bone itself. Both of these changes would only be discernible under rare pathological conditions, such as severe osteoarthritis, femoral fractures, and perhaps osteomalacia. We would like to thank Barry Bogin, Rick Steckel and Phil Walker for their friendly communication in this regard.

FIGURE 6
MALE HEIGHT DISTRIBUTION, ALL CENTURIES
Source: see Table 4

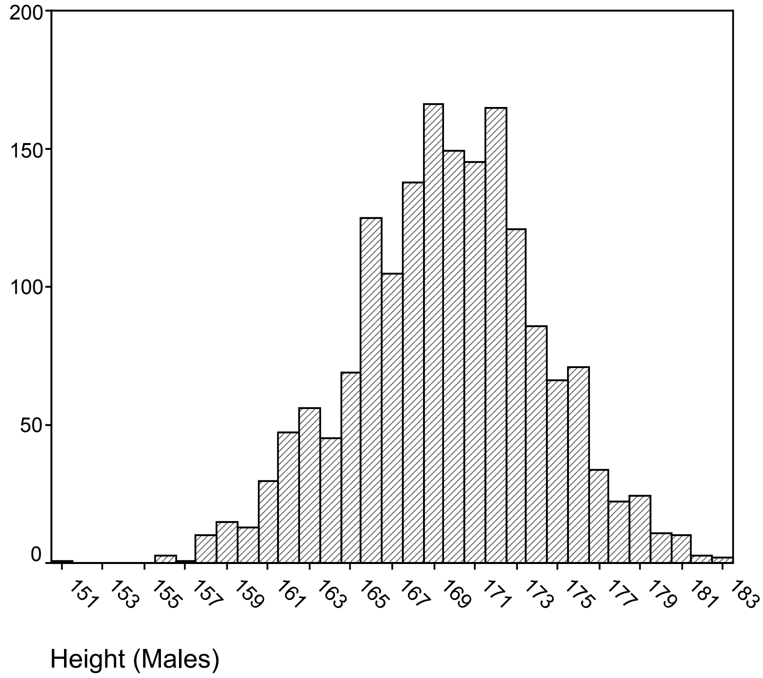
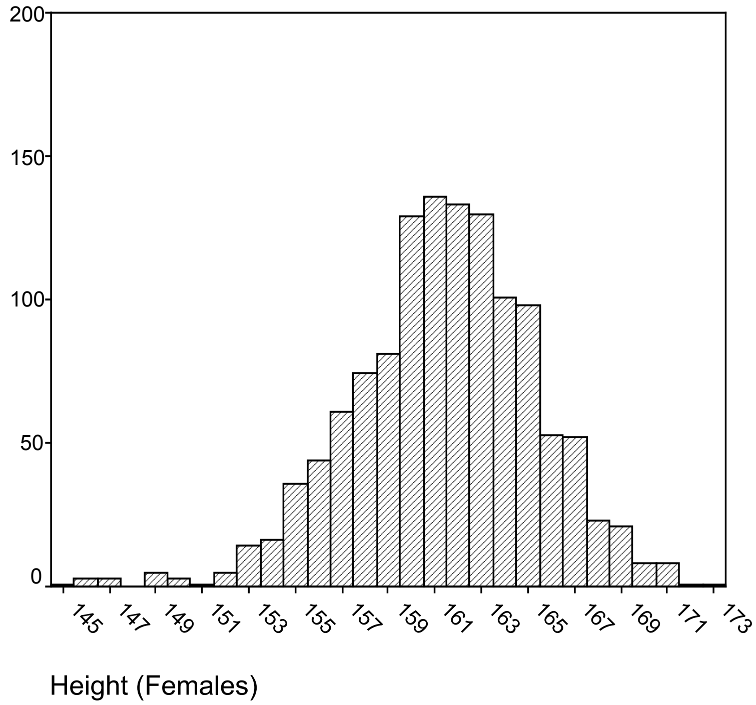


FIGURE 7
FEMALE HEIGHT DISTRIBUTION, ALL CENTURIES

Source: see Table 4



information was also derived from complete skeletons; with such measurements, we relied on the original author's judgment 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).

We also used heights that were estimated using "knight's" armours from 16th and 17th 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.[87] Fortunately, our data set contains a sufficient number of archaeological height measurements for those centuries, which can be compared to the armour data (the latter covering 12 height numbers or 198 individuals for the 16th century, and 4 height measurements or 105 individuals for the 17th century). The simple average difference between armour height data and other height data was only about 0.3 cm for those periods, and thus insignificant. Once we controlled for social, regional, and inter-temporal influences in a multiple regression, we even found the difference to be only 0.17 cm (statistically insignificant, results not shown here). We therefore decided that any adjustment for armours should be omitted, since that might introduce an artificial measurement error.

[87] Note that most knight's armours originated in fact 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 armours probably stem from males from all social strata, who were hired and received salaries as soldiers.

4.1.3. Determinants of Adult Stature and Estimation of Height Trends

Since our height data are not distributed perfectly equally over regions and over time, we run in a first step a number of regression analyses with temporal (century), regional, and other dummy variables. In a second step, we apply panel data analyses on the aggregate level, in order to explain the development of heights in the various regions of Europe.[88]

Quite clearly, studies based on archaeological data cannot take into account the same number of cases as studies which rely on written sources (those being available from the late 17th century onwards). Nevertheless, we are convinced that invaluable lessons can be learned from a study which brings together a variety of archaeological data and other information, albeit existing limitations. In order to avoid overrating the implications of our data, we should thus also address potential caveats. Measurement errors may occur for a number of reasons. Firstly, as is the case for archaeological findings in general, the dating of skeletons is not always precise. Secondly, excavators were not always able to determine the migrant status (ethnicity) or social stratification attributes of buried individuals. Even gender might be misclassified in some cases – although the latter measurement error should be randomly distributed, given the balance of gender frequencies for the various periods and regions; besides, we accounted for it by marking uncertain cases and performing regressions with and without these observations, obtaining no difference at all in the results. To a certain extent, such sources of measurement error can be controlled statistically, as will be shown below. In addition, some of these measurement problems are less severe for the late Roman

[88] In order to test the robustness of our first-step results, we ran the regressions with aggregate and disaggregated data (disaggregated by region and gender; gender-disaggregated regression not reported here).

Empire and the early to high medieval periods, for which our sample includes a relatively large number of cases. For the late Middle Ages and the early modern period, however, the small number of cases available to us renders the resulting estimates substantially less reliable.

In what follows, we will discuss the variables used in our research, as well as their potential effects on height. First of all, social status is an important variable in this regard, since many studies on the 18th to 20th centuries have found height differences of typically 2-4 cm between adults from lower classes and adults belonging to the middle and upper classes (see e.g. Baten 2000).[89] In our data set, we relied mostly on the original studies' classification schemes. Thus, unless the skeletons found were of higher social rank, excavation reports did often not consider their social status worth mentioning.[90] Therefore, we assigned dummy variables to the categories of middle and upper class origin only, leaving a "lower or unknown" group for the constant**,** which in turn implies that we should not over-interpret the coefficient of the social status variable. This variable is not only of importance in itself, however, but is also relevant in controlling for social composition and potential social selectivity when analyzing height trends. Although the bulk of our measurements stems from burial sites where all social strata are represented, we took great care of excluding the influence of potential social selectivity on height trends to the maximum extent possible. In the aggregate analysis, we find that overall middle and upper class heights exceeded the residual group by 0.6 cm (col. 2 and 3 in Table 5), a result which was at best marginally significant, however (p-value 0.11).

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[89] The latter two are usually taken together, because the share of the upper class is very low, and even the share of the middle class is not very high in most historical populations.

[90] In some cases, burial objects that would have indicated higher social status were certainly lost or robbed. This means that middle and upper class status is probably somewhat underreported.

Another challenge we faced was to obviate any potential bias due to varying burial customs. In general, the excavation reports incorporated into our sample referred to entire populations as opposed to just a few noble men's graves. When surveying the archaeological literature, we found no hints on burial customs which could have biased our results significantly, as rich and poor graves seem not to have been exposed to different preservation conditions on average. As another strategy we pursued to examine this important aspect further was to compare different regions of Europe regarding their burial customs, expecting their height trends to be only imperfectly correlated. However, our investigations revealed similar trends for the different regions – except for a plausible decline in North-Eastern European heights (Little Ice Age). We concluded that time trends were not substantially influenced by local burial customs. Moreover, we took a closer look at some individual sites which were both characterized by a homogenous culture and burial tradition, and had been settled more than one century, finding the previously observed trend confirmed in most cases.

Another factor which is to be controlled for is migration. While some anthropologists are convinced that genetic height potentials play a substantial role in determining the average height of a populace, others have serious doubts whether genetic height potential can really explain any variation in average heights (Bogin 1988; Mascie-Taylor and Bogin 1995).[91] Anthropometric historians have found environmental

[91] To be sure, this refers to aggregated height. Individual height is clearly influenced by genetic factors. It is not fully clear whether some very isolated populations such as the Pygmies have a different height potential. In addition, Japanese people are sometimes outliers in regressions (although their strongest height increase after World War II correlates well with the introduction of dairy products). Maya children who were brought to the U.S. and enjoyed good nutrition converged rapidly to North American growth paths – but never fully (Bogin 1991). Earlier views that North-Eastern French are genetically taller than other Europeans were recently rejected: once milk production and income are controlled for, the height difference disappears. The finding that Dutch people were particularly short during the nutritional crisis of the mid-19th century and that Indians (of Asian origin) and Central Asian nomads were particularly tall,

circumstances during bodily growth to be the most crucial factor for determining the variation in mean height. Two points are particularly important in this context, the first one being that most migrants were exposed to different environmental conditions than the autochthonous population during their first years of life. For instance, had they been born in a Northern or Eastern European agricultural environment and migrated to the Mediterranean region later on, we would expect them to be significantly taller than Mediterranean ‘natives’. Secondly, if the immigration rate was high enough, agricultural production techniques might have been transferred to the target region, provided that they turned out to be efficient in the new environment. If those techniques concentrated on cattle farming, there was a strong positive influence on height. We know that the most important migration streams over the period under study moved from the Mediterranean region into Central and Western Europe between the first and third century A.D., while there was also significant Germanic (and other) migration from Northern Europe to Eastern, Central and Southern Europe, as well as to the British Isles between the fourth and sixth centuries.

As our results indicate, migrants from the Mediterranean region to Central Europe (mainly Roman soldiers and officers, as well as administrative staff) were on average 4 cm shorter than the rest of the population (Table 5, col. 4). Note that the only information available to us for the purpose of identifying this group were Roman burial objects such as *balsamaria* (flacons) and/or lamps (both necessary instruments for traditional Roman burial ceremonies), so that the respective cases in our sample are mainly representative of a core group of migrants who placed particularly strong emphasis on Roman customs. However, skeletons which could be identified as “Germanic migrants” were not significantly different from Eastern Europeans. Also not

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also contradicts the explanatory power of genetic factors for mean height (Steckel and Prince 2001).

TABLE 5

FOUR REGRESSIONS: DETERMINANTS OF MALE AND FEMALE HEIGHTS IN THE THREE PARTS OF EUROPE

1	2	3	4	5	6	7	8	9
Region	**All**		**Central-Western Europe**		**Mediterranean Europe**		**North-Eastern Europe**	
Constant	159.51	*0.00*	159.78	*0.00*	161.13	*0.00*	160.13	*0.00*
Status mid/high	0.58	*0.11*	0.45	*0.35*			0.32	*0.58*
Migr. Mediterr.	-3.87	*0.01*	-4.00	*0.00*				
Migr. Germanic	0.75	*0.35*			1.63	*0.24*	-0.20	*0.89*
Male	8.20	*0.00*	7.97	*0.00*	7.72	*0.00*	8.62	*0.00*
Centuries:								
1	1.00	*0.02*	1.42	*0.03*	-0.55	*0.74*	0.59	*0.60*
2								
3	1.04	*0.00*	1.12	*0.01*	-1.20	*0.39*	1.51	*0.19*
4	0.17	*0.63*	0.20	*0.60*	0.46	*0.85*	-0.95	*0.44*
5	1.44	*0.00*	1.47	*0.01*	-0.38	*0.83*	1.76	*0.20*
6	2.80	*0.00*	2.92	*0.00*	1.30	*0.47*	2.88	*0.06*
7	1.99	*0.00*	2.24	*0.00*	0.31	*0.88*	-0.43	*0.75*
8	1.05	*0.01*	0.30	*0.51*			2.20	*0.06*
9	1.24	*0.00*	1.32	*0.02*	0.78	*0.72*	1.06	*0.35*
10	0.86	*0.17*	1.21	*0.15*			0.37	*0.78*
11	1.61	*0.00*	1.57	*0.25*			1.44	*0.19*
12	1.90	*0.00*	-0.94	*0.59*	-0.49	*0.75*	1.86	*0.09*
13	-0.14	*0.78*	0.84	*0.36*			-0.59	*0.61*
14	1.22	*0.02*	2.68	*0.01*	4.54	*0.06*	0.34	*0.77*
15	0.90	*0.32*	3.61	*0.02*	0.61	*0.75*	-2.47	*0.15*
16	1.64	*0.00*	1.57	*0.01*	6.25	*0.06*	2.61	*0.21*
17	-0.51	*0.39*	0.99	*0.23*			-1.97	*0.12*
18	1.62	*0.19*	2.09	*0.10*				
Rhine, South	0.71	*0.01*	0.48	*0.10*				
Rhine, North	1.14	*0.01*	0.62	*0.16*				
UK	-0.90	*0.08*	1.09	*0.00*				
Northern Eur.	2.21	*0.00*					1.65	*0.00*
Eastern Eur.	0.78	*0.00*						
Mediterranean	-0.01	*0.99*						
Adj.R^2	0.54		0.51		0.63		0.61	
N (original)	9477		5303		542		3632	

P-Values in columns 3, 5, 7, 9 in italics. The constants refer to a Bavarian/Austrian (col. 2-5), a not further specified Mediterranean (col. 6/7), and an Eastern European one (col. 8/9). We also included a dummy for those aged 51-59 in order to control for possible selection bias due to osteoporosis (see above), but it was never significant. The weighted number of cases (adjusting for aggregated observations using square roots) is for the three regions 1896, 86 and 990, respectively.
As we are working with grouped data, special estimation problems could arise. See, however, appendix 1, where we demonstrate that even the exclusion of observations with N > 1 does not change the results substantially.
Source: see Table 4

statistically significant, but economically relevant was their coefficient in the "Mediterranean" regression: Germanic migrants who died in the Mediterranean region were 1.63 cm taller than the autochthonous population.

As our intention was to provide a height trend estimation on the basis of all the height data available to us, we pooled male and female heights together and controlled for the gender difference by using a dummy variable, assuming that the secular height trends of both genders were moving more or less in the same direction (this assumption will be tested in further depth below). It is interesting to note that the largest difference between genders was found for the least densely populated North-Eastern regions of Europe, with the smallest difference prevailing in the Mediterranean region.[92]

Which regional differences can be observed when using the dummy variable? The tallest heights were to be found in Northern Europe; Eastern Europe ranked lower in comparison, on a similar level as the Northern Rhine region. Relatively short heights dominated in the Bavarian/Austrian, Mediterranean and British regions, and in the latter especially during the Celtic-Roman period.[93] Why these regional differences occurred is a question which will be addressed in more detail below. Finally, time dummies allow the formulation of a secular height trend, after controlling for the regional, social, age- and migratory composition of the sample.

Thus, which overall height trend evolves when considering the century dummies of column 2 of the previous regression table (Table 5)? Over the period of the Roman Empire, heights did not increase at all (Figure 8), a finding which stands in contrast to the common view that living standards and especially purchasing power increased during the Roman Empire, due to economic growth and the protection of the *pax*

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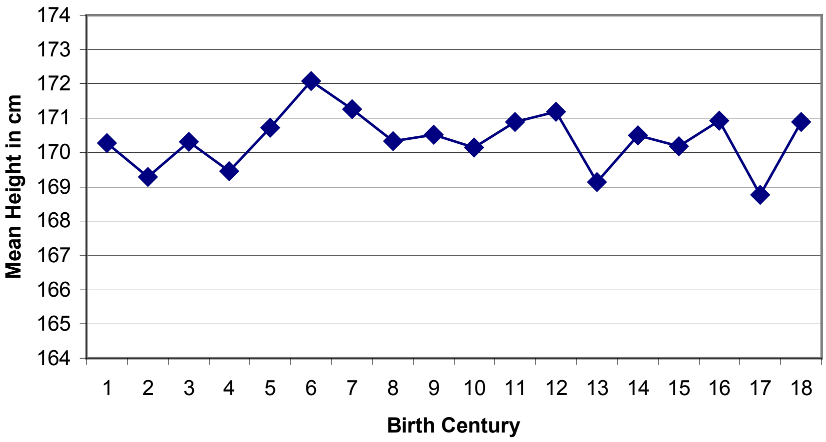
[92] For a detailed discussion of gender dimorphism see chapter 4.4.

[93] The relatively high R-squares should be regarded with caution, as they stem mostly from the inclusion of gender dummies.

Romana. What is similarly remarkable is that heights increased further in the fifth and sixth centuries, even after the breakdown of the empire in the West.

FIGURE 8
HEIGHT DEVELOPMENT, 1^{st} TO 18^{th} CENTURIES
(IN CM, MALE AND FEMALE)
Source: see Table 4. The level of heights was adjusted to average European male heights (using the regional coefficients and weighting them with sample weights).

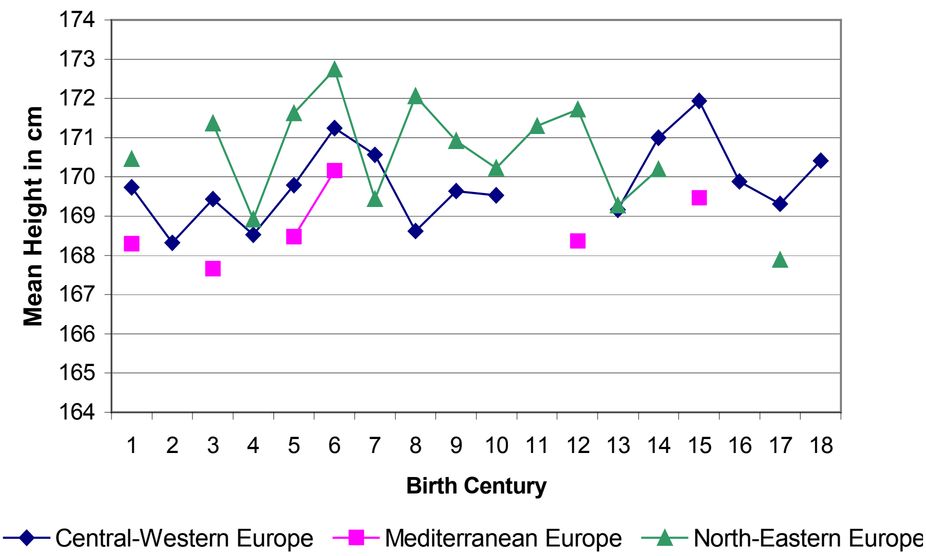


As a result of population growth and adverse climate in the subsequent period, however, adult stature declined again until the 10^{th} century A.D. Thereafter, the medieval warm period of the 11^{th} and 12^{th} centuries was characterized by a favorable height level. Heights collapsed again during the 13^{th} century, but rose between the 14^{th} and 16^{th} centuries, possibly due to better nutritional conditions. The 17^{th} century was a period of nutritional crisis. However, the estimates for the 16^{th} to 18^{th} centuries are less reliable, as their underlying number of cases is relatively small.

If we compare our skeletal measurements with other height estimates based on military archival sources, we find that skeletal male heights in the 18^{th} century moved in the same range as, but were on average slightly higher than military heights: our values of 168 – 170 cm (17^{th}/18^{th} c.) correspond with the 164 and 172 cm estimates of the military samples, respectively.[94] 17th century military heights were even lower. Thus, a height increase between the 17th and 18th century is supported by our skeleton height trend (see Komlos 1989, 2003).

How can we assess further whether this series reflects real height development? One counter-checking strategy would be to look at disaggregated data by region and gender. If the disaggregated series moved in a similar direction when expected to do so, while deviating only where this appeared justifiable from a theoretical perspective, this would consequently lend support to the validity of our overall height trend. When thus tested, the development of heights in the Mediterranean, Central-Western European and North-Eastern European regions turns out to be quite similar (Figure 9), as is the case with the decline in the fourth century in Central-Western and North-Eastern Europe, the

FIGURE 9
HEIGHT DEVELOPMENT BY MAJOR REGIONS (IN CM)
Source: see Table 4



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[94] The congruence of bone evidence (168-170) and military evidence (164-172) is either good or poor, depending on how the military evidence is interpreted.

astonishing increase in the fifth and sixth centuries and the low marks in the 13^{th} and 17^{th} centuries. The reported increase in the 14^{th} century and the high value during the 15^{th} century can also be observed in more than one region. Deviations occur for the seventh and eighth centuries. While the North-Eastern height series remains at first at a constant level above all others, it loses its leading role from the 13^{th} century onwards. In the 13^{th}, 14^{th} and 17^{th} centuries, Scandinavians and Eastern Europeans became shorter than the British, Dutch and other Central-Western Europeans.[95] It might have been the case that Northern and Eastern populations suffered exceptionally during the Little Ice Age (14^{th} – 18^{th} c.), whereas they benefited from the climatic maximum of the 11^{th} and 12^{th} centuries. In contrast, the maritime climate of the Netherlands, the British Isles and Western Germany allowed for a more favorable nutrition during the Ice Age.

In a similar vein, male and female heights moved in an overall comparable direction (Figure 10). Their common maximum during the sixth century may have been caused predominantly by the female height series, but irrespective of that, both series reached a maximum at this point in time and another high value during the 11^{th} and 12^{th} centuries. During the high Middle Ages, females lost some ground in comparison to males. While the increase of female heights during the 15^{th} century is supported by only 18 observations, the positive situation of the 16^{th} century relies on 118 cases. Women might have benefited from a change in social roles during the Renaissance period, whereas gender discrimination was particularly severe during the "Dark Ages" when women's social position deteriorated, as archaeologists have demonstrated on the grounds of other sources (see Ulrich-Bochsler 1996).

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[95] Allen (2000) finds a positive real wage development in the early modern period for the British urban case. The number of observations is (quite) comparable when combined into large regions (see Table 2: 13^{th} (c.: 82 to 195 cases), 14^{th} (c.: 553 to 120 cases), 17^{th} (c.: 80 to 58 cases)).

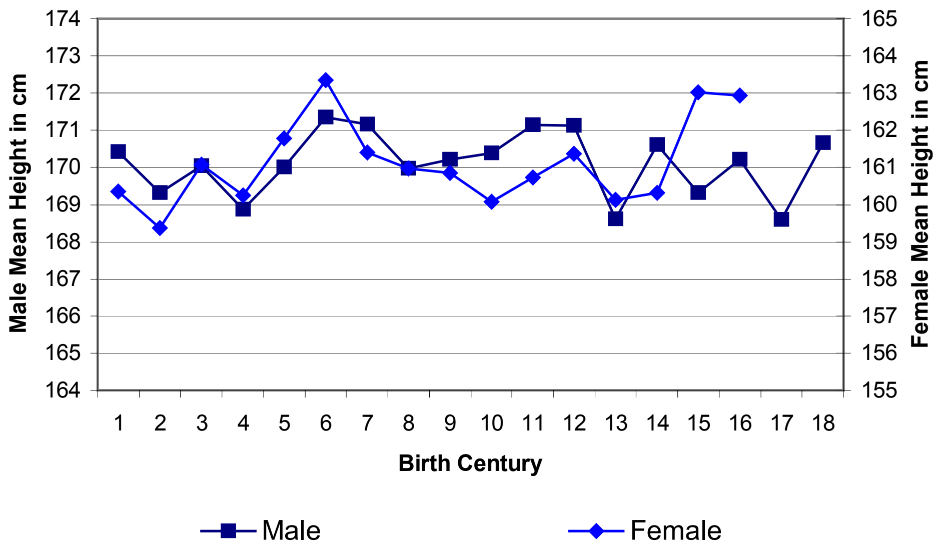
Are female heights in our sample characterized by a higher variance between birth centuries than male heights? In the following, we consider the average height's coefficient of variation by birth century (please note: this does not correspond to the CV of individual height distribution). The overall coefficient of variation is 0.68 for females and 0.49 for males.

Biologists would expect female bodies to be more robust under adverse conditions (see e.g. Ortner 1998), hence variability should be lower. As our results indicate, however, gender discrimination might have had a stronger impact on height than biological factors. This finding correlates with the argument that the position of women

FIGURE 10

HEIGHT DEVELOPMENT BY GENDER, 1st TO 18th CENTURIES (IN CM)

Source: see Table 4



deteriorates in relative terms when times are getting worse (Klasen 1996). We have to admit, however, that the higher variability established here might at least in part be influenced by the lower number of female observations.

4.1.4. Potential Economic Determinants of Mean Height in the Long Run

In the following, we perform an exploratory analysis of the potential influence of a number of variables on stature by century and region.

4.1.4.1. Land per capita and Urbanization

Was Malthus right with his argument that land is the limiting factor of human development? Did population growth tend to outpace food production as a result of decreasing marginal product until culminating in a major demographic catastrophe? On the eve of a mortality crisis, Malthus would expect a decline in the nutritional status of the population under risk, a relationship which will be tested below. In the aftermath of mortality crises, in contrast, nutritional quality might ameliorate as a result of the enhanced availability of agricultural land. Thus, to give just one example, cows and other forms of farm capital were not reduced to the same degree as the population during the major plague epidemics of the 6^{th}, 14^{th} and 17^{th} centuries.

Apart from the effect of land availability, increasing urbanization might have separated urban dwellers from *de facto* untradeable goods such as milk. In addition, infectious diseases could spread more easily in urban centers. In this study, we measure population density as a weighted average of the country estimates by McEvedy and Jones (1980), while amending and improving them wherever possible with later and more detailed country studies (such as Wrigley and Schofield (1981); Dupâquier et al.1988; for further details, see appendix 3). We estimate urbanization levels as described in the appendix (based on Bairoch 1976; Federico and Malanima 2004; Allen 2003).[96]

[96] We did not use the superior estimates of de Vries (1984), because they start after 1500 only.

4.1.4.2. Climate

One of the most fascinating topics in long run economic history is the relationship between climate and human living standards. For example, did climatic change cause the demographic catastrophes of the 14th and 17th centuries, as Galloway (1986) has argued (see also Kelly n.y., among others)? Colder winters tended to make food production (especially protein production) more difficult in Central Europe (on the 18th century climate-height effect, see Baten 2002), with a consequential immense impact on human history. Grove (2002) demonstrated how the switch from the medieval warm period (lasting from 900 A.D. up until the early 13th century) to the Little Ice Age, starting in the late 13th century, decreased harvests and protein-production from cattle and sheep.[97] Not only did temperatures decline, however, but since colder winters tended to be correlated with a higher frequency of climatic extremes, consecutive climatic problems created a deadly synergy effect. For instance, cattle epidemics spread rapidly in Northern and Western Europe as early as the 13th and early 14th centuries, killing a large share of the cattle stock. As Grove has argued, the resulting agricultural production decline took place before and simultaneously with the Black Death of the mid-14th century.

Although plague is a highly infectious disease which is only mildly influenced by malnutrition, lower nutritional status might have weakened the immune systems of the European population, thus contributing strongly to the massive population loss of the 14th century. In addition, people often leave their households during famines and start moving around in search of other possibilities of subsistence (Mokyr and O'Grada 2002). The cattle- and fishery-based economies of the northernmost region of Europe

[97] Grain yields dropped between 1220 and 1320, see Grove (2002), figure 2.

suffered most drastically. Thus, Iceland lost most of its population and the European population of Greenland disappeared completely.

The 15th and the first two thirds of the 16th century were warmer again, but the next climatic catastrophe came about in the 17th century. Pfister (1988) described how climatic changes reduced Swiss nutritional status in the last decades of the 16th and during most of the 17th century. While the major share of the population-decline in the 17th century is traditionally ascribed to the Thirty Years War and the hunger and infectious diseases following in its wake, rapid climatic deterioration could have contributed further to the large number of (at least partially) nutrition-related deaths during this devastating war. The interplay between protein malnutrition and disease-related deaths can also help to explain why population figures stagnated or declined even in countries which were not actively involved in the Thirty Years War. Lastly, milder episodes of climatic deterioration during the late 18th and mid-19th century coincided with milder average demographic effects (Grove 2002).

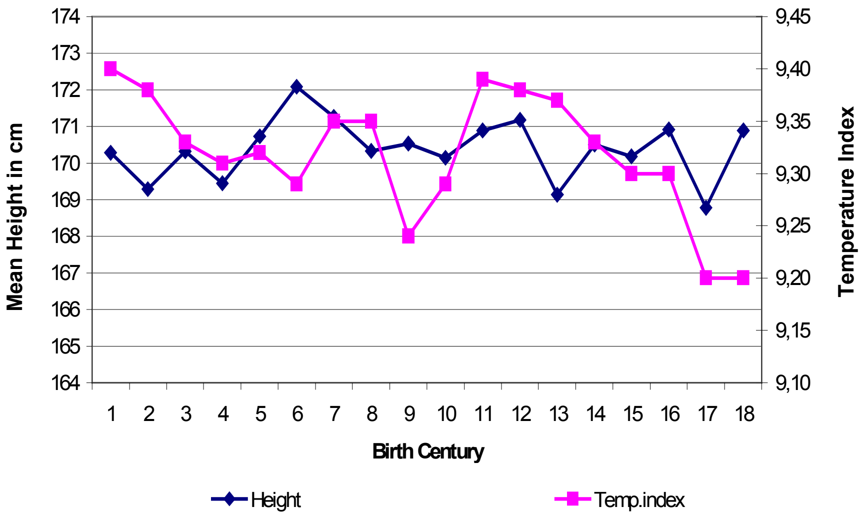
Recent research has brought forth new estimates on climatic change over the centuries by quantifying Alpine and Scandinavian glacier movements, Greenland ice kernels, oak tree rings and lake sediments. All of those series appear to be correlated in general. We mainly used glacier movements as explanatory variables, since the available data go back to the ancient period on the one hand, and might serve as more unequivocal evidence than, for instance, oxygen isotope ratios from Greenland on the other hand (see Heide 1997; Grove 2002, 316). As is emphasized in the literature, however, glacier movements reflect temperature changes with a certain time lag. We therefore calculated the average of glacier movements in the previous and current century. In addition, we corroborated our glacier series with a tree-ring series from Northern Sweden which stretches back to the ancient period as well, and compared both with a shorter tree-ring series from the Alpine area - they moved in accordance (see Huntley et al. 2002, 278).[98]

Our comparison between the height and temperature series yielded some similarities and many differences (Figure 11). The well-documented climatic optimum of the

FIGURE 11

HEIGHT AND TEMPERATURE DEVELOPMENT (1st TO 18th C), BASED ON GLACIER MOVEMENTS AND TREE-RINGS

Source: see Table 4



11th/12th centuries, as well as the lower values before and afterwards are indeed discernible in the height series. Moreover, the low values of the seventh and eighth centuries and the crisis of the 17th century could have been caused by adverse climatic conditions. Important deviations, however, occur for the first to sixth and for the 13th centuries. Either only a weak relation exists, or a measurement error occurred, especially for the early period whose temperature estimates are known to be particularly

98 We experimented with local temperature series for the three regions of Northern/Eastern, Central-Western and Southern Europe, but the differences between the series were extremely small, so that we abandoned this avenue of temperature measurement.

imprecise. In our opinion, the most likely interpretation is that after the breakdown of the Roman Empire, several phenomena increased average height and nutritional status:

(1) as a result of invasions and plague epidemics, population density and urbanization decreased and consumers moved back to the vicinity of nutrient production. Besides, infectious diseases might have occurred less frequently – although this factor is likely to be of secondary importance, as it would have been counter-acted by the disappearance of the famous Roman Public Health institutions, and contradicted by the second occurrence of the plague in the sixth century.[99]

(2) Germanic invaders introduced agricultural methods which emphasized protein production. Even if those methods were not efficient in a Mediterranean context, inhabitants might have adhered to them for a transitory period. In Central and Western Europe, they proved to be efficient as long as population density was low.

Both of these developments might explain why no climate-height relationship can be detected for the first six centuries. The low height-value of the 13th century is particularly interesting. Was it caused by the rapid urbanization of this period (along with more infectious diseases and less milk for rural-to-urban migrants)? Or was it rather a result of higher social or gender inequality? Lastly, is the height variable biased by a measurement error?

One could argue that cold climate was not harmful, but rather beneficial to agriculture in the Mediterranean region, because colder climate might have brought about more frequent rainfall. We accounted for this hypothesis by testing whether our results would change if our small number of observations on the Mediterranean were excluded, yet found the climate coefficient unchanged (the coefficient was 2.74, compared with 2.97 when the Mediterranean was included).

[99] The so-called Antonine plague is regarded as the first one ever to occur.

4.1.4.3. Income

Agricultural income was clearly the dominant source of subsistence over the major part of the last two millennia. To a large extent, it was a function of land *per capita*, land/soil quality and climate. Moreover, the level of income might have been augmented by industrial and service-sector production particularly during Roman times, the High Middle Ages, the 16th century and after the 18th century. We are unable to test this effect, however, because income estimates are completely unreliable for the first millennium, or based solely on urbanization rates and population growth (such as estimates by Maddison 2001).

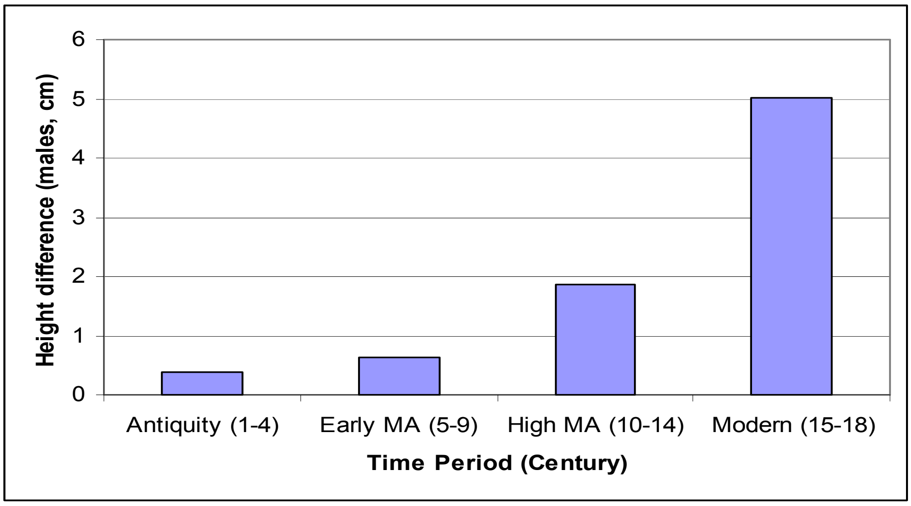
4.1.4.4. Social Inequality

Inequality was identified by previous research as an important determinant of average height (Steckel 1995). If growing income inequality and purchasing power disparity are not accompanied by changes in aggregate real GDP *per capita*, the rich might get richer and the poor get poorer to the same extent. Yet as the rich will spend a smaller proportion of their extra income on additional food, while poor people's already low nutrient level will decrease even further, average height will decline even if average purchasing power does not.

Height data sets allow rough estimates of health inequality (see Baten 2000). Wurm (1985) argued that inequality was particularly low in the early Middle Ages. In fact, social inequality increased dramatically between the early and the high Middle Ages (Figure 12), and again in the 15th – 18th century. This overall trend towards

FIGURE 12
DEVELOPMENT OF INEQUALITY

Source: see Table 4



inequality corresponds well with other studies on income inequality. O'Rourke and Williamson (2002) have confirmed this for longer periods by using rent-wage-ratios, assuming quite reasonably that land-owners were relatively rich while wage earners were relatively poor (van Zanden 1995). We controlled for social inequality by calculating the difference between individuals of middle/higher status and the lower/unknown category, by major periods.

4.1.4.5. Public Health

How did Public Health develop over the last two millennia? Is our conception of the Romans' impressive water-supply technology and especially of the Roman institution of public bathing facilities correct, and did a large share of the population benefit from these?[100] To what extent did hygienic conditions deteriorate after the breakdown of the Roman bath-system? Were Public Health investments perhaps endogenous, being made

[100] In contrast to the generally positive view of Roman baths, Scobie (1986) argued that the bathes were quite unhygienic (e.g. water was rarely changed; it was a meeting point of ill and healthy people).

primarily in times when urbanized and poorly nourished populations suffered more than usual from infectious diseases? Or did the Romans' contacts with distant populations (such as Chinese, Indians, Parthians) lead to the spread of new infectious diseases? In order to answer all these questions and to capture the potentially beneficial effects of the Roman Public Health system, we coded a “Roman Bath” dummy variable as 1 for the Mediterranean region over the first to fourth century A.D., and for Central-Western Europe for the second to fourth century A.D.[101] This specification implies that apart from the Roman hygienic system (which may well have been of great importance for height and health levels), we might also use it to capture other aspects of Roman technology and the imperial economic system. Therefore, we will name this variable “Roman bath or other technology”.

4.1.4.6. Gender Inequality

In our estimation of height by (birth) century, we assumed that gender differentials were constant over time. In the following, we will relax this assumption and control explicitly for higher or lower gender inequality. Our expectation is that higher gender inequality *ceteris paribus* reduces average height, because Osmani and Sen (2003) have convincingly argued that female discrimination affects both girls' and boys' height via their mothers' nutritional status (see also Klasen 2002). We measure the development of gender differentials over time using the dimorphism estimates graphed in Figure 10. However, here we calculate the percentage of height difference relative to the average male height, in order to adjust for possible level effects (Koepke 2002).

[101] McKeown (1955) has argued that medical technology did not play an important role in societies prior to the 20th century.

4.1.5. Results: The Biological Standard of Living in Europe during the Last Two Millennia

A large number of regression models were used in this study: fixed effects and random effects, weighted and unweighted least square, as well as generalized least square with adjustment for autocorrelation and heteroscedasticity (not shown in tables). The following results are robust across these various specifications. Unit root tests or cointegration might not have enough power based on 18 observations over time, but when nonetheless performing the ADF test, the height series for North-Eastern and Central-Western Europe turn out to be stationary.[102] Panel estimation techniques exploit the variation both over time and between cross-sectional units. We present two WLS estimates with regional dummies (equivalent to fixed effects), one of them with period dummies (for antiquity etc.) and the other without controls for unobserved inter-temporal heterogeneity (Table 6 and 7). The results are also robust when time trends are included (insignificant).

Given that we have considerable measurement error in our rough proxies for social and gender inequality, population density and urbanization, it is not astonishing that many coefficients are statistically insignificant. In addition, technological development cannot be appropriately captured over these two millennia, which means that a certain population density in 1800 might have resulted in a different average height than the same population density in 800 A.D. (simple time trends were insignificant, however). Following McCloskey and Ziliak (1996), we will not only focus on statistical, but also on economic significance, comparing the high and low height values predicted by our estimates with results from the 18th and 19th centuries, for

[102] ADF North-East: even nesting the trend (which is insignificant) -5.12 (critical value 10%: -3.24); ADF Central-West: -3.43 (critical value 10%: -3.24) without nested trend, a unit root is rejected at the 5%-level and at the 10%-levels; Mediterranean: insufficient number of cases.

which height differences between 1 and 3 cm are often interpreted as economically significant phenomena (Komlos and Baten 1998, estimated that 1 cm in additional height corresponds to about 1.2 years of life expectancy).

TABLE 6
DESCRIPTIVE STATISTICS

1	2 N	3 Minimum	4 Maximum	5 Mean	6 Std. Deviation
Climate warm	36	9.20	9.40	9.32	0.06
Gender inequality	36	4.14	6.11	5.37	0.5
Urban share	36	1.00	19.30	4.68	4.64
Social inequality	36	0.37	5.02	1.6	1.66
Population density	36	3.75	40.19	11.38	8.33
Valid N (list-wise)	36				

TABLE 7
TWO REGRESSIONS: DETERMINANTS OF HEIGHT

1	2	3	4	5
Constant	144.24	*0.00*	164.37	*0.00*
Climate warm	2.97	*0.52*	0.82	*0.84*
Gender inequality	- 0.31	*0.50*	- 0.29	*0.46*
Urban share	0.16	*0.23*	0.2	*0.14*
Population density	- 0.06	*0.37*	- 0.08	*0.20*
Roman Bath/ Roman Technology			- 2.05	*0.01*
Social inequality			- 0.17	*0.58*
Mediterranean Europe	- 1.66	*0.05*	- 1.67	*0.04*
North-Eastern Europe	1.17	*0.03*	0.89	*0.07*
Antiquity	- 1.68	*0.01*		
Late Medieval Period	- 0.48	*0.52*		
Modern (15^{th} to 18^{th} c.)	- 0.76	*0.59*		
Adj.R^2	0.33		0.38	
N	36		36	

P-Values in columns 3, 5 in italics.
Weighted Least Squares Regression: number of cases adjusted for aggregated observations using square roots. Constant refers to a hypothetical height value for the Early Middle Ages, and Central-Western Europe.1
Source: see Table 4 and text.

Both the regional dummy variables and the period dummy representing antiquity are significant. In the regression without time dummies, the "Roman bath"-dummy becomes significant as well. However, Roman bath technology and especially other technology (e.g. in agricultural terms) were not able to improve height and health quality sufficiently enough to outweigh the negative effects of the Roman economic system, which explains why the coefficient of this variable is negative. We coded it as zero for North-Eastern Europe and Central-Western Europe in the first century, and this variable remains significant if we control the antiquity effect of low heights with another dummy variable (not shown).

What was so different during Roman times, causing people under Roman reign to be shorter than others? One factor in this regard could have been income inequality. Jongman (2000) has argued that Roman wealth and income were distributed extremely unequally. A very small upper-class had an enormously large share of total income at their disposal. This upper class was too small to be captured by our estimate of height inequality, since this measure is only sensitive when the high-welfare group represents a substantial proportion of the population. Inequality of heights is typically lower if rural areas are dominated by subsistence farming, including milk production. If subsistence farming is typical, even the poor can consume some perishable products such as milk and giblets, whereas the higher market integration during the Roman period might have reduced non-market entitlements to such products. In extreme cases, the poor became vegetarians. In addition, being a provincial subject in a large empire governed by a foreign elite speaking a foreign language typically leads to perceived or actual income losses, and a smaller supply of public goods such as Public Health (like quarantine measures against infected subjects etc.). Finally, due to contact with Persia, Asia etc., new infectious diseases could have been brought to Europe, which were priorly unknown (although this should apply even more to the period of the Crusades and the contact-period of the 16th century).

All other variables are statistically insignificant, but there is some indication of the expected outcome that warmer weather is favorable for harvests and protein production in the relevant range, which in turn increase height. The difference between the two standard deviations of our climatic series is 0.12, with the difference between minimum and maximum being 0.20 - values which can be interpreted as “good” and “bad” climate. The coefficient of the more appropriately specified model in Table 7, column 2 is 2.97. The difference between “good” and “bad” climate amounted therefore to about 0.4 cm in height, with the difference between the extremes amounting to approximately 0.6 cm. Both values are at the margin of being economically significant (if period dummies are included). The tall stature of North-Eastern Europeans in the warm 11th/12th century and the subsequent dramatic decline in height lends further support to the importance of this variable.

Population density comes closest to statistical significance; in unweighted regressions, the p-value is even as low as 0.15 (not shown in table). This suggests that a lower population density is advantageous for exactly that biological component of the standard of living which was reflected in stature during pre-industrial times, after controlling for large-regional effects and inequality. The analysis of the population density’s economic significance yields a height-effect of about 1.0 cm for the difference between typical “high” and “low” population densities of the time, and 2.2 cm between the most extreme observed values. In the other specification without time dummies, the economic significance of population density would even be enhanced by one third. Interestingly, the sign of the urbanization coefficient is positive once population density is controlled for.[103] Without time dummies, it is even almost significant. The potentially large measurement errors prevent us from hypothesizing too much at this stage, but one could speculate that once the detrimental influence of high population density (which, because of the decreasing marginal product, implies: less protein *per capita*) is removed, the human capital-deepening effects of urban agglomerations on the entire country outweigh other negative effects (such as crowded cities and hygienic problems).

Both gender inequality and social inequality had negative signs.[104] Given that these results are similar to those of many other studies on the 18th to 20th centuries, we tend to attribute fairly large credibility to them. In terms of economic significance, social inequality corresponded to a height-difference of 0.63 cm between high and low, and 0.74 cm between extreme values, whereas the effect of gender inequality was about half as strong. In sum, population density is definitely economically significant, albeit not of statistical significance. Climate, social inequality and perhaps gender inequality are thus all at the margin of being economically significant.

4.1.6. Conclusion

In sum, this study is the first to offer a European time-series of anthropometric estimates over the last two millennia (excluding the last two centuries, on which much research has been conducted already), although with some limitations. Height series are often correlated to various biological aspects of the standard of living (such as longevity), but they do not necessarily capture other important aspects related to purchasing power. To

[103] For the case of the Roman provinces, some authors hypothesized that the urban population was better supplied with food than their rural counterparts.

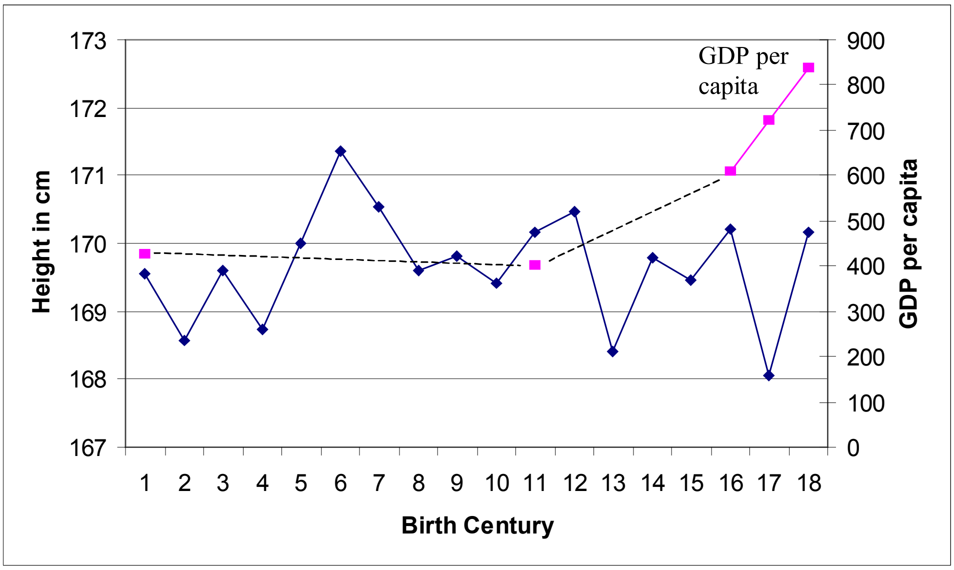
[104] The statistical insignificance is probably not caused by the fact that we controlled for social status in the regressions of table 4. We performed the same estimations without social status, and all results were almost identical.

illustrate this, a Northern Barbarian living in the sixth century was tall and certainly lived relatively long (Herrmann 1987), but in case he was amusement-loving and fond of consumer goods, he would most probably have preferred to live in second century Rome. Yet although we acknowledge this, we are unfortunately not able to measure such aspects of welfare. What we can and do capture, however, are other important aspects relating to height and development which have so far often been underrated.

The overall picture emerging from our study is one of stagnant heights over the past two millennia. We did not find much progress in European nutritional status, not even between 1000 and 1800, a period for which Maddison (2001) and others arrive at growing GDP *per capita* figures (Figure 13, but see Federico 2002, for a critical view.).[105]

FIGURE 13
HEIGHT DEVELOPMENT AND GDP PER CAPITA

Source: see Maddison (2001) and Table 4. Countries are excluded for which no height data is available



[105] In our data, Scandinavian and Eastern European heights even declined significantly. This supports Steckel's (2004) finding of a long-term height decline in Northern Europe. We took care not to use the data analyzed by him again, except for very few heights which we had recorded at an early stage of our project (6 %).

Likely reasons for this divergence are (a) relatively favorable nutritional conditions during the Middle Ages, and especially the climatic optimum of the 11th/12th century; (b) the bias in pre-industrial and early GDP *per capita* estimates in favor of industrial goods consumed by middle- and upper class consumers,[106] a possibility which is also supported by van Zanden's (1999) finding of a "negative link between economic development and the level of real wages" from the beginning of the 16th to the end of the 18th century. Van Zanden also described a decline of *per capita* meat and dairy product consumption. In a similar vein, Federico and Malanima (2004) estimated a downward trend of food consumption in Italy between 1300 and 1860.

Our analysis stretches back to ancient times, measuring living standards during the Roman Empire and the following "Dark Ages". We find that heights stagnated during the Roman imperial period in Central, Western and Southern Europe. In Northern and Eastern Europe, heights might have increased between the first and third century, but fell dramatically in the fourth century. Whether this downward trend contributed to the main Migration Period in the fourth century awaits further exploration. One astonishing result is the height increase in the fifth and sixth centuries, the largest residual in our model. Declining population density in the former provinces after the breakdown of the *imperium Romanum,* and the plague of the sixth century might have played their role in this as well.[107] Noteworthy is also the relative synchrony of the height development in the three regions.

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[106] Note also the potential urban bias of the real wage estimation (rural nutrition and living standard, in contrast, were influenced crucially by non-traded, high-quality proteins (such as milk), see Baten 1999; van Zanden 1995).

[107] We also used plague dummies for the second, sixth, 14th, and 17th centuries and found them to be insignificant. In addition, we tested whether stature was higher in the second halves of those centuries, since the most violent plague waves occurred around the mid-centuries, just as the tall stature of the sixth and 14th centuries might have been caused by the lower population density afterwards. In fact, heights were half a centimeter taller in the second halves of those centuries, which is economically, but no

Does the development of the cattle-bone rate as estimated by archaeozoologists support such a nutrition-based explanation for the fifth and sixth centuries? We find our expectations confirmed that during the imperial period of most extreme population density (but after the climax of power during the first century), large cities like Rome or Pompeii had a very small share of beef and milk consumption (grazing being too costly), and instead substituted meat and dairy products with grain and vegetables – and pork for the richer strata of society. In fact, the impressive cattle share of 28 % in Rome (*Aqua Marcia* excavation) between the first century B.C. and the first century A.D. fell to 7.9 % between the first and second century, reaching 0 % in the second and third century A.D. During the fourth century, the share was still negligible (0.6 % on the Palatine). Only in an excavation on the fifth century (*Schola Praeconum*), a substantial cattle share was found again, after the population density had decreased significantly and Germanic invaders had introduced a new agricultural system (and perhaps taste). Similarly in Naples, the cattle share was low throughout the first up until the third century A.D. (2- 6 %), and only somewhat higher during the fifth to seventh centuries (6 – 9 %). Ostia and other excavation sites display a similar, but more mixed pattern. In general, the second to fourth centuries display low urban cattle rates in Italy.

We constructed potential explanatory variables of height development on the narrow basis of what we know about this early period. We have to emphasize the limitations of those estimates, but a first exploratory look might still generate informative insights. Population density was clearly economically (but not statistically) significant. Thus, decreasing marginal product theories and Malthusian thought cannot be denied for the pre-1800 period. Of marginal significance were climate (warmer temperature being advantageous for nutritional status), social inequality and gender

statistically significant (not shown here).

inequality (both reducing average height). When controlling for population density, urbanization was positive.

Questions about the social composition of the height samples over time as well as other potential biases can only be answered within certain confidence intervals (given the current state of research). However, we would argue that the error probability is smaller than for most other methods which can be applied to the first millennium (such as the urbanization-based GDP estimates by Maddison 2001). If our intention is to study the economic history of Europe in the very long run, anthropometric techniques provide important insights into some (although naturally not all) central aspects of human life.

4.2. AGRICULTURAL SPECIALIZATION AND HEIGHT IN ANCIENT AND MEDIEVAL EUROPE

4.2.1. Introduction

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 especially 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.[108] 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

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This chapter is based on an article published in *Explorations in Economic History*: Koepke and Baten (2008). The concept for the paper was developed jointly, the analyses and writing was equally shared.

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[108] 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).

with a description of how the comparison of several regions yielded mutually corroborating evidence (chapter 4.1.). Lastly, we consider whether the meat trade played an important role during the Roman Empire.

4.2.1. Background

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-Eeast, and the Central-West) for the first to the 17^{th} centuries A.D.

4.2.2. 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 vitamins.[109] 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?[110] A variety of ancient sources suggest that the autochthonous people of *Germania Magna*, beyond the borders of the *imperium Romanum*, used milk as their

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[109] 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.

[110] 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.

basic food – in sharp contrast to the Roman-Italian population.[111] The share of cattle bones among the the three main domestic animal species cattle, pigs, goats and sheep[112] - can serve as a proxy for two aspects. Firstly, population density tended to be negatively correlated with the cattle bone share in ancient times; extensive cattle husbandry was not possible where population was dense.[113] 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).[114] 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

[111] See for example Tac. Germ. 23; Plin. nat. VIII 179.

[112] Sheep and goats are commonly considered as one group in the literature, because the bones of these are difficult to distinguish.

[113] 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.

[114] 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.

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.

4.2.3. 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.[115] 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.[116] His data were grouped according to the major domestic

[115] 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, 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, 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.

[116] King (1999b) includes data from Luff (1982), Lepetz (1996), Peters (1998) etc., thereby creating an

animal species: cattle, pigs, and sheep/goat (the latter were combined).[117] 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 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".[118] "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.[119] 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,

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overview for the entire Roman Empire. This evidence was recently used by Jongman (2007), who based his argumentation on the approximate completeness of the palaeozoological record for Roman antiquity.

[117] 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.

[118] 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.

[119] 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.

and Northern Germany (collected by Luff (1982), Benecke (1986) and others).[120] 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 8).

TABLE 8
REGIONS COVERED BY OUR DATA SET: NUMBER OF ANIMAL BONES
Source: see text

Century	Central-Western Europe			North-Eastern Europe		Mediterranean Europe			Total
	Germany /Austria	**Gaules**	**Britain**	**Danube prov.**	**Barbari-cum**	**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
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**

[120] 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.

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 Mediterranean between the eighth and third centuries B.C (from almost0.40 to approximately 0.17, see Figure 14). 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.[121] 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.[122]

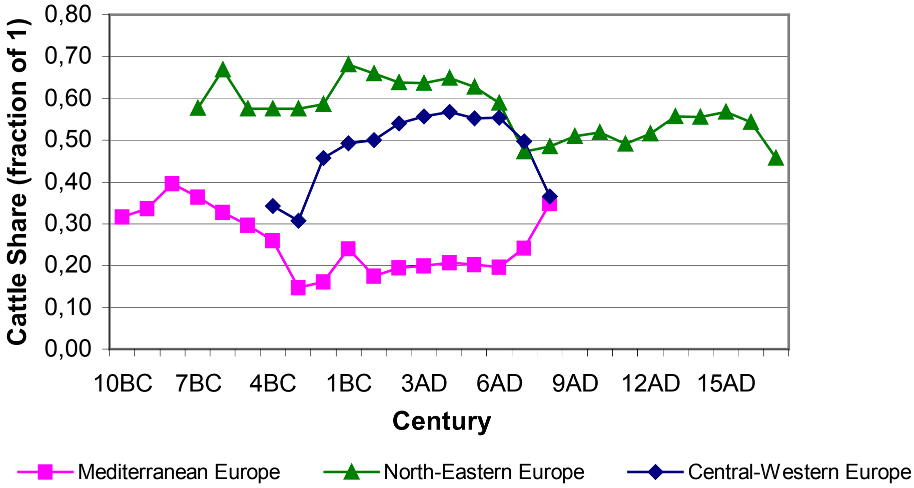
[121] There was only very small variation in between: from the third to the first centuries B.C., the percentage increased slightly. In the eighth century A.D., the Mediterranean average reached its highest share (0.23).

[122] 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 forth 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

FIGURE 14

DEVELOPMENT OF CATTLE SHARES IN THE THREE MAJOR EUROPEAN REGIONS

Source: see text



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 share developed more or less antipodally, whereas the sheep/goat share developed independently and was relatively stable overall.[123]

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

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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.

[123] 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 (2007), 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.

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.[124] The difference in pig bone levels is much smaller (only 1:3 in favor 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.

4.2.4. Taphonomic Biases

Taphonomy is the sub-discipline of archaeology that studies the process of the decomposition of bones and, hence, survival probabilities.[125] 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

[124] 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.

[125] 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).

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 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 with Figures 11a, 11b).[126] In sum, the bias from zooarchaeological counting strategies should be relatively limited.[127] Overall, we follow the conclusion of the recent taphonomic literature that it is crucial to compare data in percentages of animal types, analyzed using one homogenous method.[128] 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 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

[126] Nevertheless, King deliberately excluded data based on MNI or 'bone weight' estimates; see the discussion in Hambleton (1999).

[127] 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).

[128] 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."

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).[129] In general, at least some parts of a consumed animal are preserved and can be analyzed.[130] In the worst case, the bones are comminuted.[131] In discussing possible bone destruction, biostratonomic (relating to the sedimentary history of the fossil) and especially diagenesic (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:[132]

First, cooking may affect the degradation of the bone material due to its softening impact, as it makes the bone more vulnerable to later diagenesis conditions (see for example, 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, 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

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[129] Denys (2002, 469), for example, admits that "taphonomic processes" are "rather complex and still not fully understood."

[130] Personal communication from Dr. Cornelia Becker, Free University of Berlin.

[131] 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).

[132] Naturally, all of these different factors might interact.

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.[133] 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.[134] 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 impact on the share of the three types of large

[133] 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).

[134] 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_2 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.

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.[135] Even after digestion, the specialist can still distinguish from which animal the bone stems.[136] 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

[135] Personal communication from Dr. Cornelia Becker.

[136] Hyenas are the only exceptions.

material from a wide range of settlement types, this should not lead to a significant bias towards one particular species.

(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.

4.2.5. 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 4 in chapter 4.1.). 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 4). 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.[137] 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.[138] 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 6 and 7 in chapter 4.1.). 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' judgment and adjustments (typically, for instance, 2 cm

[137] The so-called primary deficit of females is common for prehistoric and ancient populations (Mays 1995a).

[138] The same applies to age estimates.

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).

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.[139] 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.[140] The resulting height time

[139] 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.

[140] 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 forth 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

series is given in Figure 8 (see chapter 4). 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 9 and 10, see chapter 4.1.). For example, we expected a decline of heights in Northern and Eastern Europe during the Little Ice Age (14^{th} -17^{th} centuries A.D.) because of the extreme impact of the climatic change on

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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 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.

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 2004a). Female mean height is by nature always lower than male height. However, female growth can also be inhibited by the discrimination of females (Figure 10). During the Middle Ages, female heights were even 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 chapter 4.1.).

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.[141]

[141] 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 chapter 3.3.

4.2.6. Results: Agricultural specialization and height in ancient and medieval Europe

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 above.[142] Here, we discuss estimates with regional dummies (equivalent to fixed effects) and period dummies.[143]

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,

[142] For as many centuries as were covered by our animal bone data. All time information refers to A.D. values from here.

[143] 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 (2005b) 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 Period. 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.

increasing costs of population density).[144] 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 9)? 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 9), as well as the cattle share variable, our indicator for specialization on milk and beef production.[145] 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.

[144] 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.

[145] The reference value is 'Central-Western Europeans living in the early Medieval Age'.

TABLE 9
FOUR REGRESSIONS: DETERMINANTS OF HEIGHT IN A PANEL OF EUROPEAN REGIONS AND BIRTH CENTURIES

1	2	3	4	5	6	7	8	9
Constant	86.21	*0.12*	154.90	*0.01*	148.00	*0.00*	172.10	*0.00*
Cattle share	10.83	*0.05*			7.01	*0.09*	3.23	*0.09*
Log Land per cap			1.53	*0.01*	1.26	*0.03*	1.08	*0.03*
Gender inequality	0.10	*0.90*	-0.63	*0.30*			-0.27	*0.58*
Climate warm	8.37	*0.17*	2.25	*0.71*	2.23	*0.68*		
Mediterranean Eur.	2.68	*0.17*	0.12	*0.86*	2.29	*0.10*		
North-Eastern Eur.	0.66	*0.33*	1.08	*0.05*	0.68	*0.21*		
Antiquity	-1.85	*0.03*	-0.48	*0.41*	-1.24	*0.05*		
High-Middle-Ages	-0.84	*0.29*	0.67	*0.41*	0.21	*0.78*		
Adj. R^2	0.58		0.66		0.69		0.41	
N	25		25		25		25	

P-Values in columns 3,5,7,9 in italics. Statistically siginifcant coefficients marked grey underlayed.
Weighted Least Squares Regression: number of cases adjusted for aggregated observations using square roots. Constant refers to a hypothetical height value for the Early Middle Ages, and Central-Western Europe.

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^2s 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 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 centimeters 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 10). 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.

TABLE 10
DESCRIPTIVE STATISTICS

1	2 N	3 Minimum	4 Maximum	5 Mean	6 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 observation for which sufficient height and bone data, plus values for all explanatory variables were available, are: Centre/West: 1^{st}-8^{th} century; Mediterranean 1^{st}, 3^{rd}, 5th-6^{th} centuries; North-East 1^{st}, 3^{rd}, 5^{th}-14^{th}, 17^{th} centuries.

4.2.7. 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 (see also Koepke and Baten 2007). 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 judgment 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 labor-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:[146] 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).[147] 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 3rd molar eruption) is

[146] On the methods, see also McCormick (1992); for an overview of the literature, see Wilson (1994).

[147] 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.

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).[148] 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 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, for example, 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

[148] 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.

previous clear milk orientation.[149] 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 autochthonous 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 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 (for example, 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, Pìgiere 2004).

[149] 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.

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).

4.2.8. 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.[150] 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

150 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.

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 average population in the ancient economies.[151] In general, we can assume that animals were consumed where their bone remains are excavated. Therefore, the animal bone material of a region does providence evidence on the composition of the nutrition of the people of in a given region, as we have claimed.

4.2.9. 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 urbanization 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

[151] 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).

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 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, autochthonous 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.

4.3. NUTRITIONAL STATUS OF PRE-HISTORIC AND HISTORIC EUROPE

4.3.1. Introduction

The mean height of a population is a very important proxy for human nutritional status, and therefore welfare. This finding is independent of time, but of special importance for pre-modern studies, as for the ancient periods there are no adequate written sources to provide data on aspects of welfare. So how did the mean height as proxy for nutritional status, and therefore the welfare of pre-historic, ancient and early historic Europeans actually develop over time? Which determinants caused worse, or enhanced nutritional status during these periods?

Up until now, anthropometric research on the nutritional status concentrated on periods for which written sources are available and so allowed quantitative analysis.[152] If one wants to study the nutritional status of populations dating in earlier periods, an interdisciplinary approach is necessary. This is because all data (height data, as well as data on its determinants) stems from excavations and archaeological work.[153]

For the European case in the current paper, this interdisciplinary approach is utilized, to enable a long run overview on the development of mean height beginning as far back as pre-historic times. This includes data dating from the early Iron Age and pre-Roman

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This chapter is based on a working paper: Koepke (2008a).

[152] There are a few written sources from early history, but those are locally and temporally limited, and therefore not really informative, and far from quantifyable.

[153] Despite certain limitations of the estimates due to the lack of data which is unavoidable, for study periods without quantifyable written data, one can be certain that the utitilzed methodology can engender interesting findings in other contexts as well.

Latène Period (and approx. parallel Elbe-Germanic Jastorf-culture and east-Germanic Przeworsk-culture), and the following periods. This allows one to examine, for example, possible changes in nutritional status due to the expansion of the *imperium Romanum*. The study comprises European data from the eighth century B.C. to the 18th century A.D.

In this study, we tackle questions such as: how important were periods of war or epidemics for changing mean height? How important is population density (land *per capita*) and urbanization? Does the development of the cattle bone rate (as estimated by archaeozoologists) support a nutrition-based explanation for the development in mean human height in ancient and medieval Europe? Are there differences in explaining determinants of mean height (as indicator of the quality of nutrition) in the different periods? Is it possible to detect an impact the expansion of the *imperium Romanum* might have had on the mean height?

In order to answer these questions, the paper is structured in the following way: In the following section a brief introduction is given to the anthropometric measure of nutritional status by using mean height as proxy, followed by the presentation of the data set. In section 4.3.3 the temporal development of human mean height in Europe is described. In the subsequent part an overview of the different possible explantory variables for this development is given. Finally, regressions are conducted to estimate the actual impact of the possible determinants.

4.3.2. Mean Height as Indicator of Nutritional Status

Essential to the present study is the finding of biological and anthropometric research that shows low nutritional status or net nutrition[154] leads to reduced growth during

[154] This is mainly comprised by qualitative and quantitative malnutrition, and/or a detrimental diseases

childhood and youth (to enable the best possible body functions despite the inadequate nutritional status), and thus results in lower adult final height (Silventoinen 2003; Ulijaszek 2006). Consequently, the mean height of a population can be looked at as an indicator of nutritional status.[155] Nutritional status is an important measure of wellbeing; because on the one hand it is determined by living conditions, however, on the other hand nutritional status determines living conditions and thus is a component of welfare (biological standard of living).

Nutritional status determines whether an individual can attain its full genetic height potential or whether final height will be stunted, and therefore, how overall the mean height will develop (for example see: Henry and Ulijaszek 1996; Cameron and Demerath 2002). Chronic malnutrition, such as is found in some underdeveloped countries today, can result in stable height, but at a shorter mean value (Malina 1990). However, a complex run of direct and indirect determinants affects nutritional status. These include the interaction of bio-cultural as well as natural-environmental factors, in terms of their advantageous or unfavorable nature.

The quality of nutritional status has vast, far-reaching effects, because it results not only in immediate consequences for health and body functions during childhood, but also in negative upshots later on in adult life. Any type of extreme malnutrition (under-, or over-nutrition) leads "to severe and costly physical and psychological complications in adulthood" (Bogin 1996b, 21). In the worst case, malnutrition directly or indirectly (if chronic) leads to higher mortality rates and lower life expectancy. Furthermore, malnutrition can have an instantaneous impact on morbidity (Rotberg

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environment, and extent of work stress.

[155] e.g. Eveleth and Tanner 1976; Fogel et al. 1983; Komlos 1985, 1989, 1998; Gopalan 1992; Saunders 1992; Steckel 1992, 1995, 2001; WHO 1995; Floud and Harris 1997; Larsen 1997; Steckel and Floud 1997; Komlos and Baten 1998; Komlos and Cuff 1998; Baten 2000; Bogin 1999, 2001; Bogin et al. 2001; Steckel and Rose 2002; Scott and Duncan 2002; Waldron 2006.

2000; Gluckman and Hanson 2004b)[156], but nutritional status during growth also affects disease susceptibility in adulthood (for example cardiovascular, bronchial and respiratory, or cholesterol and diabetic diseases: see Ulijaszek 1996). Additionally, the formation of physical and cognitive body functions depends on nutritional status during growth (e.g. Grantham-McGregor 1995): this could mean a reduced ability and motivation to be physically and mentally active (for example, hampers the ability to learn, which subsequently can lead to adverse adult living conditions resulting in a 'vicious circle'). The negative effect on health, as well as cognitive and physical strength also persists into adult age. Therefore, nutritional status influences welfare indirectly by inducing and influencing various other important factors, which in turn have an impact on nutritional status again, for example working capability (Stinson 2000). Inadequate nutritional status can even lead to reduced labor productivity and lower human capital accumulation, and because of this, influences economic growth (Fogel 1994).

Final mean height is determined by, and therefore indicates living conditions during the growth period (mainly childhood) of the individuals comprising a population. Nevertheless, one can assume that it reflects living conditions of contemporary adults also, because many of the determinants affect living conditions of adults similarly to that of children. Thus, mean height can be used as proxy for the whole population.

For this reason, the mean height of a population is an ideal proxy to estimate its nutritional status, and a reasonably good indicator for its overall welfare. Since the genetic height potential is relatively similar for the people in Europe (Quiroga Valle 1998) temporal or regional variation in mean height, give us hints on differences in

[156] Therefore increased mortality often is not only caused by 'pure' starvation', but by inadequate diet in combination with diseases that are sometimes also conditional on nutritional quality.

nutritional status.[157] This is especially true for archaeological periods for which no adequate written sources are given, as this is an essential method to analyze living conditions. This possibility is employed in the present study to give an overall, long run overview for pre-and early historic Europe.

4.3.3. Human Height of Pre- and Early Modern Europeans

4.3.3.1. Data Sources

One of the problems that faced us was: how can we obtain data on the mean height in pre and early historic periods? Bone material from excavated cemeteries is the only source to study earlier periods than those for which comprehensive written sources are available. We collected data on 18502 humans, originating from 484 sites in Central-Western, Mediterranean, and Northeast Europe, dating from the eighth century B.C. to the 18th century A.D.[158]

As it is impossible to specify the age of children bones thorougly enough to interpretate height, only adult individuals are used.[159] Those considered are individuals for which the age at death and burial date are known to help reconstruct the birth date, which we need in order to study the development of mean height (see above). Individuals were excluded, if it was impossible to determine the dating precisely; we considered those graves as adequately dated for which the excavators gave at least not more than a horizon up to two centuries. Due to dating limitations it is not possile to

[157] Other than on the personal individual level, differences in mean height are not the results of differences in genetic height potential, but driven by environmental factors: see Bogin (1988), Mascie-Taylor and Bogin (1995).

[158] As part of the study these were standardized to the same longbone-to-height formula to make the observations comparable. In some cases heights of two to 360 individuals were aggregated by previous investigators; thus 5041 separate height numbers are available.

[159] This has the advantage that no additional requirements in terms of truncation techniques need.

organize the data in conventional birth decades, such as in more modern studies; instead the unit of analysis is restricted to the birth century. Furthermore, the study was restricted to humans aged 23 or older at the time of death to be sure that full adult height had been obtained. This is because the growth period can be prolonged until this age due to inadequate nutritional status (see Komlos 1985). Additionally, only those individuals were included which could be sexed satisfactorily.[160] The height data provided by the previous examiners was based on different reconstruction methods; therefore, we had to recalculate the data to make them comparable.

TABLE 11
AREAS COVERED BY THE HUMAN HEIGHT DATA SET
(NUMBER OF INDIVIDUALS)

Century	Central-Western Europe	North-Eastern Europe	Mediterranean Europe	Total
-8	79	26	172	277
-7	8	33	140	181
-6	46	96	236	378
-5	3	10	404	417
-4	6	23	158	187
-3	39	117	34	190
-2	82	81		163
-1	41	37	114	192
1	88	217	211	516
2	1146	174	445	1765
3	407	181	124	712
4	1225	318	566	2109
5	222	125	468	815
6	1387	198	150	1735
7	1477	279	56	1812
8	266	787		1053
9	327	533	12	872
10	153	287	20	460
11	136	1423	51	1610
12	216	462	130	808
13	189	358	4	551
14	242	554	7	803
15	55	17	61	133
16	455	18	4	477
17	66	80	5	151
18	103	32		135
	8464	6466	3572	**18502**

Sources: see Bibliography part 1

[160] This means, that additionally to the "100%-certain sexed" individuals, those ones were included in the data set, which were classified as pretty good/decent exact by the initial investigators.

Finally, we excluded the centuries for which we could collect less than 35 individuals per major region (see Table 11).

The remaining data are given as mean height, both for men and women, and combined using an adjustment procedure for female heights (see chapter 4.1. and 4.2.). The data are separated into three main European regions. These are Mediterranean Europe, Central-Western Europe, and North-Eastern Europe.[161]

4.3.3.2. Anthropometric Method: Regression Analysis

In order to study firstly, the mean height development in the long run from early Iron Age up to modern times, and secondly, to reveal the potential determinants of mean height development we applied regression analysis to bone data (also for the centuries B.C.) for the first time.

To enable the study of European mean height, in a frist step regression analyses with variables for each century (birth century "cohorts") were applied to the data on an individual level with the aim of delineating the development of mean height (based on time coefficients) in the course of the long run (Table 12). This method also brought the possibility to control for social status and migration.[162] Europeans of higher social status

[161] We defined the borders are based on the 'relation' of the regions to the Roman Empire; for details see chapter 4.1.

[162] With respect to the human aspects for determination of mean height, the social status of the individuals in a population is of special importance. It is a coercive determinant in societies with inequality. Because socio-economic status has an important influence on mean height in early-modern times, it even has been used to reveal status differences in past societies (Floud et al. 1990). In fact, mean height can differ even more between different social classes of one historic population than between the elite of different populations (Eveleth 1979; Wolanski and Siniarska 2001). Explanation is that the socio-economic status tends to determine childhood diet and other living conditions (Gunnell et al. 1998). E.g. in the case of ancient Mycenae the difference in stature of high class and lower strata comprised notable 6 cm, which Angel (1984) explains with royal nutrition including "more meat protein than the average citizen got" (66). Migration might determine mean height, because environmental living conditions in the first years of life have the largest influence on adult height, and in comparison to autochthonous people, the migrants

have on average a taller stature compared to the rest of the population.[163] In the dataset on whole Europe we found Germanic migrants of significantly higher mean height compared to rest of the population.[164]

In a second step, panel data anaylsis was utilized with the aim of checking the possible determinants affecting mean height (concurrently controlling for possible inter-temporal heterogeneity): Weighted Least Square regressions were conducted with dummies for the periods[165] on the major regions level (equivalent to fixed effects).[166]

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probably experienced a different environment during that phase of life. Thus, one would expect a difference in mean height.

[163] Determination of social status is based on the classification schemes of the original studies by using grave goods and similar information. If skeletons were not of higher social rank, the excavation reports often did not find this fact worth mentioning. Therefore, dummy variables are assigned only to the cases of middle and upper class social origin; a “lower or unknown” group was left as the constant. Therefore, one should not over-interpret the coefficient of this social status variable. However, this variable is not only important by itself, but is also necessary to control for the social composition and potential social selectivity of one analyzes height trends. Although the bulk of measurements stems from burial sites that represented all social strata, it is important to exclude the possibility of social selectivity causing height trends as far as possible. However, it was at best, marginally significant. The impact of social status for the whole of Europe is statistically significant (on the 10%-level): people of higher social position are taller in mean height than the rest of the population (see Table 12, Col. 2 and 3). However, controlling for social status for the three major European regions separately this variable has no statistically significant impact on mean height (see Table 12, Col. 4 to 9).

[164] Similar to social status it is possible to control for provenance of the buried on the basis of analyzing small finds in the graves. On this basis dummy variables were created for being of Roman origin – in the regression named “Migrated Mediterranean” –, and being of Germanic origin – classified as “migrated Germanic” –, in contrast to the rest of the population.

[165] Prehistory was separated in an early (8th - 5th century B.C.) and a late part beginning with the 6th B.C. as around 500 B.C. in Central-Western Europe (and far into France, and also Spain) the change of the Hallstatt to Latène period took place, and approximately parallel in the North-East the Jastorf culture arose, and on the Apennines Peninsula the Etruscans ‘entered’ their golden age after centuries of formation. It follows the ancient period which starts differently in the different regions, but continues approximately similarly long in any of the three major European regions until the 5th century A.D. when the Migration period/early medieval ages set in, followed in each region by the high and late medieval periods, from the 10th and from the13th century A.D. onwards, and the modern period starting with the 16th century.

All models are weighted by least squares to limit the danger of a wrong assesment in case of also including centuries with a small number of observations. Additionally, to ensure best reliable results, the centuries where we could collect less than 35 hight observations for each region were discarded.

4.3.3.3. Development of European Mean Height from Pre- to Early History

In figure 15, we depicted the height development in the long run from the eighth century B.C. to the 18th century A.D., including all regions, males and females pooled. The overall development over time is based on WLS regression on the individual level (including all collected data), adjusted by the regional distribution. The new, enlarged data set confirms the previous results as discussed in chapter 4.1.[167]

In the course of this long run development, there is only a modest increase in the mean height of about 1 cm per 2000 years. Moreover, the last observation is based on a small number of cases; if the 18th century A.D was omitted, the trend would be even smaller: in the course of the eighth century B.C. until the 17th century A.D. mean height increased only about 0.6 cm per 2000 years. However, strong temporal variations can be seen. This means that periods when people were slightly taller were continually succeeded by periods when they were smaller. From this, we can interpret the long-term stability of these numbers as a long duration and constraints on human welfare during pre-industrial history.

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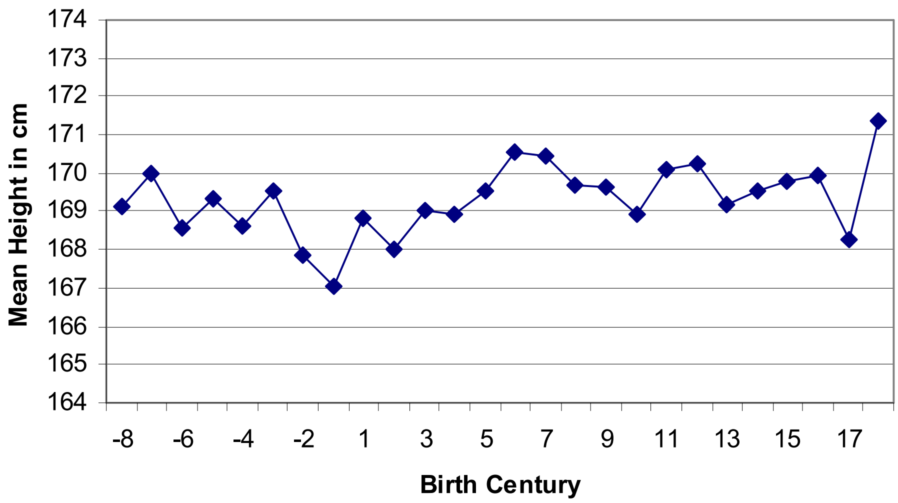
[166] In all models the reference group is 'Central-Western Europeans of the Migration Period/early Medieval Age'. The data are weighted be regional share. Females and Males are pooled; female mean height adjusted to male mean height; thus gender dimorphism should be controlled for.

[167] In both data sets the up- and downward movements in mean height are more or less the same, however with reduced extremes in the enlarged data set.

FIGURE 15
HEIGHT DEVELOPMENT, 8th CENT. B.C. to 18th CENT. A.D.
(IN CM, MALE AND FEMALE)

Source: see Bibliography part 1. The level of heights was adjusted to male heights of an average European (using the regional coefficients and weighting them with sample weights). Development over time is based on WLS regression on the individual level, adjusted by the regional distribution. All compiled observations considered.



This development of the mean height in the long run can be taken as reliable, as we made sure that there is no large bias regarding the 'representativity' of the population.[168] Moreover, mean heights separated by sex move parallel (not shown here). Furthermore, it was controlled for, and certified that the inclusion of cremations makes no important difference in the development over time.[169] Similarly, those individuals we

[168] Thus, only those cemeteries were taken into account that included the whole population and not just some noblemen's graves. In the archaeological literature, there are no hints on burial customs that could have biased our results significantly: it seems to be not the case that rich and poor graves are exposed to different preservation conditions on average for the periods and regions under study.

[169]This has to be checked because the custom of cremation is not consistently distributed over time. Although results based on the commonly used reconstruction model for cremated bones (cf Rösing) are combinable with inhumated bones reconstructed by the model used as algorithm basic (cf Breitinger/Bach) (thanks for friendly communication Prof. Wahl, Landesdenkmalamt Baden-Wuerttemberg & University Tuebingen), one has to have in mind that actually heights reconstructed on the burned bone remains are siginficantly smaller than inhumated remains. But comparing the temporal

included whose sex could be determined with a high degree of accuracy, albeit not absolutely definite, to ascertain that these cases make no difference in the height development. Also, because of a certain dating insecurity due to the archaeological basis of the data the development, only the definite dated observations (proof dating in one century) was compared with the development of the whole data set, to clear up possible differences in the temporal development. The comparison elucidates that the development moves quite similarly over the centuries. Only in some centuries the values differ only slightly: so for example the definited dated series shows a mean height on a very high level (sixth and seventh century A.D.) for the fifth century A.D. already, staying on this high level until the eighth century included. Whereas in the 13th to 15th century A.D. the mean height is a little lower.

Since the mean height, and its temporal development, is somewhat different for the various parts of Europe, figure 16 shows the height development for the long run between the eighth century B.C. to the 18th century A.D. again, but independent for the three main European regions. Again, a small increase in mean height can be seen for the overall study period, which is strongest for the Central-Western case, and lowest for North-Eastern Europe. Moreover, the Mediterranean region shows the strongest variability. During the eighth to third century B.C. mean height moved quite consistently around 168 cm in this region, while for the other two regions there too is no trend, but the data is scarce, and the variability so large that no real information can be taken from the data on these centuries B.C. In the last two centuries B.C. mean height strongly declined in the Mediterranean case.[170] During these centuries, a reduction to

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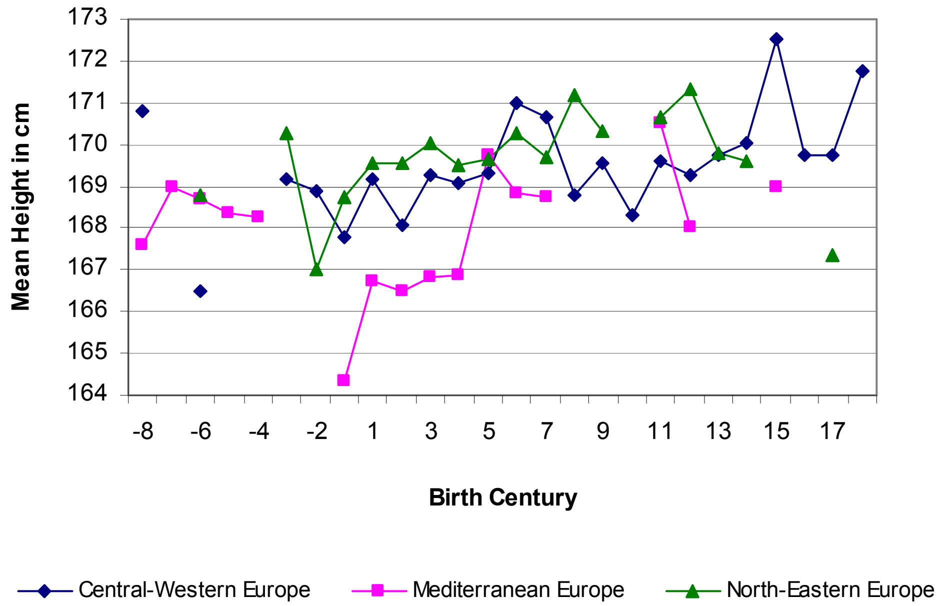
development of mean height based of the whole data or solely of the inhumations, it makes no important difference.

[170] The low mean height in Mediterranean Europe in the first century B.C. is not caused by an especially

FIGURE 16
HEIGHT DEVELOPMENT BY MAJOR REGIONS
8th CENT. B.C. to 18th CENT. A.D.
(IN CM)

Source: see Figure 1 (N >= 35)



some extent also can be found in Central-Western Europe. This could be explained by the increasing expansion of the Roman Empire, which deducts manpower formerly dedicated to food production for military recruitment (in combination with increasing population numbers due to net immigration, for example - slaves), and additionally by worsening climatic conditions during these centuries.[171] For the first four centuries A.D. – the period of the *imperium Romanum* – mean height is quite stagnant in all regions. Possible reasons for this are the strong population growth, distance to protein

small number of observations. And they can be directly compared to the observations dating in the first century A.D., because all of them stem from the Roman heart land. Furthermore, our finding is in accordance with the preliminary results by Jongman (2006), who found a similar development of an extreme increase in ancient Roman mean height from the first century B.C. to the first century A.D.

[171] See Schönwiese's assumption about the general Northern hemisphere climatic development during these centuries (1995).

production, and the creation of grain-oriented supply systems in the Roman Empire, which seems to be an indicator that the authority knew about the importance and the necessaries of a secured supply situation. The development in the third and fourth centuries indicates that due to political condition becoming aggravated, living conditions worsened.[172] Nevertheless, despite the political struggles – probably due to the (beginnings of) withdrawal of Roman imperial people to Apennine Peninsula – the fifth century had a positive impact on the nutritional status of the provincial people in Central-Western Europe.[173] Additionally, the little increased mean height in the third century could be explained by the impact of the Antonine plague at the end of the second century, which reduced population pressure. The end of the Roman Empire, and the 'setting' in main Migration Period result in a strong increase in height in Mediterranean Europeans in the fifth century – the Goths and other Germanic tribes practicing pastoralism move in, whereas in Central-Western Europe (and anyhow the North-East) changes in husbandry were not so extreme. Mediterranean mean height even 'adjusts' to the one in both other regions. This means that the Migration of People resulted in a similar nutritional status all over Europe due to increasingly similar living conditions.

The increasing development in nutritional status in the sixth century A.D. presumably can be explained in particular by the proximity to protein-rich nutrition due to the nomadic lifestyle of the migrating people, which balanced out the other unfavorable factors after the destruction of the *imperium Romanum*. Additionally, the total disintegration of the Roman world in the west, in combination with the Justinian

[172] Although slightly 'counterbalanced', probably due to a reduction in population density.

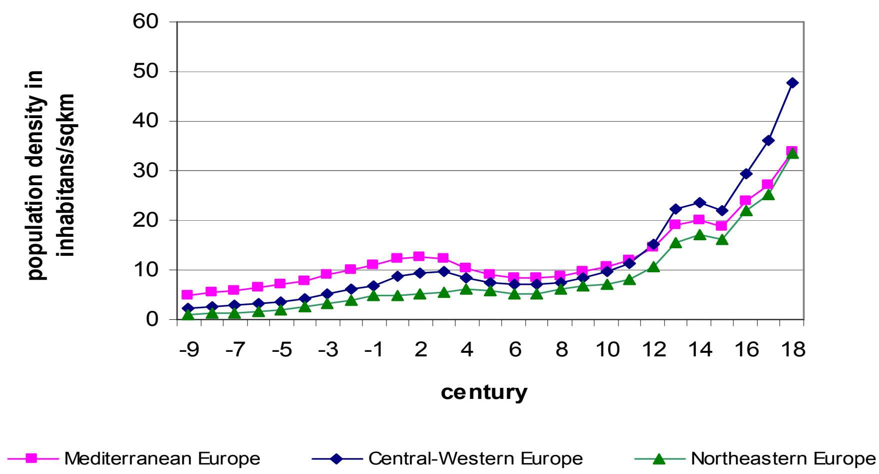
[173] The finding that the increase in height is much less pronounced than according to the preliminary data collection used for Koepke and Baten (2005a) can be explained by the high number of additionally collected observations, which approximately doubled the number.

plague, resulted in declining population numbers (see Figure 17), and a steep decline in urbanization.[174]

During 11th and 12th century A.D, mean height moves on a higher level in Central-Western and especially North-Eastern Europe, but not in Mediterranean Europe. This can be explained by the medieval climate optimum,[175] taking into account that the effect of increasing temperature could be of larger importance for the Northern regions, and even have an opposite effect for Mediterranean Europe.

A negative effect of the so-called crises of the 14th century (Hundred Years War, Great Famine, and the plague) cannot be seen. A reason could be that the inadequate temporal resolution of our data, and the fact that a negative influence might have been leveled out by a positive impact of the contemporary population density reductions (see Figure 17). Mean height experienced a decline in the 16th and in the 17th century, especially in

FIGURE 17
DEVELOPMENT OF POPULATION DENSITY
IN THE THREE EUROPEAN MAJOR REGIONS
Source: see text.



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[174] According to the specific sources, including in particular a massive reduction in parasitism.

[175] Although it was not as pronounced as previously thought, see very recent climate research (IPCC 2007, Figure 6.10).

North-Eastern Europe. This development was probably caused by the coldest phase of the Little Ice Age (Figure 19) (Jordan 1996).[176] Negative effects for nutritional status also could have been resulted from the Thirty Years War, which caused a decline in welfare due to 'scorched earth', and deteriorated disease environment.

Besides the temporal variations in times and regions, the overall increase of mean height in Europe was very small over the pre-industrial centuries under discussion. This is in agreement with the conclusion by Clark (2007) and others that during these centuries the general population always lived on the limit of life-maintaining nutritional status.

4.3.3.4. Variability during the Roman period

One thing of particular interest is the question of the influence of the *imperium Romanum* on the people of Europe. The temporal and regional mean height development, shown in figure 18, indicate whether, and in which direction, ancient Roman imperialism influenced Europe.

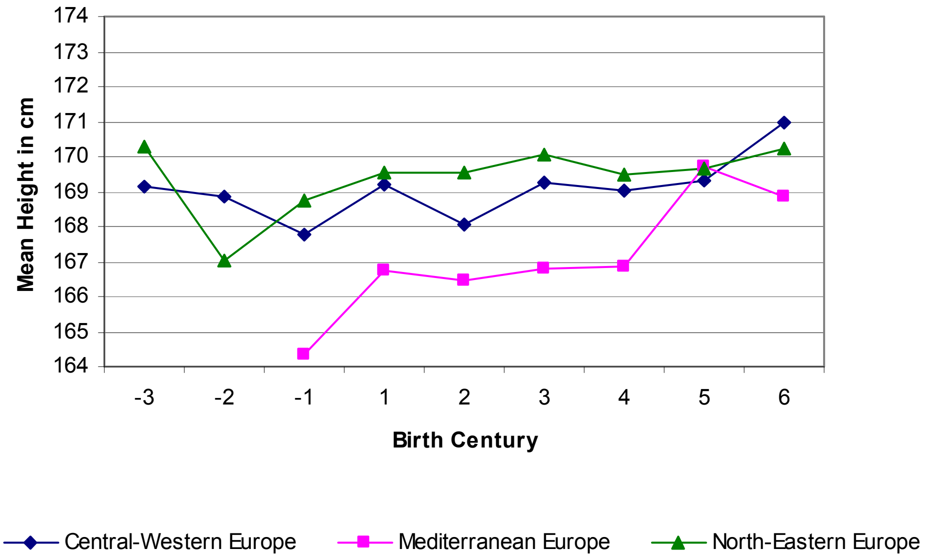
Roman imperialism started in the Italian home country in the third century B.C., and the region was Roman until the fifth century A.D.; Roman imperialism was expanded to Central-Western Europe from the first century B.C. onwards, and Roman impact remained active until the fourth century A.D. Throughout this time North-Eastern Europe remained unaffected by the expansionism of the ancient Romans.[177] This is in

[176] Unfortunately for this time we could not compile any data for Mediterranean Europe, where both the effect of climate and war should be less pronounced.

[177] Means this region stayed free from Romanization, and was only affected by the Roman imperialism to a negligible extent in terms of single trade contacts. Except for some, in terms of nutritional status negligible trading contacts, and in this contest the rare foundations of emporia and military bases east of

FIGURE 18
HEIGHT DEVELOPMENT BY MAJOR REGIONS
IN THE COURSE OF ROMAN OCCUPATION
(IN CM)

Source: see Figure 1 (N >= 35)



concurrence with the finding of no decisive change in North-Eastern European mean height during the first to fourth centuries A.D. (which is the time when Roman impact could, if at all, have been perceptible).

The temporal developments in Central-Western and Mediterranean Europe actually give some support for the hypothesis of detrimental imperial impact.[178] Compared to the pre-Roman period Central-Westerners had neither substantially shorter mean height, nor a taller one. The decline in Central-Western Europe in the first century

the Rhine during the first years of the first century A.D. prior to the clades Lolliana ("battle in the Teutoburg Forrest", now located at Kalkriese, near Osnabrück).

That the contact was rather loose can be also seen e.g. in the spreading of agricultural techniques which were not introduced beyond the limes.

178 Strictly speaking we would have to utilize Italian data, if we want to control for the impact of Roman expansion on the 'mother country'. But as our Mediterranean data mainly consists of observations from the region 'Mediterranean Europe' is used here in terms of/equal to 'centre of the imperium Romanum'. Roman expansion within this part of Europe is somehow taken hold of by the temporal solution.

B.C. can be explained by the negative impact of military 'infringement'[179]: It reduced the number of laborers, and therefore food production output, but also indirectly damaged the husbandry production. Moreover, the arrival of an additional population reduced the available food resources per person, the army possibly bringing in new diseases, et cetera.

The remarkably low mean height in Mediterranean Europe in the first century B.C. can also partly be explained by a neglect of agriculture, in benefit of a focus in supplying troops with armament, and the dispatch of men to the frontiers (and therefore a withdrawal from local economy). However, the main impact was probably the change from protein-intensive to grain-intensive agriculture.

The first century A.D. shows increased height in both regions – probably due to a certain stabilization during the early Principate under Emperor Augustus (after a long period of distress during the Roman revolution).

In the second century A.D, mean height declined again in both regions – albeit to a lesser extent in the Mediterranean case. This seems to be astonishing at first, because this is virtually the 'heyday'-century of the *imperium Romanum*. However, because of this fact there was an extremely increased population density (see Figure 17), especially in the former comparably low populated area of Central-Western Europe. In addition first time in European history a system of a 'not-everyone-performing-subsistence'-economy occurred with the result that only a part of the population 'produced' food, were as the other part had to be fed, which also created a dependence of these working people on wage income (Haines 2004).[180] Moreover, an increased 'distance-to-protein'

[179] Due to both immediate killing of people during the primary occupation phase, and subsequent relocating esp. of autochthonous men to prevent rebellion.

[180] Which presumably, furthermore, even resulted in increasing inequality in income and wealth, and thus aggravate the influence of food price fluctuations.

of a large part of the population, and the increased urban rate[181] may result in a lower nutritional status in Central-Western Europe in particular.[182] The perceived decrease in Central-Western Europe could also be explained by similar processes, as for example Komlos (1989; 1994) found for Austria-Hungary of the 18th century A.D.: After initiation with Roman occupation, and in the course of Romanization, the extension of the market integration of remote regions (a widespread street net was constructed) took place, which probably could have had a negative impact on the nutritional status there.[183] Except for the alteration of the established economic structure, another far-reaching consequence of the construction of long-distance roads was the change in the settlement structure. The creation of service enterprises for the street users also resulted

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[181] At the time of Roman land-grab of the formerly (around 100 B.C.) frequently existing so-called Celtic oppida (and farms) only a small was remaining in the North-Western provinces (means Central-Western Europe) (Reuter 2006; Zanier 2000). Along the river Rhine autochthonous people lived (see e.g. Metzler 1995). In the case of South Germany the research discussion is converse whether even a population hiatus can be detected in the pre-occupation phase, which would have made the effect of the inclusion in the Roman Empire and resulting population dynamics even more extreme. The very recent research opinion (Steidl 2007) is that there were certainly autochthonous people living, although the archaeological remains in the pre-occupation period are small. But nevertheless archaeology and archeo-bontanic pollen analyses provide pieces of circumstantial evidence of continuity. Moreover, in particular the (early) post-occupational remains clearly speak for a presence and survival of the autochthonous population (see e.g. Tropaeum Alpium in La Turbie (victory monument mentioning many defeated autochthonous tribes), so-called military diplomas mentioning Celtic origin of the soldiers etc.). Of special interest are phenomenons like the emergence of the so-called ‘Heimstettener Gruppe’ – female graves in Celtic tradition, with lavish folkloric costumes – in the second ‘pre-occupational’ generation, which is interpreted as revivalistic behaviour (as reaction on the cultural shock based on the newly introduced *ritu Romanorum*).

[182]Furthermore, the question arises in how far in the second century A.D. the introduction of the annona militaris (payment of the soldiers in non-monetary form, but food rations, equipment etc.) had a negative impact. This was the case in these regions, where the military was based, and where the local people were in charge of the supply of the soldiers. Kloft (2006, 116) presumes that these compulsory levies (esp. in combination with further rigid tax policies) caused distress and misery in the civilian population.

[183] Due to the integration transaction and transport costs decreased, and a high percentage of the locally produced high-quality food was withdrawn from the rural autochthonous population and sold to townsfolk and armed services.

in the growth of already existing settlements as well as the emergence of new settlements, which in turn had an impact on increased population density – and all the succeeding factors influenced nutritional status negatively. A possible explanation for the situation in Mediterranean Europe, where height was declining less, could be that the ancient Roman elites were incumbent in providing their home towns with 'acts of generosity' in order to gain further personal political achievement. To finance this it was necessary to increase personal wealth, which "might in itself have significant consequences for the agricultural structures of the territory, as landowners sought to maximize revenue, exploit estate more intensively, or adopt new methods of farming" (Patterson 2006, 266).

In the third and fourth centuries A.D. conditions stagnated. This is of interest because, in particular, the third century A.D. is often labeled as the century of crises that lead to the decline of the Roman Empire (Nuber 2005b).[184] Therefore, we would have expected decreased mean height due to decreased living conditions being the result of perturbation by the turmoil in connection with the Gallic "Sonderreich" and the related civil war. Germanic infringements and attacks on the *imperium Romanum* probably caused devastation of agriculture, resulting in spreading of the woods over formerly agrarian areas from the end of the third century A.D. onwards. Desertion, and

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[184] Several archaeological findings let us assume worsened conditions. In contrast, on the Iberian Peninsula large late Roman villas were in use still by the Visigoths (Bowden et al. 2004). But toward the second half of the third century A.D. augmented abandonment of villae rusticae took place in Central-Western Europe. This probably owes not only to the political changes, but also to the previously extensive utilization of land due to an eluviation of the soil (Gaitsch 2002); the disappearance is also detectable by the re-afforestation. Moreover, people moved back out of the open country to densely settled hilltop sites. On the other hand, Germanic settlers start to colonize the provincial regions. Furthermore, a transformation of the appearance of still existing towns took place from the mid third century A.D. onwards in the Central-West, in 'Italy' from the fourth, and fifth century A.D. onwards (Krause and Witschel 2006): All cities (some sooner, some later) received defense walls – that generally enclosed a smaller area than before – to reduce the danger of invasion.

destruction of settlements, as well as concentration of Roman forces in the affected regions, caused other burdens of war for the local population (due to recruitment, logistic appropriation of equipment, infringements during billeting). Nevertheless, recent excavations indicate a period of reconstruction (for example repair measures), which indicate that conditions could not have been more adverse.

One would expect that overall these changes decreased the biological standard of living. However, the situation in terms of nutritional status was obviously not as bad. The reason could be that population numbers have been reduced to a certain amount, which still made a more or less adequate nutritional status for the remaining population possible; in combination with a 'back to' proximity-to-protein agricultural emphasis. Additionally, 'barbaric' attacks might have been less extreme than one could expect, as also a mutual acculturation took place (for example Germanic mercenaries in the late Roman army). The current archaeological, numismatic and historic sources have made no clear statement possible.[185] What seems to be clear, according to the newest archaeological excavations, is that there was no hiatus between remaining late Roman and early Merovingian residents (Fingerlin 2005; Nuber 2005b).

It is remarkable that during the Roman Empire, the mean height seems to have more or less stagnated, but begins with a strong reduction in Mediterranean Europe, indicating that, if at all, conditions did not improve. In the Mediterranean region they

[185] E.g. in the case of the Rhine-Danube-provinces the comparably high number of hoards dating in the third and fourth century A.D., which could be located by archaeologists on the one hand speak for the fact that the former owner presumably died in the course of a raid (because otherwise he/she would have recovered his possessions some day), on the other hand these findings do not indicate how bad the attacks actually had been. Similarly, the findings of contaminated wells (at least in case carcasses were used for this purpose) can be interpreted differently: as indeed destructed by the enemy, or spoiled by the former owner to leave behind conditions as worse as possible for incoming Germanic settlers (Alamanni) when heading South.

were clearly worse compared with the eighth to fourth centuries B.C., and the later period (see Figure 16).

The generally small variation between the first and fourth centuries A.D. is similar in all regions, also in North-Eastern Europe, which had no Roman influence. Hence, other factors, such as climate, or disease environment, might have had the strongest effect.

Also remarkable is the development of mean height in the fifth century A.D: there is no real change in Central-Western, and North-Eastern Europe before the sixth century. However, a very pronounced increase occurs in Mediterranean mean height. This indicates that after the decline of the *imperium Romanum* nutritional status of the former Roman heartland improved, probably due to the renewed proximity-to-animal protein, which was introduced by the invaders who brought with them their agricultural system (Hirschfelder 2005, 96 f.). Correspondingly, mean height is the same in all three major regions in the fifth century, being the 'climax'-phase of the Migration Period, which resulted in equal economic conditions all over Europe.

4.3.4. Potential Variables Explaining Mean Height

Nutritional status is shaped not only by diet conditions, but also by health environment, and workload. Thus, a wide range of determinants can have an impact on the quality of nutritional status of a population, and therefore can be used as possible explaining variables of mean height.

Particularly when concentrating the study on the aspect of food provision and consumption, one has to bear in mind that many possible causes of food poverty and deprivation exist, other than food shortage. Recent research on famine has found that massive hunger crises often arise despite aggregate food supplies being no less adequate than usual (see especially the work of Amartya Sen). Underlying reasons for temporal and regional differences in nutritional status of a population can be (other than from a shortage of food) a variation in the lack of access to food for people of different social groups within a population. Lack of food may result from general environmental conditions that can cause production shortfalls and thus food shortages: anything from climatic conditions – or even short time weather – as far as political problems. Lack of access to food results from varying attitude towards different groups in different societies, and can also arise within a household. For example, gender inequality will result in unequal support and allocation between the concerned groups, with an effect, which might vary in different populations (see chapter 4.4.).

A conglomerate of various factors influences nutritional status, and thus mean height. These can be natural, population development-related, socio-economic, cultural, society-dependent, political determinants. In the following, those determinants are discussed that could be of relevance on the one hand, and for which it is possible to gain information despite the study period on the other hand.

4.3.4.1. Natural Factors

Natural factors are divided into regional effects, for example: extreme altitude and climatic effects.[186] However, since the populations examined in this paper come from similar environments these factors can be seen to have little or equal effects on the populations.[187]

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[186] Basic height in populations living in polar or tropical climates is adjusted in terms of adjusted body surface for a thermal-balance uphold: being shorter respectively longer to minimize respectively maximize heat loss population in Polar Regions (Jurmain 2000, 423 ff.).

[187] A natural variable, which could cause regional differences is the extent of navigable water ways in a region, providing a special situation in terms of trading connections and thus food supply. But it cannot be tested for the effect of this variable in this study, because it is not possible to reconstruct which smaller

What, furthermore, could have made a difference by region, are the soil conditions (indirectly affecting mean height due to their impact on harvest yields). Nevertheless, these differ too locally to be measured in the context of our study, and do not differ on average between the three large European regions. Therefore, data of informative value are not available to test this effect.[188]

Another natural factor influencing especially the quality of nutrition could be changing climatic condition. The annual variation in precipitation and temperature could have had an impact on the harvest and so food security. Also, the effects of climate change can be different for various regions in Europe – despite an overall Northern Hemisphere development – since the effects of a change may both be either more negative or more positive, depending on the starting conditions.[189] For the time after 800 A.D, different authors have recently analyzed the overall climate change for the Northern Hemisphere. The summation of the results has been published by IPCC (2007). The temperature development resulting from twelve investigations is shown in figure 19. Here, the variability and consequently the uncertainty of the temperature curves are the dominant impression. Brázdil et al. (2005) concluded that a more precise chronology on climate is needed. However, both the climate optimum in the Middle Ages and the Little Ice Age can be seen. In contrast to older climate reconstructions, according to IPCC 2007 it can be stated that the climate optimum comprises only a

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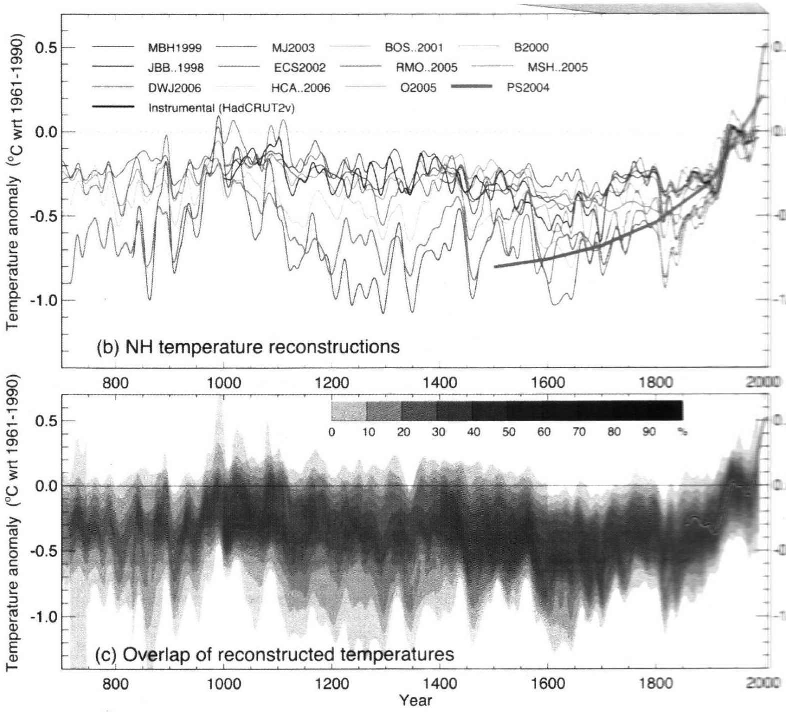
rivers were usable for transport of goods. E.g. it is proven for Roman times that ‚Plattboote' (flat bottom skiffs) were used in the Rhine region opening also shallow waterways for transport (Höckmann 1985), but for other regions and periods the knowledge is not available.

[188] Correspondingly the attempt to use recent measures of soil quality brought no result.

[189] General temperature change will have different effects for different regions: In a colder region temperature increase will be positive (Greenland during the medieval climate optimum), while it may be rather negative in an already warm region. The opposite holds for a temperature reduction, which even could improve regional climate conditions with respect to food production in the Mediterranean case.

FIGURE 19
SERIES OF NORTHERN HEMISPHERE TEMPERATURE RECONSTRUCTIONS
(after ICCP 2007)



small temperature increase in the 11th century A.D. More pronounced is the Little Ice Age from the 15th to 17th century A.D, with a temperature nadir in the 17th century that is three times larger than the increase during the optimum.

For the time before 700 A.D, only very little climate information is available (for details see Koepke and Baten 2005b).[190] It is a widely supported hypothesis that climate was at all times an important determinant (see Baten 2002; Grove 2002; Pfister 1988). Koepke and Baten (2005b), see also chapter 4.1., showed that the negative impact of

[190] The only little longer series are Mann and Jones (2003), and Moberg et al. (2005), with reconstructed temperature from 133 A.D. onwards. But these data also show no significant statistical effect on overall mean height. Climate data going much further back in time are available (IPCC 2007), but have a resolution that is useless for this study.

colder climate becomes perceptible from the ninth century onwards concomitant with the increase in population numbers.[191]

In this study, all possible natural factors affecting a region (including basic climate) are subsumed into dummy variables standing for the three major European regions. The same applies to temporal changes in natural factors (including climate changes), which are subsumed into dummies standing for the periods under study.

4.3.4.2. Agriculture

Essential for the nutritional status is the type of agriculture products, method and technology.[192] For many pre-industrial people (especially in periods of high population numbers) grain, whether as 'porridge' or bread, was the dominant part in their diet (Hirschfelder 2005, 81 ff.; Walter and Schofield 1989; Drummond and Wilbraham 1991; Stone 2006; Miedaner 2006).[193] Since "meat and meat products were scarcely present in the diet … any element of protein … derived from cheese, milk, and butter must have been a particular significant addition to diet largely based on cereals" (Woolgar 2006, 100). Consequently, we assume that what makes the difference in net nutrition is the additional supply and thus consumption of animal protein, which also

[191] Additionally, short time weather may affect diet supply: Even a single frost night in late spring (when plants are in full bloom) can destroy completely the harvest of a year. Even today under comparably favourable conditions for agriculture – where compensating technologies are available (e.g. by fertilizers), a series of harsh, frosty springs has a negative effect on food production. And even the inter-annual variation of precipitation can have an impact. However, weather data do not exist for the period before the 18th century A.D.

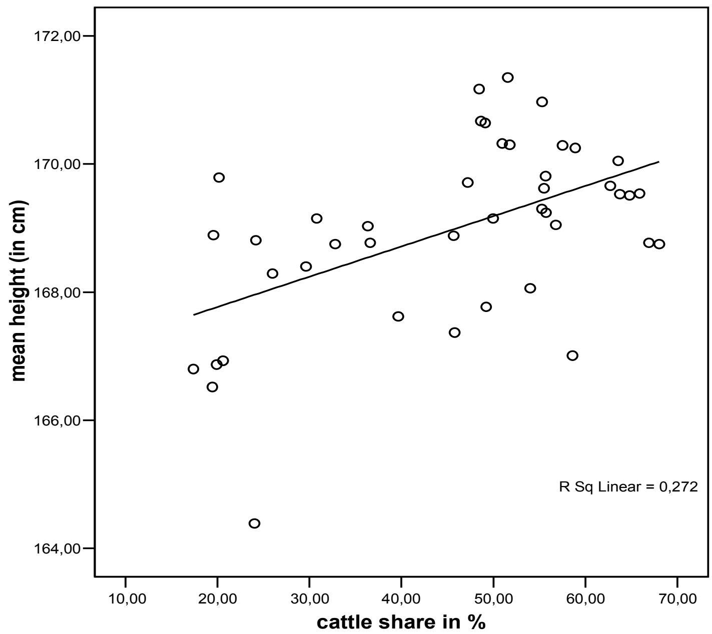
[192] One has to have in mind that the type chosen for a region, as well as the output can be determined by natural factors, starting from type of soil, ending with factors like weather conditions and related spread of varmints. E.g., requirements for (acceleration of) wheat growing are long growing season and good soil.

[193] The dependency upon grains resulted in starvation due to harvest failure caused by weather extremes (see Schofield in Woolgar et al. 2006, 247).

applies in early history. The positive effect of milk increased due to geographic proximity and local supply. This was due to transport limitations prior to the innovation of refrigeration.

In recent centuries, there have been several studies (for example Baten 1999; Komlos 1998; Baten and Murray 2000; Prince and Steckel 2001) that found animal protein to be a decisive factor for a high nutritional status, and that particularly milk makes an essential difference in nutritional status. This is because the proteins of milk, whey and some cheese types are of especially "high biological value, that is to say, they contain all the amino acids essential for growth and maintenance" (Scott and Duncan 2002, 11).

FIGURE 20
CORRELATION OF CATTLE SHARE (IN %) AND MEAN HEIGHT (IN CM, MALE AND FEMALE) IN EUROPE
8th CENT. B.C. to 18th CENT. A.D.
Source: see text. only centuries which also included in regression (N >= 35)



The scattergram (Figure 20) indicates a modest correlation of higher cattle share and higher mean height. Dairy products' "availability was closely linked to the scale of livestock husbandry" (Woolgar 2006, 94). The question remains whether its effect is also significantly visible in the very long run pre- and early historic data.[194] Did the development in milk and beef availability support an explanation for differences between major regions? Interestingly, several ancient authors (for example Tacitus, see chapter 4.2.) mentioned (in contrast to the "civilized" consumption habits of their Mediterranean contemporaries) that the Germanic tribes regularly consumed large amounts of meat and milk[195]. This started with *Poseidonius* (approx. 80 B.C.), who passed on that the Germanic people enjoy "per extremity" grilled meat and drink milk (and un-mixed wine) with it for their daily main meal.[196] Likewise, *Tacitus* (*Germania* 5,1), and *Caesar* (*de bello Gallico* 6,35,6) emphasized that *Germania Magna* is rich in cattle, as all the German tribes' pride are their cattle herd sizes (numbers of rather than dimensions) *(Thüry 1980)*. In agreement with this argument, particularly the milk giving cow is registered in the *leges Barbarorum* (e.g. in the L Bai IX,2, see Weber 1985) of the Germanic tribes dating from the end of the fifth to the end of the eighth century A.D.[197] In contrast, traction power seems to have been the main motivation for cattle husbandry in the heartland of the *imperium Romanum* – and subsequent to Romanization, perhaps also in some of the Northern provinces. Likewise, several

[194] As Koepke and Baten discussed the 'milk-question', and linked questions (like lactose intolerance, production and consumption possibilities) in detail already in an earlier paper (Koepke and Baten 2007), here a synopsis is delineated.

[195] Additionally, also butter was – in contrast to the Northwestern provinces – not consumed as food on the Apennines Peninsula (only used as unguent); instead olive oil was the only fat in use, which was also introduced, and widely spread, outside the Roman mother country in the course of Romanization (Thüry 2007, 34).

[196] Poseidonius, book 30.

[197] Other predications on the exploitation of domestic animals are not given in these texts (except for hen eggs, which naturally cannot be analyzed in an archaeology based study).

authors emphasize the special value of large animals, particularly for traction power (for example. *Cassiodorus*, *variae* 3,50).[198]

To study regional and temporal supply differences in animal husbandry zooarchaeological data were utilized. As it is commonly performed in faunal remains quantification, here the relative proportions of the different species in archaeological assemblages are used in order to extrapolate the relative importance of each species. In the same way, we use the share of cattle bones as a percentage in respect to the total animal share (the means of cattle, pigs, and sheep/goats) as proxy for milk/beef supply. Cattle share is usable as an indicator because on the one hand taphonomic biases tend to affect the total number of surviving bones, but not the shares of large animal types. On the other hand, changes in the relative composition of cattle bones in general reflect milk consumption. This is because several different sources indicate that cattle have always (at least to some extent) been used for milk production (Crabtree 1996; Seetah 2005); from medieval written sources it is known that "cream and butter were produced primarily from cow's milk" (Woolgar 2006, 95). Furthermore, in general[199] the use of cattle for meat production was less important than its use for milk production due to its much lower efficiency in terms of protein gain, and the stronger influence of milk availability on regional human nutrition. The third important fact that we can assume, is that the animal products were actually consumed in the region where their bone remains were excavated.

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[198] But nevertheless we can presume that even in the Roman case milk (other than cattle meat) was somehow seen as a product of interest in cattle husbandry – consulting esp. Plinius the O. (naturalis historia 8,179), who stresses that the milk efficiency (and working capacity) even of the autochthonous cows was remarkable (actually highest) despite their smaller size.

[199] Although some temporal and regional differences in the aim of cattle husbandry arose in the course of the long run, means especially the utilization of cattle as draft animals for grain production in Roman times.

So, what is the actual impact of regional differences, and temporal changes in husbandry in pre- to early historic Europe? The levels of cattle share are different for the major regions (see chapter 4.2.). The lowest cattle share is found in Mediterranean Europe, including an extreme decline that occurred during the centuries before the turn of the eras. After the first century A.D. the cattle bone share stagnated on a low level until the sixth century A.D. The highest cattle share is found in North-Eastern Europe, with only a slight decrease over the course of the centuries. Central-Western Europe lies "in between", with a substantial increase from the third century B.C. onwards was followed by stagnation in the cattle share from the second until the sixth century A.D., and a decline afterwards. Overall, the Mediterranean cattle share was constantly lower than the Central-Western one, with the share in North-Eastern Europe ranking highest.[200]

Another aspect that we analyzed as an explanation for human mean height is cattle plague.[201] Even today, cattle plague causes devastation of livestock, resulting in heavy

[200] When comparing the development of of the domestic animals species by regions (not shown), it can be found that in all three parts of Europe, the pig and cattle share developed more or less antipodally, whereas the sheep/goat share developed 'independently' and was overall relatively stable. Although the Romans substituted beef with pork the overall meat consumption was still relatively high in the Roman Empire (e.g. Jongman 2007) – albeit not necessarily per capita. Cattle husbandry provided particularly important advantages in terms of proximity to milk production, and based our results not directly on meat per capita values. By levels of absolute bone numbers, it can be conducted that the diet of the Mediterranean region with its high population density was probably marked by much lower overall meat consumption. The Mediterranean population was larger; and 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. A part of this gap can certainly be explained by taphonomic distortions. It is unlikely that the Mediterranean population consumed more meat per capita than the Central-Western Europeans. The differential of 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 the differential of cattle bones is almost 1:20.

[201] See Spinage (2003). It is „an acute febrile disease resulting in mortality of almost 100% with strains of different degree of virulence" (Barret and Rossiter 1999, 91).

economic losses. Even more one would presume that periods of livestock disease (not only cattle, but also other large ruminants can be affected) had a negative effect on the supply situation of animal protein and milk, as well draft power (and main source of fertilizer[202]) when no effective vaccine was available.[203] First descriptions of cattle plague and its effects stem from the Roman times.[204] Since the effect of cattle plague could be independent from cattle share, we created a relevant determinant in the form of a dummy variable in order to test the impact of cattle plague in each major European region. We based this on the data collected by Spinage (2003, esp. 81 ff.): 1 for centuries of known 'regional large-scale' disease prevalence, 0 for disease free centuries.

Improvements of cultivation methods could have an impact on nutritional status. However, most methods, like intensification of irrigation, the invention of the artificial manuring (1809), steam engine, the potato, or different steps in medical improvement only came about to be in regular use after the period under study here. Thus, the only potential variable from this group is the three-field crop rotation system.

This method meant the introduction of summer and winter crops, and also the beginning of fallow fields (Küster 2006) that led to soil regeneration as well as effective weed killing that was possible for the first time, and so this could have resulted in an increased productivity.[205] A controversy is going on, whether the three field rotation

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[202] Furthermore marling, lime, and conflagrative fertilizer were utilized; from the 13th century onwards ash was scattered about the fields (Comet 2000, 161). But none of these methods came near to the effect of modern fertilizer.

[203] According Barret and Rossiter (1999, 102) e.g. in the 19th century the loss of a very large part of cattle stock resulted in the incapacity to till the land which "led directly to the great Ethiopian famine of 1880-1892".

[204] Barrett and Rossiter (1999).

[205] A higher output due to an advanced agricultural exploitation of preset natural conditions – esp. in

technology can be seen as a revolutionary novelty or not. Research debates in particular whether the crop rotation at an agricultural area in use resulted in an increase in the quality of the output (see, for example, Grupe 2003; contrary Comet 2000).[206] Despite this research debate, the introduction of the three-field rotation technique certainly brought important improvements due to the 'dispersion' of risk factors over more seasons, and crop types (new diversity). In particular, it enabled a provision of the livestock with fodder grain (oat) and grazing possibility on the fallow land – whereas heretofore pastures were lost due to the shift to grain cultivation; regular quality food increases the milk production of cows. Therefore, one would imagine that the three field rotation technology improved nutritional status, because this innovation somehow enabled enhanced food production.[207] Is an impact on nutritional status visible *in realitas*? Did the agricultural-technological invention affect the provision of the livestock with fodder sufficiently enough, to produce more animal protein, resulting in a higher average nutritional status? Or was this improvement "eaten up" by subsequent population growth?

To test these different aspects a "three-field rotation"-dummy was created for the 11th century onwards: with 0 standing for 'untouched' centuries, and 1 standing for for the 11th century A.D. onwards, when three field rotation certainly was in common, widespread use.

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combination with the introduction of the so-called ‚Flurzwang' to yield larger surpluses, which could delivered to the towns – presumes e.g. Schultz-Klinken (1981).

[206] Furthermore, it becomes not clear from the literature whether improvements in pre-industrial food production immediately cause a counterbalancing increase in population numbers, or whether the innovations are only initiated due to the prior occurred increase in population density (Boserup 1983; Cohen 1989; in contrast to Floud 1983).

[207] e.g. Wiese and Zils (1987) 38.

4.3.4.3. Other Economic Aspects

It is to be expected that population density – region-specific population numbers, as well as concentration in settlements (urban rate) – has an impact on nutritional status due to several factors. For instance, Cohen and Armelagos (Cohen and Armelagos 1984; Cohen 1989), or Steckel and Rose (2002) emphasize how the detrimental impact of 'civilization' on health and nutrition quality developed over time. For example, Maat (2003) confirmed this for the Netherlands (s.a. Brothwell 2003).

In pre-industrial societies, higher population density results on the one hand in land to labor ratio changes, which in turn result in declining marginal labor productivity. In Malthusian terms (Malthus 1798) this means less food *per capita*; if population numbers outweigh the available food due to the decreasing marginal product, this will result in a demographic disaster. However, on the other hand, it results in a higher infection rate. It also causes changes in agricultural production, which again reduces the availability of food (see chapter 4.2.). Likewise, Woolgar et al. (2006, 268), and also Dyer (1998) found in the case of Medieval England: "As the population increased, quantities of livestock *per capita* diminished … This decreased productivity of agricultural land and animal husbandry, restricting for many both the variety of diet and amounts of food – and at some points, leading to starvation. … After the late fourteenth century (after the Great Famine and the Black Death) famine was a far less significant element … and the pattern of diet was considerably improved, with a greater availability of meat and dairy products".[208] One also has to contemplate the problem of the "vicious circles" of endogenity: for example the dilemma of overpopulation, which was reached towards the end of the 13th century A.D. in Central Europe (relative to the existing abilities in food production), which resulted in permanent settlements in regions being

[208] Dyer 1998, 70 f.

(rather) unsuitable for agricultural production. This, in turn resulted in considerable impacts on "the local ecosystems … and … accompanying alterations of the landscape with its fauna and flora" (Grupe 2003, 281).

Furthermore, it is to be supposed that in particular the increasing urban rate had a negative impact, because it implies a higher percentage of people living in cramped conditions. This can result in a number of worsening factors: the concentration of people living together closely results in a more difficult equable provision with food in general – and urban dwellers were separated from de facto non-tradable goods, in particular, milk. Additionally, in towns, diseases could break out more easily (due to densely built dwellings, bad air condition and water quality), and this led to infections spreading faster. In addition, the phenomenon of high population density also results in high rates of refuse disposal, which in turn has an impact on the diseases environment. In towns probably the prices for goods were higher than in the country due to transport costs and intermediate trade; although also loans could have been higher Komlos (1998) states that in general commodities, which result in a higher nutritional status were less available and affordable for the average urban dweller. A further possible negative aspect is that "high levels of violence are commonly associated with high density living" (Scobie 1986, 433). Interestingly, the observation that cities are unhealthy places for living can already be found in several ancient texts (listed in Nutton 2000); however, no practical recommendations on the topic of practical improvements are added in the early written sources. Consequently, – far from implementation approaches at a municipal level – no concept of 'public health' concerning the whole community existed (Thüry 2001).[209] Also in later centuries, "apart from exaggerated responses to

[209] Exception seems to be the rule to bury the dead extra muros (Patterson 2000; Lindsay 2000); but with respect to the missing of any other sense of settlement hygiene actually this fact can only explained by the

lepers", communal action to protect public health in generally was more or less crises oriented, and not performed in advance as precautionary measures; this only began to change from 1500 onwards (Carmichael 1995).

In comparison to modern standards, (Townsend 1979) early historic townspeople lived in poor housing conditions (with structural defects, inadequate facilities, and overcrowding) for example; Scobie (1986, 402) even describes the common situation as "similar to the shacks in slums today".

To measure population density and its change over the pre- and early historic centuries is obviously difficult. Zimmermann (1996) begins his work on the population density in prehistoric Europe with the remark that one has to be conscious. In some cases, within the literature, the numerical data are contradictory because estimations for a local area are extrapolated on larger regions, whereas according to Zimmermann, an interpolation of given isolated information would be reasonable. Different archaeological sources allow the estimation of population numbers, which complement one another: in particular, frequency of settlement sites (with the number of residential buildings within), and frequency of cemeteries (and number of buried individuals within).[210] Because it is impossible to find (and furthermore completely excavate) all permanent settlements and cemeteries of a period, the resulting approximations are minimum estimations. Taking into account, how many people can be fed in a certain region of known economy one gets to maximum estimations.

In order to control for population density we used data collected by McEvedy and Jones (1988). Their work is the only one of many, which gives detailed population estimates on all European regions for the centuries B.C. in Europe.[211] Utilizing these

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Romans being frightened of wraiths.

[210] Furthermore written sources or e.g. archaeo-botanical pollen analyses give hints.

[211] The numbers given in Zimmermann (1996) are – although in parts of newer research stage – primarily

population numbers and the size of the respective areas we reconstruct population density for each of the three large European regions. Urbanization degree is estimated based on data by Bairoch (1976), and Federico and Malanima (2004).[212] Hence, we used two population-related variables to explain mean height: "Land *per capita*" for depicting population density[213], and "urban rate". Nevertheless, we have to remember that the data on population numbers are generally rough estimates, as is also the case with approximation of the urban rate.

How did population density develop in the three major European regions from eighth century B.C. until the 18th century A.D.? The development is shown in figure 17. According to the estimates, population was by far the most heavily dense in the Mediterranean region until the 15th century A.D., when finally the North-Eastern and Central-Western Europe caught up. Overall, population density increased gradually in all the three European regions until the ninth century A.D, when a strong increase set in. Before then one marked exception is the development during the *imperium Romanum* when already a dramatic increase took place (especially intense in Mediterranean Europe[214]); but this incident was 'neutralized' with the decline of the empire. Population density moved on a reduced level until a boost occurred from the ninth century A.D.

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local estimates. Other estimates in the literature on prehistoric centuries are only discussing the whole world as one research unit. For the centuries AD different studies exist on single periods and regions. Looking at the 'world level' in all cases the estimates of McEvedy and Jones (1988) are comparably low values, but these fit together with UN-estimates: see webpage of the U.S. census Bureau, Population Division. Newer estimates would have been available for the later centuries; but those data was not used here, because the combination with the data for the earlier centuries could result in some discontinuity.

[212] See Koepke and Baten (2005a).

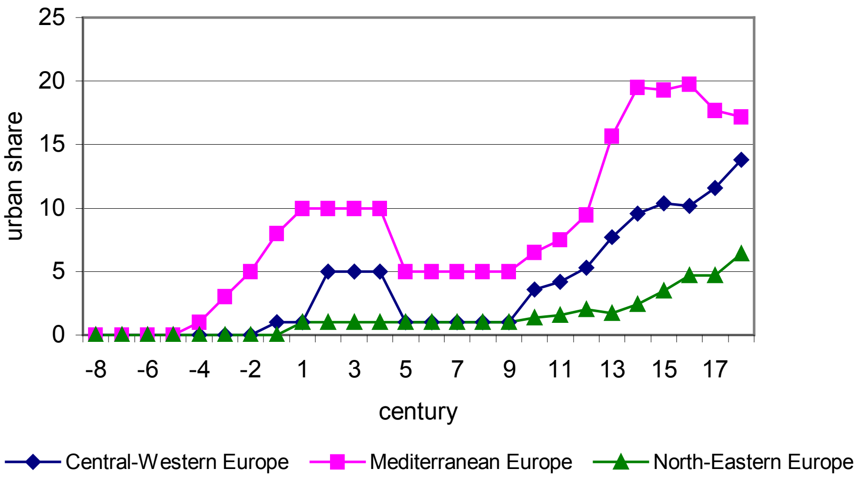
[213] It was included in logarithmic form to account for decreasing marginal product effects (or inversely, increasing costs of population density).

[214] This development was/seem to be promoted by Roman law (introduced by emperor Augustus) that forced women (aged 20 to 0 years), and men (aged 25 to 60 years) to be married (otherwise being subject to an administrative fine).

onwards. European population in total increased at about 140% from 950 until 1300 (these are approximately 22 to 55 millions) prior to the crisis in during the 14th century (Comet 2000, 156). The only exception in the following, is the stagnation in the centuries, which were negatively affected by the great plague, the Hundred Years War et cetera. Interestingly, the Thirty Years War is not discernible in the data in terms of an obvious decline in population numbers (see also Livi-Bacci 1991).

How did the urban rate develop in the three major European regions? As one would expect (see Figure 21), – different than in North-Eastern Europe – in both,

FIGURE 21
DEVELOPMENT OF URBAN RATE IN THE THREE EUROPEAN MAJOR REGIONS
Source: see text.



Central-Western Europe, and particularly in the Mediterranean region, the urban rate increases during the period of the Roman Empire. In the centuries afterwards, population density experienced a decline, and then grew again all over Europe from the tenth century onwards.

As another determinant of possible relevance for nutritional status, we tested periods of supra-regional wars, and prosecution if they affected large parts of the population. We only included those that would most likely have an impact on the nutritional status due to their duration or frequency (e.g. civil wars in Mediterranean Europe at the end of the Roman Republic or the Thirty Years War for Central Europe). A possible effect could be worsened nutritional status due to long time fallow fields and scorched earth-tactics. However, better circumstances could be possible for the survivors due to a reduction of population density to an extent that this leads to an overall positive effect for the remaining population. As detailed information of the 'correlates of war' is only available for later centuries, we created a dummy-variable named "war/prosecution".[215] For centuries where conditions presumably affected a European region on the whole major level the dummy was coded as 1, for the remaining centuries the dummy was coded as 0.

Of course, diseases affecting large parts of the population also could have an impact on the nutritional status. Various diseases existed in early historic times, and are described in written sources, but a clear taxonomy did not exist. For example, plague' stands for any severe disease of epidemic proportions. Ancient sources mention many different occurrences ranging from widespread ergotism (especially in medieval periods of distress (Willerding 1986, 248) to the Antoninian plague. Moreover, those in Roman annals very commonly mentioned major epidemics, but the cited epidemic diseases are actually only very rarely detectable other than in non-literary sources. In order to

[215] The information is taken from www.ancientworlds.net, and http://de.wikipedia.org/wiki/Liste_der_Kriege.

capture a possible effect of major epidemics, we created a dummy only for those centuries in which plague epidemics predominated the environment.[216]

One of the important aspects of human-made determinants is the formation of different genders. Consequently, gender discrimination might be of special importance for mean height – in particular in explaining differences in average stature, if societies of (probably) different patriarchalic structure are studied (see chapter 4.4.). Here, the degree of gender discrimination is measured as relative height difference between males and females (dimorphism index DI); the variable in our regression is called "gender inequality". The expected impact is negative.

The expansion of the *imperium Romanum* brought direct changes, and resulted in indirect changes for the heartland and in the occupied regions. This caused differences in the living conditions and welfare, and therefore presumably affected the nutritional status of the population of people under Roman government in comparison to populations in non-affected Europe.[217] Overall, a positive, as well as a negative impact could have been the effect. In the case of the 'mother country' the expansion probably brought changes as this was the aim of any imperialistic efforts. This involved utilizing a new area in terms of an expanding arable land, cheap supplier of natural resources, and labor force (soldiers and workers) and the founding of new trading bases to enhance contact with regions further afield.

In the case of the new provinces, changes took place due to the impact of the offensive and battles. This was followed by changes in the population density due to an

[216] It is difficult to measure the impact of epidemic periods in a comprehensive way. For alternative strategies, see Steckel/Rose (2002).

[217] It depends on the region, whether the Roman occupation was more an integrative process, or performed as "extinctional" act: e.g. friendly trade contacts with the kingdom of Noricum, the Gallic War, or the annihilation of Alpine tribes. For an overview on the Roman provinces see Bechert (1999), with detailed bibliography on various aspects of military and settlement history, etc.

influx of the army, civil servants, traders and their families, and furthered due to newly introduced infrastructure – anything from a trading net, to water supply and public bathing –, and habits.[218] Even the newly established administration (and law) affected various aspects of individual and common living circumstances. In turn, this could range from sheer population number to the process of 'Romanization', and related changes in customs and techniques, as well as the economic restructuring. For example, the introduction of organized food supply could have equalized increased population density.[219]

The 'traditional' idea of Roman sanitation and hygienic facilities is a comparatively high standard.[220] However, a closer look reveals rather inadequate conditions as common (Scobie 1986; Thüry 2001); baths were often unclean and therefore unhealthy places. Furthermore, *cloacae* were constructed inadequately, and in

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[218] To some extent a positive impact also seems possible (or a 'counterbalancing' effect on the overall impact of predominant negative factors) thinking in particular of the typical Roman, in any context regularly consumed garum (fermented fish-sauce). However, considering Asian countries were much protein-rich seafood is consumed, only the increasing milk consumption of recent years brought the increase in height (Takahashi 1984). Moreover, it is questionable whether the fermentation process reduces the quality in comparison to fresh fish. Similarly, the cultivation of new crops, and diversification of food production (Willerding 1979) might had a positive effect. Furthermore, bettered housing quality could have had a positive impact (stone houses with heating systems common in Central-Western Europe during Roman times, resulting in lower energy intake requirements to sustain body temperature?).

[219] The Romans undertook measures to supply at least their male citizens with grain donations. – in particular in combination with increased grain production. Although Garnsey (1998) questions whether this support was adequate to cope the needs of the whole population, at least it could have been one factor in helping to provide 'stable' food supply conditions. – But then also in medieval times urban councils took action for supplying the population with cereals (with an economic interweaving between countryside and towns as important basic requirement in feeding a large part of the population); Engel (1993, 265) calls it a "kind of care policy". Thus, the question arises whether the Roman conditions make any differences for nutritional status in terms of caloric provision of the population.

[220] As many scholars presumed, having in mind aquaeductūs, and esp. balnea and thermae of complex technology.

insufficient amounts.[221] Moreover, water for consumption commonly only could be taken from public wells (Filgis 2005), for which the danger of contamination is passed on by ancient sources (Thüry 2001). Additionally, in Roman times people seem to have had a much undeveloped hygiene awareness (as emphasized by Jackson 1988; Thüry 2001). Sewage and latrines were often located near to wells, to kitchens, and even rivers, which were used for drinking water supply. At the same time, they functioned as garbage dumps. This resulted in a widespread spreading of parasites, which became even more pronounced because of the common use of public latrines, resulting in a spill of bowel diseases into vast parts of the population. According to Thüry (2001, 54), the circulation area of pathogens and diseases was augmented with the expansion of the *imperium Romanum.*

Another important factor, which presumably also explains stagnation of height during the Roman period, is that the exposure to lead was comparably high at that time. The ancient Romans not only used lead water pipes, but also utilized lead in cooking pots, beverage storage vessels, toys, cosmetics et cetera.[222] This could be important because lead is a toxin that affects growth (and thus height) negatively.[223]

Moreover, the impact of Rome's conquest and 'unification' of formerly isolated regions on infection conditions was of special importance (Duncan-Jones 1996; Stannard 1993). The army's movements and trade contacts resulted in long-distance disease propagation affecting more people, and thus increased the severity of diseases

[221] In the cities of Rome or Pompeii, households were by no means endowed with a comprehensive channel system, or other sanitation equipment; in most of the smaller cities sewage and all other rubbish apparently was 'lead away' straightaway on the streets. E.g., even from the famous Cloaca Maxima sewage was funneled into intra-urban sections of the river Tiber.

[222] see Stuart-Macadam (1991) 103: From the written sources we know that lead was even "incorporated into wine in as many as fourteen [known] different ways as a preservative and to improve flavour", this may be was also the case for some foods.

[223] See Stinson (2000), 434.

with impact on the economy. For example, the Roman army spread the so-called Antoninian plague (around 170 A.D.) over the whole empire after the Parthian War. Mass outbreaks in military camps, on the one hand, were probably made worse by the easy transmission of diseases (due to adverse sanitation, dense housing et cetera.). On the other hand, ancient physicians (such as *Herodianus*, *Hist*. 6.6.2.) blame inadequate diet as a cause; and “with such an explanatory bias, there might seem little place in medical discourse for questions of public health and of urban pollution” (Nutton 2000, 66). At the same time, average health condition was rather meager in those days.

To test whether an overall effect of becoming/being part of the Roman Empire is also recognizable in the mean nutritional status – and if so, in which direction the overall impact affected mean height – we generated a dummy-variable. It is paraphrased as being influenced by “Roman bath/technology”, being 1 for centuries and regions belonging to the *imperium Romanum* and there being under Roman impact, 0 for ‘untouched’ parts.

Which of these variables were most important for the development of mean height in pre- and early historic Europe?

4.3.5. Results: Determinants of Mean Height in Pre-Industrial Europe

In table 12 the results of different combinations of the variables are presented (the coefficients and p-values of each model are displayed in two adjoined columns). The conducted panel regression models are discussed in the following. As a reference group we employed Central-Western Europeans of the Migration Period/early Middle Ages, because this is the best represented group in the data set.

To start, we look at a model including all possible variables (Table 13, col. 2 and 3).[224] This model has an explanatory power of 49 %. In this case none of the possible variables has a statistically significant impact.[225] Exceptions are the period dummies standing for late prehistory and antiquity; both are statistically significant – on the 5%-, and the 1%-level; in both periods people were on average smaller in height than during the reference group.[226] In terms of economic significance,[227] higher cattle share results in a 0.59 cm increase in height, whereas the estimated log land *per capita* is also economically insignificant (see Table 13).

If we do not control for cattle share and land *per capita*, the adjusted R_2 is 0.43, and the regional dummy 'denominating' Mediterranean Europe becomes statistically significant on the 5%-level (Table 13, col. 4 and 5)[228]: Overall, Mediterranean Europeans were smaller in height than the people stemming from the other European regions. These regional differences in mean height indicate inequality in the nutritional

[224] We included all discussed variables except for climate, as data on this variable only cover the centuries A.D., whereas we have (as describe above) a much better temporal composition in height data. In a model were the climate variable was included (not shown here) the former finding could be varified that warmer temperature is of no siginifcant importance for overall mean height in the long run. That even the Medieval climatic optimum had no siginifcant positve impact probably can be explained by the contemporaneously extremely increasing number of population.

[225] Even innovative changes in the cultivation method make no change. Probable explanation for the missing effect of the utilization of 'three-field rotation' is presumably the paralelly exponential increase in population numbers. Controlling for changes in the cultivation methods solely we found this determinant to have a positive impact on the long run height development: it is statistically siginifcant on the 1% -level (not shown).

[226] A possible explanation, which we unfortunately cannot test at this stage of climatological research (see above), is the comparably detrimental climate in comparison to the reference group; at least for the pre-historic period climatologist give a first assumption that climate was presumably comparably bad; this could be also the case for antiquity, as their presumption that climatic conditions were rather good concern the later Roman period from the second century A.D. onwards.

[227] Multiplied with the standard deviation.

[228] If we exclude only cattle share from the model the 'Mediterranean Europe'-dummy also becomes statistically significant, but on the 10%-level. Moreover, the adjusted R_2 decreases a little.

TABLE 12

THREE REGRESSIONS
DETERMINANTS OF MALE AND FEMALE HEIGHT
IN THE THREE PARTS OF EUROPE

1	2	3	4	5	6	7	8	9
Region	**Whole Europe**		**Central-Western Europe**		**Mediterranean Europe**		**North-Eastern Europe**	
Constant	159.08	*0.00*	159.09	*0.00*	159.71	*0.00*	160.60	*0.00*
Status mid/high	0.50	*0.09*	0.11	*0.79*	-0.43	*0.79*	0.58	*0.37*
Male	8.01	*0.00*	8.09	*0.00*	6.75	*0.00*	8.23	*0.00*
Migr. Mediterr.	-1.42	*0.15*	-1.44	*0.16*				
Migr. Germanic	0.63	*0.09*	0.71	*0.20*	0.25	*0.67*	2.57	*0.31*
Centuries:								
-8	1.08	*0.01*	2.72	*0.00*	1.10	*0.05*	-6.90	*0.00*
-7	1.93	*0.00*	0.37	*0.82*	2.51	*0.00*	1.41	*0.34*
-6	0.53	*0.25*	-1.60	*0.04*	2.24	*0.00*	-0.77	*0.46*
-5	1.31	*0.02*	2.80	*0.29*	1.88	*0.00*	-4.44	*0.04*
-4	0.58	*0.35*	-2.51	*0.18*	1.77	*0.02*	-1.99	*0.18*
-3	1.49	*0.00*	1.09	*0.18*	1.98	*0.01*	0.	*0.30*
-2	-0.17	*0.77*	0.82	*0.26*			-2.2	*0.02*
-1	-0.97	*0.08*	-0.28	*0.72*	-2.13	*0.02*	-0.78	*0.55*
1	0.77	*0.03*	1.09	*0.05*	0.28	*0.72*	0.01	*0.99*
2								
3	0.99	*0.00*	1.18	*0.00*	0.35	*0.57*	0.52	*0.45*
4	0.89	*0.00*	1.00	*0.00*	0.43	*0.47*	-0.02	*0.98*
5	1.50	*0.00*	1.25	*0.00*	3.27	*0.00*	0.12	*0.87*
6	2.51	*0.00*	2.91	*0.00*	2.37	*0.00*	0.72	*0.29*
7	2.43	*0.00*	2.61	*0.00*	2.29	*0.03*	0.17	*0.86*
8	1.64	*0.00*	0.72	*0.09*			1.63	*0.01*
9	1.60	*0.00*	1.51	*0.01*	2.64	0.16	0.78	*0.24*
10	0.92	*0.02*	0.25	*0.63*	3.72	0.00	0.77	*0.33*
11	2.03	*0.00*	1.55	*0.05*	4.05	0.00	1.11	*0.06*
12	2.21	*0.00*	1.23	*0.10*	1.54	0.10	1.81	*0.01*
13	1.14	*0.00*	1.69	*0.07*	-2.03	0.33	0.27	*0.69*
14	1.46	*0.00*	1.94	*0.01*	6.41	0.00	0.09	*0.91*
15	1.71	*0.04*	4.41	*0.01*	2.51	0.02	-2.50	*0.12*
16	1.92	*0.00*	1.69	*0.01*	6.56	0.01	2.34	*0.23*
17	0.22	*0.71*	1.66	*0.06*	3.56	0.15	-2.16	*0.02*
18	2.30	*0.02*	2.63	*0.04*			1.06	*0.50*
Rhine, South	1.27	*0.00*	1.20	*0.00*				
Rhine, North	0.88	*0.02*	8.66	*0.09*				
UK	1.75	*0.00*	1.48	*0.00*				
Northern Eur.	2.24	*0.00*						
Eastern Eur.	0.77	*0.00*					-1.34	*0.00*
Mediterranean	0.26	*0.25*						
Adj.R^2	0.52		0.51		0.58		0.54	
N (original)	18502		8464		3572		6466	

P-Values in columns 3, 5, 7, 9 in italics. The constants refer to a Bavarian/Austrian (col. 2-5), a not further specified Mediterranean (col. 6/7), and an Eastern European (col. 8/9).

status, which is specified by the missing impact of the two excluded variables resulting in the height gap. Both factors subsume the benefical aspects of a pastoral economy, as Sandberg and Steckel (1987), Haines (1998), Prince and Steckel (2001), or Moradi and Baten (2005) found. The two variables of cattle share and land *per capita* are proxy for proximity-to-protein, and comparably good epidemiological environment, which are not given in the Mediterranean region to a similar extent such as in the other parts of Europe. This is because there agriculture is less specialized in cattle farming, which caused the negative effects of lower milk-supply, and coherent inequality effects due to the untradability of milk. Similarly, agricultural emphasis in cattle husbandry came into effect particularly for the local nutrition if population density was low, and as a consequence if land *per capita* was high. This finding is of special importance, because it confutes the assumption of the previous anthropological literature, which took for granted “racial” differences between different European populations, and explained height differences between Mediterranean populations and North-Eastern European populations by different genetic potentials. Thus, we have the confirmation also for the long run, which could be found for early modern Europe before (Komlos et al. 2003, Quiroga Valle 1998).

As a third model variation (Table 13., col. 6 and 7) only the two crucial variables: cattle share, and land *per capita,*[229] are utilized to test for their specific impact. In this model (adj.R^2 of 0.30) cattle share is positively statistically significant on the 1%-level, and in terms of economic significance, an additional standard deviation of cattle share implies 0.72 additional centimeters in height. But for the long run data from the eighth

[229] Results are more or less the same, it does not matter whether gender inequality is included or not.

TABLE 13

FOUR REGRESSIONS: DETERMINANTS OF HEIGHT

1	2	3	4	5	6	7	8	9	10	11	12	13
Constant	167.51	*0.00*	169.63	*0.00*	165.95	*0.00*	168.57	*0.00*	169.02	*0.00*	167.41	*0.00*
Mediterranean Europe	0.34	*0.79*	-1.10	*0.02*			0.26	*0.82*	-1.36	*0.16*		
North-Eastern Europe	-0.12	*0.86*	0.44	*0.25*			0.02	*0.96*	0.03	*0.96*		
Early Prehistory	-1.61	*0.23*	-0.89	*0.18*			-1.85	*0.06*				
Late Prehistory	-1.36	*0.08*	-1.07	*0.07*			-1.56	*0.01*				
Antiquity	-1.72	*0.01*	-1.39	*0.01*			-0.75	*0.21*				
High Medieval Period	-0.14	*0.91*	-0.81	*0.37*			-0.05	*0.96*				
Late Medieval Period	-1.00	*0.60*	-1.05	*0.38*			-1.19	*0.38*				
Modern	-3.17	*0.19*	-1.70	*0.19*			-2.92	*0.11*				
Cattle share	0.04	*0.22*			0.05	*0.01*	0.01	*0.66*	-0.01	*0.80*	0.04	*0.01*
Three-field rotation	0.79	*0.55*	0.72	*0.45*			0.82	*0.46*	0.24	*0.79*		
Cattle plague	-0.07	*0.89*	-0.24	*0.54*			0.25	*0.58*	-0.07	*0.89*		
Land per capita (log)	0.31	*0.82*			0.20	*0.70*			0.11	*0.90*	-0.22	*0.65*
Urban rate							-0.29	*0.01*				
War-prosecution	0.05	*0.90*	-0.04	*0.92*			0.10	*0.80*	0.20	*0.65*		
Plague	-0.08	*0.88*	-0.09	*0.86*			0.27	*0.59*	-0.03	*0.95*		
Gender inequality	1.22	*0.30*	0.53	*0.59*	1.67	*0.15*	1.20	*0.24*	1.51	*0.21*		
Roman bath&technology									-1.46	*0.02*	-1.43	*0.00*
Adj.R^2	0.49		0.43		0.30		0.61		0.44		0.43	
N	42		52		42		42		42		43	

P-Values in columns 3, 5, 7, 9, 11, 13 in italics. Weighted Least Squares Regression: number of cases adjusted for aggregated observations using square roots. Constant refers to a hypothetical height value for the Early Middle Ages, and Central-Western Europe. Statistically siginifcant coefficients marked grey underlayed.

century B.C. until the 18th century A.D. land *per capita* is again insignificant (also in terms of economic significance).[230] For this reason, the potential contributions of the protein proximity effect seem to be particularly important; perhaps because land *per capita* did not yet matter as much for the periods B.C., or because estimates are less precise.

To test in more detail a possible negative impact of a detrimental living conditions in terms of epidemiological conditions and actual supply situation, we control for urban rate in a further model level in combination with the other possible determinants (see Table 13, col. 8 and 9).[231] This model can explain 61%; here higher urban rate has a statistically – namely the expected negative – effect on mean height (p-value 0.01). However, none of the other variables are statistically significant except for the time-dummies comprising both pre-historic periods (on the 5%-, and 1%-level).[232] Both regional dummies become insignificant. If we do not control for urban share. Mediterraneans might have seemed to have lower mean height because in this region not only less husbandry was performed, but because of the higher urban rate there, which had the presumed associated detrimental effects. Higher urban rates 'induce' a bad disease environment, and inadequate housing conditions becoming particularly common in towns, as well as further accompanying precarious aspects such as worse hygienic conditions. What is more, it results in an increased decoupling of the urban settlers from the supply cycle of protein-rich food[233], which resulted in a relatively low and un-equal

[230] The importance of this determinant, which was discovered in an earlier paper, counts for the centuries A.D. – especially the ninth century onwards, when population pressure obviously became essential.

[231] Except for cattle share (and ln land per capita) to prevent multicolliniarity

[232] A possible explanation for the statistical significance of the pre-historic periods affecting mean height in any case could be the supposed, but by now not testable effect of worse climate conditions.

[233] Food supply became less ample (in quality and quantity) due to the competition between town dwellers, and even more extreme due to the novel introduced ratio of not in food production working people).

protein supply for the mean population. Thus, higher urban rate influences the mean height of the population negatively.

Finally (see Table 13, col. 10 and 11), the first model was varied by supplemeting the ‘Roman bath&technology’-dummy instead of the time dummies in the regression (but with all possible explaining variables considered; adj.R^2 is 0.44), revealing that actually the ‘gross-effect’ of being part of the Roman Empire was a negative one: the ‘Roman bath&technology’-dummy has a statistically significant negative impact on mean height of -1.46 cm (on a 1%-level). But again, none of the other variables turn out to be significant. We can see that, other than the temporal development by the major regions (discussed above) would suggest, the ‘Roman impact’ has a considerable effect on the provinces outside the Italic heartland as well. Testing the effect of ‘being part of the Roman Empire’ for each concerned region solely (not shown here) we found the impact for Mediterranean Europe was more extreme than for Central-Western Europe – correspondingly to the impression one gets, studying the temporal development. However, the Roman influence is negatively significant in both regions.[234] Also in this version, the insignificance of the ‘Mediterranean Europe’-dummy disappears as soon as one excludes cattle share (and land *per capita*) from the model (not shown).

If we control solely for the ‘Roman effect’, cattle share and land *per capita* (Table 13, col. 12 and 13), the former variable remains statistically significant, and additionally cattle share becomes positively statistically siginficant (both on the 1%-level). In terms of economic significance overall the positive impact of a higher cattle share

[234] Testing the Roman impact by single region we can see that one finds the Roman impact to be also a significantly negative one in the Central-Western case (albeit affecting mean height little less than in the South): -1.14 cm, p-value 0.02 in Central-Western Europe, in comparison to -1.57 cm, p-value 0.01 in Mediterranean Europe (not shown here), and as expected, no impact on North-Eastern Europe. The Roman impact on Mediterranean Europe remains negatively significant also if we exclude the extreme low value of the first century B.C.

predominates the negative Roman impact: +0.6 cm versus -0.5 cm (see Table 14). Although this regression model has a somewhat lower adjusted R_2, it still can explain 43% of mean height.[235]

TABLE 14
DESCRIPTIVE STATISTICS

1	2 N	3 Minimum	4 Maximum	5 Mean	6 Std. Deviation
Log land per capita	78	-3.78	-0.17	-2.15	0.77
Urban rate	78	0	19.75	4.49	5.33
Plague	78	0	1	0.15	0.36
gender inequality (relative)	56	0.26	1.35	0.95	0.20
Cattle share	53	14.64	14.64	45.04	15.79
Roman bath&technology	78	0	1	0.17	0.38
Cattle plague	78	0	1	0.18	0.39
War&prosecution	78	0	1	0.36	0.48
Three field rotation	78	0	1	0.31	0.47

The regressions show the expected hypotheses to be verified that higher cattle share has a positive impact, whereas increasing urbanity, as well as ‘Roman

[235] One explanation for the less detrimental impact in Central-Western Europe could be that additionally to the specialized ‘mass production’ on the latifundia (large estates) in the “breadbasket” of Rome in the provinces of Aegyptus and Africa, and brisk trade with the so-called North-Western provinces and the Italian region (negotiatores cisalpini et transalpini), as well as the farther Mediterranean region, necessary food was primarily produced in the vicinity around military and civilian settlements: A ‘net’ of villae rusticae (farms) was established to cope with the growing demand for food (clear aim was to go beyond the volume of production for internal consumption). It seems to have been a downright ‘colonization program’ (Sommer 2002). Remarkably the villae (Czysz 2002) were primarily situated in areas of best soil quality, combined with other site advantages like proximity to water resources, or good connection to the transportation infrastructure and vicinity to the selling market (and even preference of southward oriented hillsides) – and in these optimal locations the villae covered a region densely: see e.g. middle Neckar river region (Nuber 2005, 272). According to the archaeological findings the agricultural enterprises worked provitably in the North-Western provinces until the beginning of the third century A.D. In this context one should keep in mind that it is not only the extremely increased population density per se, with which the authorities had to cope; moreover, the first-time in European history, people hade to cope with the newly ‘introduced’ structure that large parts of the population had to be supplied with foods, because they were not employed in agriculture themselves, and thus dependent on provision.

bath&technology' has a significantly negative impact.[236] The question of whether being part of the Roman Empire has a negative impact on nutritional status of early historic Europeans or not, could be clarified for the first time by an anthropometric approach. Overall, the negative aspects of belonging to the Roman Empire outweigh any positive aspects. In contrast to the common idea of a positive Roman impact, being part of the Roman Empire and the accompanying changes, including any efforts made by the administration, did not result in better living conditions. Those aspects were not sufficient to make the Roman period an improving one in terms of height development: Our results display a negative effect for nutritional status in the European population.[237]

The result that in any of the models none of the other possible determinants, except for some of the time dummies, actually show an impact on mean height can have different reasons. On the one hand, insignificance of the variables may result from the vague information on the determinants, which results in rough proxies. In particular, this holds presumably for war/prosecution and cattle plague. On the other hand, however, the finding of no significant impact can be explained by 'counterbalancing effects'.[238] These might come into effect in case of war/prosecution and plague, which in the present study cannot be differentiated due to the low temporal resolution of the

[236] Because of a certain dating insecurity (due to the archaeological basis of the data) the impact of the discussed possible determinants for only those observations, for which an exact deposit date could be ascertained, was studied, to discard possible estimation errors. The results are very similar: The only determinant of statistical significance is urban rate (not shown here). This also applies to the results if one excludes heights stemming from cremation burials (which actually provide a statistically significantly lower mean height than data from inhumations).

[237] In terms of food supply, an important factor certainly is that the concentration lay within the feeding of people with calories to enable their surviving, whereas an adequate supply with animal protein could not be provided.

[238] For example, in the case of the "agricultural invention" dummy, the contemporary very dense population probably can explain the missing impact. An intense research discussion is going on which of these both factors actually was the trigger for the other one.

data. Counterbalancing effects could be the explanation, particularly considering the missing impact of land *per capita*. This indicates that in the long run the assumption of the “Malthusian trap” might be correct: as soon as population density decreased, nutritional status improved, which immeditaley initiated an increase in fertility rate, and thus an increase in population density (or decrase in land *per capita*), which resulted in inadequate nutritional status, and vice versa. Similarly, Scott and Duncan (2002, 15) summarize that “density-dependent constrains (operating via exacerbated malnutrition) reduced fertility and increased child mortality, thereby returning the community to steady-state conditions”. However, this Malthusian ‘up and down’ cannot be analyzed in this study due to the low temporal resolution of the data. Thus, it also could be possible that the explanation by Boserup (1966) – that the population is always able to feed their members – is correct. Similarly, Garnsey (1990) stated that food crises were frequent, but not disastrous “in large part because of human anticipation and adaptability. Secular responses to … vulnerability of populations led to increase agricultural production, emergency imports and food distribution”[239], which seem to have compensated a possible negative impact of higher population density (or lower land *per capita*).

4.3.6. Conclusion

To conclude, final adult height ‘subsumes’ nutritional status that is ‘composed’ chiefly of quantity and quality of diet, disease and work load, and therefore living conditions. This fact provides the possibility to measure differences in nutritional status by using mean height as indicator, which enables the study of living conditions in periods for which no adequate written sources exist, but information from physical anthropological

[239] Garnsey (1990) 144.

data provided by archaeology. The anthropometric approach was employed here in order to study the development of the biological standard of living and its determining factors in Europe in the long run from pre-, to early modern centuries. The study period naturally ‘induces’ some unavoidable uncertainties as a result of the archaeological context. However, despite certain shortcomings of the estimates the study certainly provides interesting findings – also for other contexts.

We found only a very small positive trend in mean height for the total study period, but remarkable variations between centuries, and the three different European major regions. This means, that the nutritional status experienced no continuous improvement (or deterioration).

Within the context of long run mean height development the influence of the expansion of the *imperium Romanum* on the European population is remarkable. In contrast to the public idea of benefit due to ‘civilization’ the data indicate that it was of negative impact, especially for the Mediterranean region.

Controlling for cattle share we could make the finding that overall no significant regional inequalities in nutritional status did exist in the three major European regions: If husbandry was present, basic human needs were met comparably well. Consequently, the statement of earlier scholars who supposed that height differences between Mediterranean Europeans and North-Eastern Europeans in pre- and early history were genetic, is corrected by observations collected on these periods presented in this paper for the first time.

A third important determinant for mean height is urban rate. The negative effect of increased urban rate is in agreement with the idea of problems in competition for food supply, and detrimental health conditions in pre-modern towns.

None of the other supposed explaining determinants actually had a significant impact on mean height in the long run. The set of endogenous variables in use (such as animal protein availability, climate etc.) can explain up to 61% of the European mean height development.

Aspiring after knowledge on the very long run economic history, the interdisciplinary approach of combining anthropometry and archaeology is an ideal method, because it makes available indispensable insights into some of the central aspects of human life.

4.4. THE RELATIVE STATUS OF FEMALES IN PRE- AND EARLY HISTORIC EUROPE

4.4.1. Introduction

Females generally have a smaller mean height than males due to biological factors, but this difference is varying due to socio-economic and cultural factors. The resulting environmental conditions cause different nutritional status (Eveleth and Tanner 1976). The relative height difference does not increase with mean height (Gustafsson and Lindenfors 2004).[240] Based on these facts, the question is analyzed whether females had a better or worse relative status than males in particular periods and regions of prehistoric and ancient times. In addition, we used the survivability of females in comparison to males in order to measure the varying impact of socio-economic and cultural factors on the relative status of females.

The study is based on data from archaeological burial excavations that bring information on males and females in a representative amount. This is an advantage in comparison to most of the studies on height in early modern times where mainly men appear in the data (such as in recruitment lists) or, if at all, only a low number of female observations are given (such as in church books or prisoner lists). This possibility of quantitative analyses allows us to check the quite vague image of the status of pre-, and early historic women that one gets when considering solely archaeological small finds (grave goods) and historical sources.

This chapter is based on a working paper: Koepke (2008b).

[240] They were able to reject the hypothesis of increasing relative difference with increasing mean height by reanalyzing data using the so-called phylogenetic method to correct for errors resulting from the study of people of similar ancestry.

As a result, on the one hand, an overall picture of the whole population can be created for the centuries 800 B.C. until 1700 A.D., and on the other hand a comparing study of males and females and of the differences in their welfare in terms of nutritional status development can be conducted.

The paper is structured in the following way: firstly, we will give an introduction on height dimorphism between males and females, including a detailed review and discussion on female buffering vice versa female discrimination, and an introduction on the so-called primary female deficit (differences in the survival rate between males and females). Secondly, the obtained insights will be applied on skeletal material: the development of the difference in the survival rate and the height dimorphism is studied for pre- and early history in Europe, based on a collection of more than 18500 observations.

4.4.2. Factors of Dimorphism

The term dimorphism is defined as "having two forms"; usually it means the existence of two distinct types within one species. Studying dimorphism in height between male and female human beings, one can differentiate sexual and gender dimorphism. Sexual dimorphism here is used in its meaning of physical or behavioral differences associated with biological sex. Gender dimorphism is used in its meaning of physical or behavioral differences caused by the environmental, cultural and socio-economic perception of females and males: "Gender is a cultural creation (gender is not something we are, it rather is something we do that is a result of nurture)" (Lippa 2005, 118).[241]

[241] Further discussion of sex versa gender see e.g. ICIMOD newsletter, cited in Reinhold (2005); Sørensen (2000, esp. 42 ff.).

4.4.2.1. General Aspects: Dimorphism in Height and Differences in Survivability between Males and Females

One characteristic of dimorphism in biology of humans is the difference in height, because in general, females are smaller in mean height than males (Frayer and Wolpoff 1985). Various factors have had an influence on the extent of sexual dimorphism during evolution with the result that the height difference in humans is relatively low in comparison to other primates.[242]

Apart from the basic biological difference it has been found that mean height can additionally vary due to socio-economic factors.[243] This is called gender dimorphism: resulting from inequitable resource allocation between the genders.

Hence, height dimorphism is determined (1) by the genes – they predefine the potential for human height (for example the impact of sexual differences regarding the growth hormone[244]) –, and additionally (2) in particular by environmental circumstances – they determine the attainability of this height potential (Connellan et al. 2000) –, which can be differentiated into the consequences of available net nutrition and its distribution on males and females.

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[242] Thinking of evolution, a complex research discussion is going on, which are the most important impacts (ontogenetic or genetic) resulting in height dimorphism (Ghesquiere et al. 1985), and in how far sex and gender and vice versa are related (Gilchrist 1997). Various different determinants are discussed in the literature, like male-male competition, reproductive strategies, or the women's work hypothesis, and task sharing between males and females etc.: Anderson 1994; Plavcan et al. 2002; Lee 2005; Thorén et al. 2006; Nettle 2002; Ruff 1987. But "no consensus has yet emerged" (Guégan et al. 2000, 2533).

[243] Eveleth and Tanner 1976; Bogin 1988; Floud et al. 1990; Fogel 1994; Steckel 1995; Steckel 1998; Komlos 1989; Komlos and Cuff 1998; Baten and Murray 1998; Boldsen and Sogaard 1998; Baten 2000; Clarke 2000; Smith et al. 2003; Meisel and Vega 2004; Moradi and Guntupalli 2004.

[244] e.g. Rosenfeld 2005; Seemann 2001. Before puberty, there are only small sex differences in body shape and composition. (see also Wolanski and Antoszewska 1992). According to the current state of research this basic sexual dimorphism in height is based mainly on the fact that in comparison to girls boys start approximately two years later (and accordingly taller) into the adolescent growth spurt, having a higher peak (Gaulin and Boster 1992).

Furthermore, female-male differences in the survival rate can indicate differences in the treatment of males and females: it is known from various studies on recent decades (Sen 1985; Fathalla 1998; Klasen 2002; George 2006; Olds 2006; Zilberberg 2007) that immediate killing of girls with birth, or starvation to death during infancy (feminicide), due to their disadvantageous status in societies, can reduce the number of adult females drastically. Whereas, in contrast boys are rated much more highly (because of their contrasting economic power in later life).

4.4.2.2. Elementary: Nutrition Effects

Adequate nutritional status (or net nutrition) has a positive impact, whereas inadequate conditions have a negative impact on the survival rate as newborn and infant, as well as on final height for both females and males. Temporary shortage or chronic dearth of adequate nutrition causes retardation in growth or even stunting, and in extreme cases can lead to death. This can result not only from immediate starvation, but also due to gradual deterioration of the nutritional status, which also can lead to other problems, for example, debilitation of the immune system. This is confirmed by various studies, which found detrimental environmental conditions to have a negative impact on stature, whereas increased nutritional and overall health levels have a positive effect on mean height.[245]

If females and males have to cope with different conditions, therefore this will affect them differently, which will result in differences in height dimorphism. Therefore, particular fluctuations in the degree of height dimorphism are dominantly determined by changes in environmental conditions regarding nutritional status (Al-Dabbagh and Ebrahim 1984; Scott and Duncan 2002), which in turn is influenced by economic as well as non-economic role differences (Sørensen 2000, 99 f.). Clarke

[245] Floud et al. 1990; Gray and Wolfe 1980; Eveleth and Tanner 1976; Ruff 2002; Stinson 2000.

(2000, 85) sums up the aspects which demonstrate female neglect. Several of these determinants do not solely result in the 'missing females' the author discusses, but also in reduced female mean height, because poorer nutritional status results in reduced final height.

An important basic finding for the current study is the result of Gustafsson and Lindenfors (2004): They focus on the relative height diversity that is the difference between height of males and females divided by the height of males. The ratio is used as quantity to describe the height dimorphism, called dimorphism index. This quantity is independent of the mean height of a population, although in any case the absolute difference between males and females is increasing with increasing height, obviously.

The dimorphism between the sexes does not necessarily increase with increasing stature in humans. Once a correlation between height and dimorphism can be eliminated, the question remains, whether variations in the dimorphism index can be explained by the female biological superiority in reacting on changes in nutritional status, or by the dimension of socio-cultural set, gender specific differences in nutritional status.[246]

4.4.2.3. Females, the More Robust Sex?

The idea of better buffered females – means greater stability of females against nutritional pressures – is based on the hypothesis that the female body makes provisions against perturbations to ensure its function in pregnancy, lactating and rearing[247]: Thus,

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[246] The effect of socio-cultural determination can be pronounced due to class system with resulting social inequality in resource allocation (see Bogin and Keep 1999); but here looking at the overall population this aspect makes no difference.

[247] If the female body actually would be more buffered in order to ensure the continued existence of the species, overall, females should display a high(er) survival rate. Or at least, it would be sagacious in terms of evolution that worsened conditions during pregnancy have no (extreme) detracting effect on the foetus and infant, which even influences adult health – however, actually this is the case: see various works by

the assumption is that in females rather than in males, height fluctuates to a lesser degree in either direction because hormonal compensatory mechanisms act to cope with the demands of the female role.[248]

Guatelli-Steinberg and Lucacs (1999) discuss the question of female buffering by analyzing studies of different researchers on various possible indicators of female biological superiority showing divergent results in terms of whether it is 'fiction or fact'. In particular, differences between males and females in enamel hypoplasia clearly indicate "that cultural practices of sex-biased parental investment after birth have more powerful effects … than does greater male vulnerability" (Guatelli-Steinberg and Lucacs 1999, 118). However, results of the review are less clear when looking at the long bones. Nevertheless, conforming to the later publication to of Gustafsson and Lindenfors (2004), already Stinson (2000) in her overview on human biology, assumes that females do not show a stronger biological buffering against stressors than males

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Barker et al. (cited in Scott and Duncan 2002), De Onis et al. (1998); Wu et al. (2004); Langley-Evans and Carrington (2006); Martin-Gronert and Ozanne (2006), Roseboom et al. (2006). In particular, (1) preterm birth – which is an especially detrimental basic for further life – is related to low maternal pre-pregnancy body-mass index (Merlino et al. 2006), and (2) inadequate nutritional conditions in the pre-natal period result in small birth size, which both in turn determine neonatal morbidity and mortality negatively (Mericq 2006). Furthermore, maternal nutrition influences lactational performance, which is significant for the growth development after birth until weaning. The only aspect which hints towards a somehow sensible evolution strategy is that the set in of menarche seems to be related to nutritional status (Ong et al. 2006).

[248] For example, Ortner (1998) proceeds on the assumption that females are better buffered; however, the author refers mainly to differences in the impact of infections on and differences in the immune response of both sexes. But at the same time he remarks that "pregnancy is a significant cause of death in developing countries", thus apparently the proposed adaptive response is not sufficient. Moreover, for example, recent studies on myocardinal infarction found that the lower number in affected females in comparison to men can be explained by lower diagnosis probability in the former. Furthermore, "early invention … resulted in a beneficial effect only in men which was not seen in women" (Tillmanns et al. 2005, 375); and 30 days after a myocardinal infarction health status in women "is similar to or worse than that of men" (Garavalia et al. 2007).

which is in contrast to Stinson (1985) and others' earlier assumptions.[249] Stinson (2000) convincingly concluded that the earlier explanation that individuals of small height (without concurrent wasting) have an advantageous position under nutritional stress due to their lower nutrient needs cannot mean that stunting is a no-cost response to undernutrition. Furthermore, she adds that by now no exact mechanisms are known "that may lead to females being less sensitive". Thus, there probably is no "natural selection against those with certain genes but rather environmetal factors … affect both body size and the probablity of survival" (Stinson 2000, 454). Similarly, Stinson (1992) came to the conclusion that the hypothesis that males are less buffered is mainly supported by the prenatal period, but that "investigations of postnatal responses to environmental stress have yielded much less consistent results, in large part because of the fact that male children are given preferential treatment in many societies".

Osmani and Sen (2003) have compellingly argued that gender inequality *ceteris paribus* has a reducing effect on mean height, because female discrimination hurts both girl's and boy's height if their mother lives under unfavorable nutritional conditions. This also explains decreasing dimorphism other than less buffered males.

Therefore there may be a biological difference in 'robustness', but this difference is more than compensated by cultural factors, inducing male dominance, and thus worse female position (instigating an ample spectrum of discrimination).

4.4.2.4. Females, the Discriminated Sex?

In general, females are exposed to more aggravating circumstances, because they are the ones who are regularly discriminated more, in terms of nutritional and health care, especially under overall insufficient conditions (Clarke 2000).

[249] See for example: Ortner 1998; Schweich and Knüsel 2003; Frayer and Wolpoff 1985; Gray and Wolfe 1980, 1982; Stini 1969, 1972, 1975, 1982, 1985; Buffa et al. 2001.

Many recent studies on modern times support the 'not better buffered females'-theory (Neumayer and Plümper 2007; Plümper and Neumayer 2006; Holden and Mace 1999; Klasen 1996; Yang et al. 1996; Walker 1997; Bennett and Eisenstein 2001; Larson et al. 2006; Chun et al. 2006; Choi and Lee 2006; Lopez-Blanco 1995). All of them found gender discrimination to have an important impact on dimorphism in different fields of the living standard. For example, female deficit results from gender specific discrimination due to social atmosphere, cultural and religious impacts in the access to food and health care, are resulting in under-supply, which brings about excessive mortality of girls and women (Klasen 2002).[250] Similarly other studies found gender differences in health care and expenditure resulting from parents who practiced neglect of girls (Hill et al. 1995). If one gender is treated with preference, this naturally affects nutritional status, and therefore has a direct impact on gender dimorphism.

In the extreme worse case female neglect result in femicide, which means that females are 'disposed' as children to yield resources for males[251]: being directly killed shortly after birth, or during early childhood being gradually eliminated through neglect and discrimination, resulting in fatally inadequate net nutrition.[252]

Gender discrimination results in adverse conditions impinging especially on female mean height more than on male mean height – which is tantamount to the negative effects of gender bias in allocation (Boldsen and Sogaard 1998, esp. 472; Baten 1999; Baten and Murray 1998, 2000; Svedberg 1990; Eveleth and Tanner 1976; Bogin 1988; Floud et al. 1990; Fogel 1994; Steckel 1995; Steckel 1998; Baten and

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[250] On inequality in food allocation: see also Croll (2000), and on inequality in health care e.g.: Aldermann and Gerter (1997).

[251] On femicide Fathalla 1998; Oomman and Ganatra 2002; Boix and Rosenbluth 2004; George 2006; Zilberberg 2007.

[252] On infantile malnutrition as abuse, resulting in marasmus or kwashiorkor: see Piercecchi-Marti et al. (2006).

Murray 1998; Boldsen and Sogaard 1998; Baten 2000; Smith et al. 2003; Meisel and Vega 2004; Moradi and Guntupalli 2004).

Particularly, gender bias in food provision favoring boys, and its subsequent effects on growth and illness are subject of various studies. (Sabir and Ebrahim 1984; Al-Dabbagh and Ebrahim 1984; Khuwaja et al. 2005; Hugo et al. 2001; Shah et al. 2003; Zhou et al. 2005; Baig-Ansari et al. 2006). Within this context Frongillo and Bégin (1993) already remarked that gender bias in food intake can “be exacerbated by conditions of seasonal scarcity, famine or chronic poverty … [and that] in areas where women’s economic productivity is high gender bias … may be less common.”(189). Similarly, more recently, Moradi and Guntupalli (forthcoming) could prove that improved nutritional conditions influence male and female mean height in similarly positive ways, but that aggravated nutritional conditions result in increased sexual height dimorphism index indicating increased gender discrimination.

In more recent times the tradition of a dowry, and daughters leaving the family (patrilocal marriage) have an effect on discrimination and neglect of females (Hill and Ball 1999; Klasen 2002; Baten 2006; Clarke 2000). Universally valid is that, where a “child has the potential to contribute to subsistence needs of the parents or siblings, the child in question will be less vulnerable to the withdrawal of parental investment in early life (be it by infanticide or reduced investment as the less-favored sex)” (Hill and Ball 1999, 33, and correspondingly e.g. Holden and Mace 1999).

The less powerful bargaining position of females finally nowadays results in the fact that females are ignored as protection-, and maintenance-worthy (Al Gasseer et al. 2004). For modern times, Plümper and Neumayer (2006) found wars – in terms of their indirect consequences on public health provision, agriculture et cetera – to have a more negative impact on females. In addition, Neumayer and Plümper (2007) found natural disasters to result in more negative direct, as well as indirect consequences for females in comparison to males.[253]

Moreover, it is important to keep in mind that discrimination practices, which neglect girls can have serious consequences for their health that “may even jeopardize their ability to fulfill their future roles as mothers, workers…” (Frongillo and Bégin 1993, 189), which result in a negative impact for the welfare of the overall population.

Hence, changes in environmental conditions affecting both genders differently result in temporary-temporal or regional variations in height dimorphism.

4.4.2.5. Females in Past Times

Additional to the studies on modern times providing concurrent evidence that females are not better buffered, instead, cultural factors determine dimorphism, qualitative interpretation of archaeological small finds dating in early prehistory in combination with osteological data and corresponding theoretical assessment provides information speaking for (more) discriminated females.

However, discrimination in females did not arise until sedentariness: most recent findings show that in pre-sedentariness periods both males and females worked in similar and overlapping fields. There seems to be no (definite) gender separation in hunting-gathering-societies (Hamlin 2005; Owen 2005; Bolger 2006; Brumbach and Jarvenpa 2006; Peterson 2006). Likewise, Cohen and Bennett (1993), reviewing different studies on health indicators in female skeletons (such as anemia symptoms), found more beneficial conditions for hunter-gatherer women in contrast to women of

[253] In these studies the effect on life expectancy in modern time is the subject, but the results certainly can be transferred to pre-modern periods, and to all BLS representing aspects; especially as Neumayer and Plümper (2007, 27) found “a systematic effect of disaster strength on the gender gap … if the disaster affected societies, in which the socio-economic status of women is low”.

agricultural societies (MESO).

This equality was probably the case even in horde defense: females presumably did not only hunt to feed their children, but also defended their offspring themselves. Likewise, one would presume a lower degree of dimorphism due to equal working fields of females and males in the beginning of human existence. Nonetheless, what certainly did make a difference from the very beginning of human evolution onwards is that generally the females, in addition, had to raise their offspring (Nettle 2002). Thus, because both males and females basically need similarly high energy input to cope with the tasks of life, and are skilled in a similar way in obtaining food – in the case of males a higher supply amount can be produced per person, which they can use for themselves, or to support the females in rearing the child. Therefore, those females benefit "who are more successful at obtaining male parental support", in contrast to the females without the advantage of additional supply (Wooders and van den Berg 2001).[254]

If the male parental support is provided, the next factor determining dimorphism is whether female and male offspring are treated similarly, which means whether good 'quality food' (and health care) is distributed equally to both male and female children or not.

Later congregational of evolution, after hunting and gathering societies, the situation changed from early farming societies onwards. With the emerging of sedentary societies – accompanied by increased population density and resources running short(er)

[254] This is especially pronounced in hunter-gathering societies, but it is transferable to later ones (here additionally to time, moreover money of each male is the limiting factor for the males parental support - except for the basic limiting condition that the males do not use the achieved surplus for their own to compete against other males); even today mothers assume greater responsibility for demanding tasks of their children in comparison to the fathers, irrespective the basic fact of biological reality of pregnancy (and the period until weaning) ensuring "that most mothers invest more time and energy in their babies than fathers do"(Lippa 2005, 245).

– the pre-eminence of males followed (Peterson 2006, 537 ff.). For example, Bandarage (1997, 121) concludes that "evidence from around the world shows that women in agricultural societies came to enjoy a less favorable status than women in the band-organized gatherer-hunter societies". Similarly, Roosevelt (2002, 327) states that there is "a strong… trend from patterns of gender equality in hunting-gathering societies to relative inequality in state societies".[255]

In this context it is of special interest that with the Neolithic sedentariness violent assaults and struggles ascent: Beyneix (2007) defines the phenomenon as 'the beginnings of war'.

In the course of state constructions males were enabled to assert themselves, and suppress females. The female's equal status has been degraded by a general propagation and finally 'pure' association of men to any kind of troop defense in a wider sense, and warfare.[256] Likewise, Hamilton (1982, 145) states that one "may hypothesize differential treatment of males and females … [to be] possibly encouraged by the warfare" – which is backed up by Bandarage (1997), Boix and Rosenbluth (2004) and others. Therefore, the existence of (regularly) two genders was employed to introduce distinct power structures: this fact influences aspects such as the distribution of resources and it establishes, in turn, social roles that again in turn are used to justify

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[255] Gender equality means social and economic power of women, and gender-balanced ideologies; inequality related to organized physical oppression, as well as centralized economic and political control in societies that are oriented to value males more in comparison to females. Community, governmental and religious organizations invent an ideology of gender-dominance in sedentary and crowded contexts.

[256] In general graves with weapons provide physical anthropological material indicating that males were buried: this is the case all over Europe, and not only for men of the Bronze period (see Reinhold 2005, Treherne 1995); it does not matter whether taking into account early ore late Iron Age people, Romans, or Migration period and medieval populations. Albeit the general rule naturally single exceptions are known (Fantham et al. 1994, 274).

inequality (and dimorphism) between men and women (Lippa 2005; Gerry and Chesson 2000, 261; Gero and Conkey 1991).

Another aspect that is discussed in the literature is whether in the course of sedentariness, the contribution of females in agriculture declined or not, due to intensified agriculture and technological change, which were caused by increased population density. The introduction of the plough seems to have been an important determinant in affecting the female status negatively: Boix and Rosenbluth (2004) presume that it could be shown in ethnographic comparison (for example Boserup 1970) – also in pre- and early history it was mainly men who were steering the ploughs, because this needs a lot of muscle power. For example, records from late medieval France show that "plowing was carried out exclusively by men …while … women were responsible for the smaller livestock" (Crabtree 2006, 585). But on the other hand women were active in many exhausting fields, in which muscle power would have been advantageous.

Women's "relegation" to the domestic realm followed, which further resulted in the decline of their social status (Peterson 2006, 539): patriarchalism began. A discussion is going on whether or not, and to what extent, females were still working in approved/honored sectors, and thus could strengthen their relative status in the following centuries. The debate refers to when in the course of time women were regularly active 'only' in the household, including textile production, pottery, basket making et cetera (Sherrat 1996) or whether females were additionally employed commonly.[257]

[257] For example, contrary points of view are given in the literature relating animal husbandry and pastoral production: whether mainly men worked in this field (Barfield and Chippindale 1997), or also women were active in this field. At least for medieval Europe Women are proven to have been active in husbandry (according to written sources especially for Early Medieval Ireland: Boyle 2004).

Finally, this development caused a general social control and dominance over females 'legalized' on an ideology of a dichotomous division of the world (male/female, brains/body, reason/emotion et cetera), which resulted in an ideology of 'true womanhood'. The common mobile-immobile labor division between genders of sedentary societies means the preponderance of men in paid work and the predominance of women in the home "with women's subordination to the needs of the family" (Bose 1989). Women's property of goods and facilities were for the most part not formally recognized in these systems. "Men gained power through the establishment of formal military and political roles, tipping power relationships in favor of males over females" (Roosevelt 2002, esp. 276 f.). This strengthens the male status as breadwinner, because only chances of both partners outside the family are seen as decisive. Furthermore, this results in more economic independence enabling them to act more autonomously –, whereas inner-household work is not adequately appreciated in most societies (Sen 1990; Klasen 2002; Boix and Rosenbluth 2004; Ott 2002). This results in a more powerful bargaining position of males, and therefore the status of males is seen as the part which has to be especially supported, cared for, supplied with more food et cetera (see Halsall 2004, esp. 302 f.). Correspondingly, Holden and Mace (1999) found height dimorphism to be negatively correlated with the participation of females in labor force, both in archaeological as well as in modern populations: they found women to be taller, in relation to men, in societies where women contribute more to food production, because the possibilities of females induce balanced parental investment. Thus, relative height dimorphism is related to variation in sex-biased parental investment.

Correspondingly, another aspect, which indicates differences in the 'valency', status and treatment of males and females, is the discrepancy in their survival rate: An important indication of female discrimination in pre- and early historic populations is the phenomenon that all pre-historic and ancient populations display a so-called primary deficit in females (Volk et al. 1988). Distinctly fewer females can be found in archaeological context than male remains.[258] This phenomenon certainly cannot be explained on the 'preservation level' by sex specific difference of skeletal material[259]. Instead, the main reason for the primary female deficit is that a smaller number of adult, mature and senile women are deposited in graves in comparison to men, because a smaller number of females lived until this age. Similarly to modern times (in developmental countries) the explanation for "missing women" is femicide. Because the bone remains of children[260] cannot be sex determined, the 'equal' existence predominance of females cannot be identified in these age groups.

The femicide is probably mainly caused, not due to 'conscious' or 'unconscious' control mechanisms[261], but results from patriarchy, which was the common ideology and organization of former societies. The misogynistic strategy of patriarchy results and resulted not only in the subordination of females to male control (and thus preference of males in all aspects of life), but in particular this also motivated fathers in wanting a

[258] Additionally, the so-called secondary deficit describes the phenomenon that fewer females of old age can be found in skeletal material in comparison to males, and thus that females mostly died in younger adult age due to problems in the course of parturition, and childbed fever.

[259] Walker (1995) pointed out that it is possible for some sites that female bones survived in smaller numbers, because women's skeletons often are more gracile and more easily subject of decay. This might be the case at a few sites, but overall this should not be a problem for Europe. Anyhow other than according to his statement that this could be a plausible explanation for the puzzling finding, this explanation is not required, because it is not at all 'demographically unlikely' that less females survived to adult age: as shown below.

[260] Furthermore the number of surviving children bones is comparably small due to several factors resulting in bad preservation conditions of the very delicate bones.

[261] These could be a 'preventive check' (femicide and debilitation of women and children by food taboos as method of population regulation/control) and/or a 'positive check' (reduced fertility and increased infant mortality during famine periods): see Scott and Duncan 2002, 15; Haidle 1997, 14 ff. Moreover, e.g. according Freud (cited by Volk et al. 1988) another explanation could be that a woman wants to have a son due to her heterosexual affinity.

fully legally capable male descendant. Moreover, parents felt protected in their retirement only if they had a male offspring. This commonly caused a ‘denial’ of daughters, because dowries had to be invested in them, and they had no (real) economic independence. In the case of military oriented states, such as ancient Rome, the need of males for warfare certainly was another influencing factor (Scott and Duncan 2002, 271 ff.; see also Banderage 1997, 120 ff.).

Baten (1999) found that decreasing real wages had a negative impact on female mean height in 19th century Bavaria, what he explains with a probable different allocation effect between the genders: In case of a decline in real wages, at first parents were sparing with nutrition for their female offspring, because they had a lower income expectation for their daughter (and thus anticipated a worse provision effect at old age).

In summary, various empirical studies on modern time as well as qualitative archaeological-osteological studies provide concurrent evidence that females are not better buffered, and that cultural factors determine dimorphism in height and survivability.

4.4.3. Dimorphism in Europeans from 800 B.C. until 1700 A.D.

It has been shown that human growth, and thus height, is “a cumulative record of the nutritional and health history of a person or a population” (Bogin and Keep 1999) reflecting the environment of living: small (respectively tall) height reflects unfavorable (respectively favorable) environmental conditions in terms of differences in food, health care access, and workload – it does not matter if female or male (Steckel and Rose 2002, 512; Walker and Lambert 1989).

Hence, relative differences of male to female height, as well as differences in the ratio of male to female individuals survived until adulthood, can be used as proxy for gender-biased differences. Differences in the survival rate between the genders can detect preference, and accordingly the treatment of children.

Therefore, these quantities, relative difference of male to female height, and the ratio between the numbers of males and females have been used to analyze the relative status of women in pre-historic centuries up to modern Europe.

What do the pre- and early historic data indicate? How extreme was the presumed negative effect of the patriarchic societies for females? And did the female relative status changed in the course of the approximately last three millennia?

4.4.3.1. Female Status according to the 'traditional' Sources

Even though interpretation of archaeological small finds and written sources give an idea how the position of females in society developed, only an equivocal picture of the status of females for the periods under study can be obtained. The picture based on non-anthropometric data is vague because no definite statement is possible: historic sources bear the peril that they were written by the author with an intention, which results in subjective statements, for example criticism of "barbaric Northerners" or portrayal of an ideal to arouse 'revitalization' of moral values in the reader (Lorentzen 1993). Moreover, grave goods do not show the relative position of females with respect to males.[262] However, probably it can be taken as a hint for male oriented societies that male graves, in contrast to female graves, include varying goods indicating the former owner's position in public economic life, like physician's utensils or a blacksmith's

[262] The question is whether weaving and spinning equipment in female graves hint towards a textile craft specialization supporting the importance respectively status of women, or if this objects can be interpreted as indicator for their connection to the household. Chapman states that "the onset of secondary products created new opportunities for the consolidation of economic power, but in spatially differentiated and gender-contrasting sectors - the domus and the agrios" (Chapman 1997, 137).

tool.[263] Furthermore, in funerary iconography, studied for Roman and provincial-Roman regions, in contrast to men, women generally are represented mostly in domestic context, but only very rarely "in images with allusions to occupations or any obvious professional activity" (Larsson Lovén 2003, 66).

Considering the 'traditional' sources one gets the impression that females did not experience significant status changes, except perhaps during medieval times (see Excursus for details).[264] A more or less pronounced patriarchy seems to be the universal scheme in the pre- and early historical societies in Europe. Like Sheffield (1989, 172) express it – "maleness is glorified and females denigrated". Although both males and females had crucial economic roles for the survival of families and communities, women's opportunities were far more limited (Frader 2003). Nevertheless, the question remains how the extent of the ideology inducing female's subordination, and accordingly gender specific discrimination was. Something else that still has to be clarified is whether there were differences in the degree of discrimination over time, and whether female neglect was practiced in varying intensity in the three main European regions?

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[263] From a archaeological point of view it "is difficult, therefore, to find any support for the assumption that objects ascribed to females were inherently inferior to 'male' objects and that female roles were correspondingly limited and of lower status" (Bevan 1997, 82). Most often an interpretation of grave goods has it restraints, because the, for archaeological periods, typical weapon-jewellery 'dichotomy' only to a limited extent can indicate social status. Despite the fact that most female graves are supplemented with jewellery, whereas male graves include weapons (Lucy 1997) in some cases, of course, objects interpreted as 'typical' male appurtenant are present in female graves (Schefzik and Volpert 2003), of course. Moreover, often no grave goods exist.

[264] At least it should be mentioned that in contrast to the public idea of emancipated Teutonic women and more suppressed Roman women a detailed analysis of the historic sources gives a little different picture: obviously women had a better status according to Germanic law in comparison to Roman law, but anyhow both are patriarchic societies with women's dominantly task being mother and not breadwinner.

To answer these questions, in the following skeletal material from pre- and early historic Europe is studied anthropometrically in a long run overview for the first time.[265]

4.4.3.2. Bones as Source of Information for Female Position

The human height in pre-historic, ancient, and medieval times can be determined from skeletons, and even bone parts from excavated cemeteries (chapter 4.1.). The advantage of skeletal material is that the information on formerly living adult women can be found in the graves in the same representativeness, like men. Therefore, data for study of gender dimorphism exist, which is not the case for many of the studies based on written sources.

How can we distinguish male and female bones? Physical anthropological methods have been developed to differentiate females and males biologically (see chapter 3.2.1.): morphological diagnosis draws on sex specific differences in the scull, and especially the pelvis (Acsadi and Nemeskéri 1970; Cox 2001; Hermann et al. 1990; Grupe 2005). Both skeletal parts provide several indicators; the usual method is called "combined method", which analyzes each indicator, and unites these for sex determination. The results are quite reliable. Nevertheless, one has to have in mind that the sex determination naturally has its restraints. False sex identification could under- or overestimate size differences between the sexes. In order to provide exact interpretation only data of precisely ascertained sex was utilized here.[266]

The current study is based on a dataset utilizing the source of excavated bones; data was compiled for three main European regions (North-East, Central-West and

[265] With the research field of stable isotope ratio analysis (Schwarcz and Schoeninger 1991) the opportunity opens up to determine nutritional differences between the sexes respectively genders. Unfortunately, by now only very few studies are done on this subject: one was conducted by Fuller et al. (2006) on Late Roman and sub-Roman data indicating an inadequate nutritional status in women.

[266] Cremated individuals were kept included in the data, because they do not distort the results.

South-Europe[267]) for the time between 800 B.C. and 1700 A.D. Overall, the dataset comprises 18502 individual heights from 484 sites.[268] For the current study, only the data were taken into account which can be definitely sexed to avoid any bias. These are 17972 individuals (see Table 15).

TABLE 15
NUMBER OF DEFINITE SEX DETERMINATED OBSERVATIONS
AND MASCULINITY INDEX (MI)
IN THE THREE PARTS OF EUROPE

	♀	♂	*MI*	♀	♂	*MI*	♀	♂	*MI*
Cent.	**Central-Western Europe**			**Mediterranean Europe**			**North-Eastern Eruope**		
-8	16	63	*394*	74	98	*132*	12	14	*117*
-7	3	4	*133*	59	81	*137*	12	21	*175*
-6	12	32	*267*	141	95	*67*	51	45	*88*
-5		2		154	249	*162*	9	1	*11*
-4	3	3	*100*	57	98	*172*	11	12	*109*
-3	13	17	*131*	12	20	*167*	52	44	*85*
-2	38	41	*108*				28	50	*179*
-1	16	24	*150*	33	81	*245*	4	30	*750*
1	38	35	*92*	82	128	*156*	48	150	*313*
2	457	643	*141*	151	293	*194*	48	124	*258*
3	113	232	*205*	45	78	*173*	71	109	*154*
4	489	674	*138*	238	325	*137*	77	238	*309*
5	66	132	*200*	105	363	*346*	61	62	*102*
6	193	1125	*583*	63	86	*137*	65	132	*203*
7	493	931	*189*	16	39	*244*	27	252	*933*
8	122	144	*118*				303	461	*152*
9	128	199	*155*	7	5	*71*	230	303	*132*
10	16	68	*425*	8	12	*150*	117	164	*140*
11	26	110	*423*	9	41	*456*	628	785	*125*
12	136	80	*59*	39	91	*233*	193	268	*139*
13	1	186	*18600*	2	1	*50*	171	187	*109*
14	68	174	*256*	4	3	*75*	172	382	*222*
15		55		32	29	*91*		17	
16	117	338	*289*		4		1	17	*1700*
17		66		1	4	*400*	12	68	*567*
18		103					1	31	*3100*
N	**8045**			**3556**			**6371**		

[267] These regions have been distinguished to differentiate between regions with and without Roman influence, with different other cultural basics, and with respect to nutritional sources and climate.

[268] In some cases heights of two to 360 individuals were aggregated by previous investigators; thus 5067 separate height numbers are available now.

The relative female status is manifested in two components: (1) gender dimorphism in height, and (2) female deficit (as measured by the masculinity index).

(A) Mean Height and Height Dimorphism Index

As discussed above human growth and therefore height, is "a cumulative record of the nutritional and health history of a person or a population" (Bogin and Keep 1999).

In general men are taller than women.[269] The resulting correlation between female height H_f and male height H_m often is given with the linear approach:

$$H_m = m_f * H_f + const. \qquad \text{(eq. 1)}$$

As a consequence, the absolute difference in the height of males and females increases with the mean height of the population. Rensch (1950) furthermore proclaimed the dependence of relative dimorphism on mean height. But Gustafsson and Lindenfors (2004), Baten (2007), and also Moradi and Guntupalli (forthcoming), show that the relative height differences between male and female are independent from height development (this is valid for male and female height). This means that the influence of both sex and gender (defined as gender specific behavior, such as discrimination) is included in the development of mean height.

To show the differences between men and women independent from the general height of a population, a relative difference is used. This quantity is called Dimorphism Index DI:

$$DI = \frac{H_m - H_f}{H_m} \times 100\,\% \qquad \text{(eq. 2)}$$

[269] It should be mentioned that the absolute height difference between males and females is not an indicator for dimorphism, because it depends directly on the height of the people. Both, the absolute heights and, as a consequence the height difference, are an indicator for general nutrition, but not for dimorphism.

This quantity gives the difference between the height of male and female in % of male height.

Another quantity that also does not increase if the general height of a population increases, is the ratio

$m_f = H_m / H_f$. (eq.3)

Since these quantities are independent from absolute height, they are adequate to show the effects of sexual differences. In this paper, the DI is used to describe dimorphism.

For the dimorphism index follows

$$DI = \frac{H_m - H_f}{H_m} = \frac{m_f * H_f - H_f}{m_f * H_f} = \frac{m_f - 1}{m_f} \qquad \text{(eq. 4)}$$

and

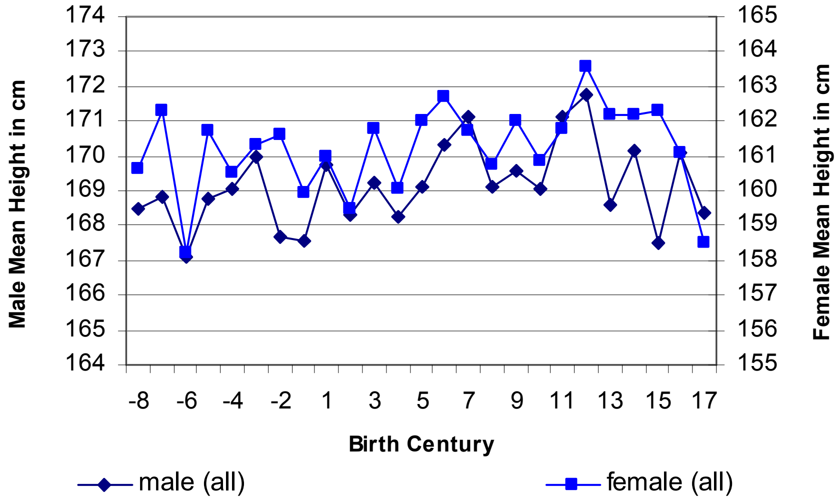
$$m_f = \frac{1}{1 - DI} \qquad \text{(eq. 5)}$$

The higher m_f or DI is, the greater is the relative difference in height between men and women.

The value of the ratio m_f, and correspondingly of DI, results from the different reaction of the sexes on the living conditions; but, of course, it can be influenced by different nutritional status of each gender. Thus, height dimorphism between the males and females of pre- and early history can be used as proxy for gender discrimination in terms of nutritional status, indicating gender-biased differences in preference, according treatment and supply allocation of children (Baten 2000; Steckel 2002).

The general overall height of full grown females and males from 800 B.C to 1700 A.D. is shown in Figure 22 with two different axes for men and woman, separated by 10 cm.

FIGURE 22
HEIGHT DEVELOPMENT BY GENDER IN OVERALL EUROPE
8th century B.C to 18th century A.D.



note: only absolutely confidently sex determined observations are included.

The heights of females and males are more or less parallel over the centuries. However, there is some variance between the height developments of women and men: If the development of mean height for both sexes is different, this indicates changes in the relative status of females in society. The largest differences between the height of males and females, which indicate unfavorable position of females relatively to males are during the sixth and fourth centuries B.C. and the seventh and eleventh century A.D.[270] But this absolute development gives only a very rough idea of the conditions. More exact is to look at the relative differences that is the development of the dimorphism index DI (eq. 2)

The relative height difference between men and women results both from the different reaction of the sexes on same nutrition (sex effect), and from the different availability of nutrition for the genders and other socio-cultural differences determining the final height (gender effect).

[270] This development fits together well with the archaeological findings: Ulrich-Bochsler (1997).

Except for periods where one would expect no impact of gender discrimination due to similar work fields for males and females – which is said to be the case for pre-sedentary periods, particularly in Paleolithic hunter and gatherer-societies, as discussed above – the difference in height between males and females, and thus the dimorphism index is determined by both biological basic sex effect as well as gender effects.[271]

In case that no gender effect is affecting the height dimorphism, DI gives the basic height discrepancy, which results only from the sex factor and thus is called DI_{sex}. This quantity holds for the biological difference in height; and thus is independent of time and region (in homogenous Europeans). If this basic sexual height dimorphism DI_{sex} is known, we are able to elucidate gender effects in the data under study.

In order to reveal DI_{sex} data should be used, which on the one hand should be sex-, but not gender-affected (see above)[272], and on the other hand entirely consist of *homo sapiens sapiens* skeletons, which means assured non-biased by the formerly parallel living *homo neanderthalensis*. The data for which this precondition are given stem from the Early Upper-Paleolithic (EUP) dating 35.000 B.C. onwards (Aurignacien). Naturally, the known skeletal material is extremely scarce. Moreover, commonly Palaeolithic data is only sex and age determined, but height data is not available (see e.g. Binant 1999). Thus, the number of height observations on this period is rather small (N: ♀10, ♂20), but Formicola and Giannecchini (1999) give a good overview.[273] To

[271] Overlapping, mutually influencing effects could be possible over very long time series, as part of evolution, but this will not be the case in the time period which has been analyzed.

[272] In archaeological excavations of Upper Palaeolithic graves it was found that males and females were both buried with weapons and tools: flint blades and hand axes are uniformly distributed, although hair ornaments can be only found with females (e.g. Broglio 2006; Cocchi Genick 1994).

[273] They collected the largest N, and display all available data in a detailed list, other than Frayer (1981a; 1981b), and Hermanussen (2003).

make these data comparable to our height data their height estimates were recalculated to the height reconstruction models by Breitinger and Bach.

After determining the basic DI_{sex} based on the EUP-data, in a next step, gender effects can be separated as an additional effect on height development, based on the following formula:

$$DI = DI_{sexgend} = DI_{sex} * F_{gend} \qquad \text{(eq. 6)}$$

The gender effect is shown by the factor F_{gend}

$$F_{gend} = \frac{DI}{DI_{sex}} \qquad \text{(eq. 7)}$$

where DI is calculated by eq. 2, based on the actual height measurements that include gender effects; and DI_{sex} is taken from the EUP data, as explained above without gender effects..

The F_{gend} has been determined for the compiled data, and used in the following to show gender effects: $F_{gend} = 1$ means no difference between DI and DI_{sex} that is no gender effect. $F_{gend} < 1$ means: The height difference between males and females is reduced against pure sexual height difference. Thus, for $F_{gend} < 1$ females are relatively taller, thus do better. And vice versa: $F_{gend} > 1$ means female status is worth in comparison to the initial situation, resulting only from genetic that is sexual differences.

(B) Masculinity Index

As mentioned above, an important indication of female discrimination in populations is the so-called primary deficit in females. This phenomenon is especially pronounced in all pre-historic and ancient populations (Volk et al. 1988): this means that distinctly fewer females than males can be found in skeletal material, who reached the adult age. To analyze this effect the masculinity index (MI) has been used:

$$MI = \frac{N_{males}}{N_{females}} \times 100 \qquad \text{(eq. 8)}$$

which shows the number of men for every 100 women.

If MI = 100 (or slightly below[274]) the data have a well balanced sex ratio, if MI < 100 a female surplus is given, and vice versa MI > 100 represents a male surplus.

4.4.4. Results: The relative status of females in pre- and early historic Europe

4.4.4.1. Gender Factor

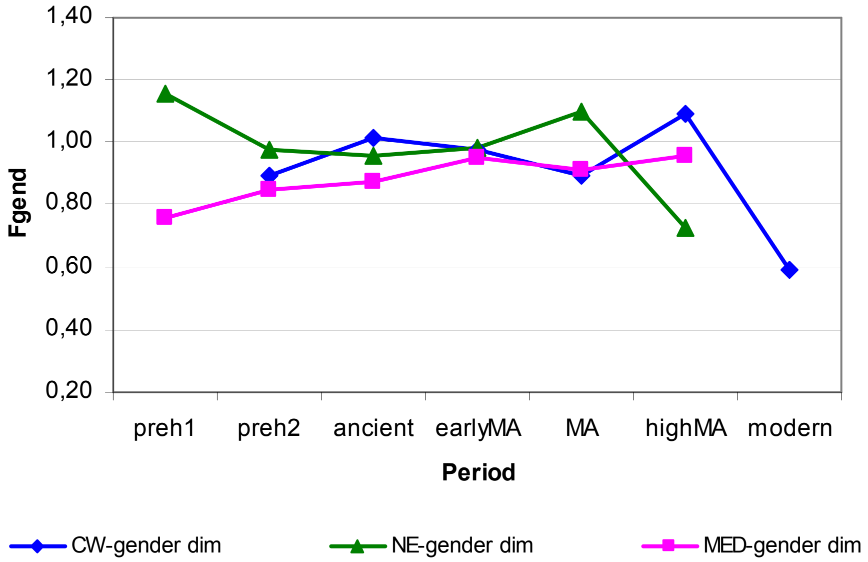
The resulting F_{gend} of the compiled data are shown in Figure 23 for different time periods, which are taken to combine different political and socio economical effects (chapter 4.3.) and for the three major European regions. The development of F_{gend} includes up and downs – indicating that females did better in some periods, and worse in others – but overall no extreme variation between the single epochs can be found. High gender effects, affecting women negatively, stem from the early Iron Age and medium Middle Ages in North-Eastern Europe (NE), and from high Middle Ages in Central-Western Europe (CW). Low values F_{gend}, showing relatively good living conditions for females are found for the Mediterranean Europe.

It is remarkable, that in the long run the overall development of the gender factor F_{gend} is increasing in Mediterranean Europe (MED) over the centuries under study, whereas it shows a decreasing trend in both Central-Western and North-Eastern Europe (Figure 23). This means that in contrast to the rest of Europe, Mediterranean women lost in their relative status in the course of time. But, remarkably, despite what one would expect due to the population density conditions, the Mediterranean woman's

[274] The values of modern MI in societies without much discrimination (Sweden etc.) are slightly below 100.

status did not "move" on an overall low level. In contrast, the Mediterranean women (as indicted by the low F_{gend}-value) 'start' where the North-Eastern and Central-Western women end: by a value of approx. 0.8 (with the value of 1 given by the EUP data, as explained above).

FIGURE 23
DEVELOPMENT OF THE GENDER EFFECT IN MEAN HEIGHT DIMORPHISM
IN THE THREE MAJOR EUROPEAN REGIONS
IN THE COURSE OF PRE-MODERN PERIODS



note: By definition a lower gender effect and factor F_{gend} denotes better relative status of females (see text). To study the development of F_{gend} only those individuals were taken into account, which could be confidently sex determined; centuries were excluded, which have an N < 10 either for men or women (see Table 15), and centuries were excluded which represent an extremely diverging masculinity index (means MI >300).

The female discrimination seems to be more pronounced in North-Eastern Europe and also Central-Western Europe. Nevertheless, general regional deviations, based on the mean value of F_{gend} averaged over all centuries, show no remarkable differences in three main European regions. In the Central-Western Europe the mean value of F_{gend} is approx. 0.91, for North-Eastern Europe approx. 0.98 and in Mediterranean Europe approx. 0.88. Cultural differences became smaller during the Migration Period, as can be seen in Figure 23 for the early Middle Ages.

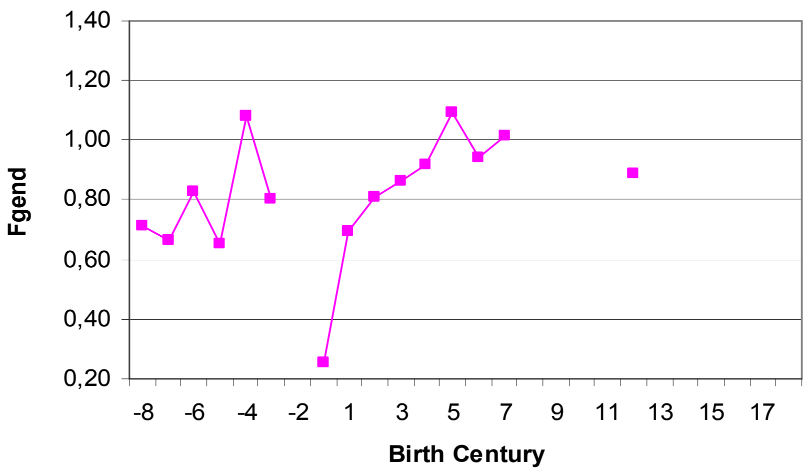
The regional development of F_{gend} is shown in Figures 24, 25 and 26 in more detail by centuries. Here, only data on those centuries have been used, where more than 10 observations for men as well as women are available. Also in these figures the effect of the Migration Period can be seen: during the fifth to ninth centuries A.D. in all three major regions F_{gend} is around a value of approximately 1.[275] With this value, moreover, it seems that there was no specific gender effect during this time.

One can see that in the Mediterranean (Figure 24) the female status obviously was comparably beneficial during overall prehistory (with an exception in the fourth century B.C.), for which Etruscan women are said to have held a particularly good status. This is also the case in the first century B.C., the beginning of Roman occupation. A bold explanation could be that (despite patriarchy) females had the prestigious 'function' as mothers, which was of special importance in providing soldiers for the expansion of the empire. However, in the main phase of the Roman imperial period conditions worsened. For example, from the third century A.D. onwards, in contrast to the ancient sources that would suggest bettered conditions for females due to the introduction of the *donatio*

[275] This comparably low gender effect can be also explained by the fact that in pre-modern times discrimination against females, affecting their nutritional status, could only take place in terms of diet supply and food allocation. Other factors which are theoretically (and today) important for overall nutritional status – like maternal education resulting in a bettered status of females, as well as in particular different aspects of (sophisticated) health and medical care – naturally could not make a difference in the centuries under study. In terms of food allocation it could be moreover possible that females (as esp. closely related to housekeeping) were able to provide themselves with food during food preparation – starting from taking milk away while milking, up to while cooking. This could have compensated discrimination, and strengthen their nutritional status despite their overall certainly existent disadvantaged status in the official allocation of food in comparison to males in pre- and early historic Europe.

propter nuptias[276], no incisive changes took place. According to the data, the gender effect was highest in the fifth century A.D. (with an F_{gend} of 1.09), becoming lower (and thus better for women) again in the following centuries, although not reaching the mean low level of the prehistoric centuries.

FIGURE 24
DEVELOPMENT OF THE GENDER EFFECT IN MEAN HEIGHT DIMORPHISM
IN MEDITERRANEAN EUROPE
8th century B.C to 18th century A.D.

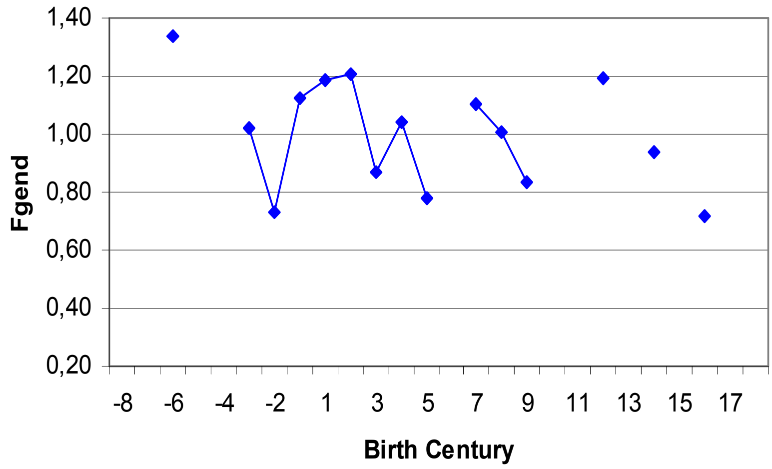


In Central-Western Europe (Figure 25) the highest F_{gend}-value is given in the sixth century B.C, the first century that could be analyzed. F_{gend} is fluctuating in the following centuries, but falling as shown by the trend line. F_{gend} is especially low (0.73) in the second century B.C. In the following centuries F_{gend} had high values again, since the early Roman Empire had a detrimental impact on the female relative status. This can be explained by the deduction of nutritional sources due to market integration (affecting females more, due to patriarchic structures which here were not compensated by the importance of females in soldier ‘production’). Such high level of F_{gend} is reached again

[276] This means donations that the husband and his family had to give to the women in order to provide bail for situations such as the case of divorce, see Excursus.

not before, and only in the 12th century A.D., which experienced a decrease again in the following centuries, down to the lowest level given for Central-Western Europe in the 16th century A.D. (0.71), which could be explained by the beginning Renaissance (see Excursus).

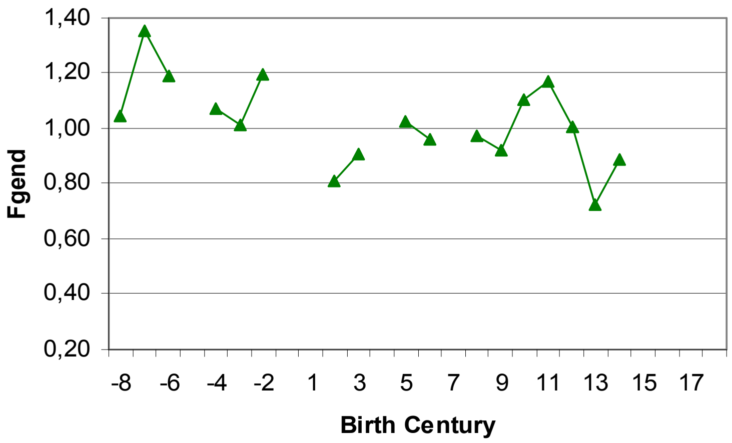
FIGURE 25
DEVELOPMENT OF THE GENDER EFFECT IN MEAN HEIGHT DIMORPHISM IN CENTRAL-WESTERN EUROPE
8th century B.C to 18th century A.D.



In North-Eastern Europe (see Figure 26) F_{gend} – although fluctuating in between – decreases quite continuously during the centuries under study, showing no extreme change in either direction during Roman times. This is in agreement with what we would expect, because Roman influence was rather tenuous in this region.

The gender effect is shown with the factor F_{gend}, which is derived after Eq. 7 under the assumption that the sex-effect that describes the genetic differences in height, is completely described by the DI = DI_{sex} resulting from early upper Palaeolithic data (EUP). The number of EUP observations is low, but this dataset is the only one available for a time, where gender effects can be neglected. Thus, here a cause for uncertainty is possible, but this would not result in changes in the temporal and regional behavior of the results shown.

FIGURE 26
DEVELOPMENT OF THE GENDER EFFECT IN MEAN HEIGHT DIMORPHISM IN NORTH-EASTERN EUROPE
8th century B.C to 18th century A.D.



The same is valid, if there was already a gender effect during the EUP time, which has not been assumed. Such an effect could result if the Palaeolithic woman had to feed and hunt for not only themselves, but also their progenies without getting adequate support from their male fellows (see above, Wooders and Van den Berg 2001).[277] If this was true, the consequence would be a systematic bias of the F_{gend} shown as results in Figures 4.4.2 and 4.4.3, into the direction of lower values, which means that the status of the woman would seem systematically better.[278]

[277] Due to the missing family structures before sedentariness it was probably not clear, who the father was in each case. Thus, women had to carry the full care of the brood themselves, which brought additional stress (see above), and correspondingly unfavourable nutritional status compared to males.

[278] However, already for late Mesolithic Europe Zvelebil (2000) found differences between females and males related to nutritional status: Females show greater incidence of stress indicators. “This differential pattern of markers of stress is consistent with the higher intake of meat among the males, and a more

Another uncertainty may result from the fact that the heights of men and women have been derived from bones (chapter 3.3.). Thus, naturally – due to the study period – the nuisance of measurement error cannot be fully excluded. On the other hand, it could be the case that the utilized models may result in perhaps not (only) a systematic bias, but (also) in biased results at the lower and upper end of the reconstructed height range, because these models presumably are based on originally taller heights than the ones which were reconstructed.[279]

However, this effect is not of importance for the study, because the use of Pearson (1899) against the Breitinger (1937) and Bach (1965) models, shown in Figure 27, generate only a modest difference, which is visible for levels, but not for changes over time. Thus, we keep using Breitinger and Bach reconstruction as basic model – as we already found this being the best to use for the compiled data.[280]

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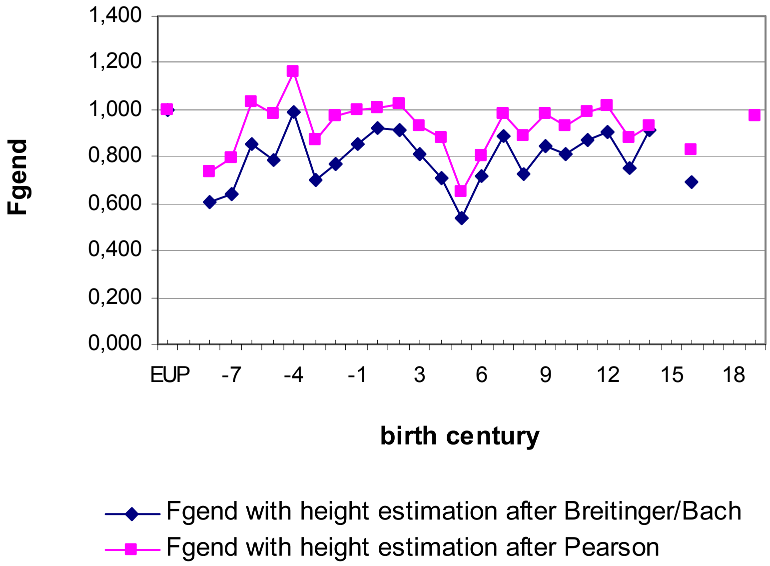
carbohydrate-oriented diet among the females". Zvelebil (2000) points out that the pattern of unequal food access with detrimental situation of females was similarly found in other studies, like among the North American hunter-gatherers of the Woodland period (see Cohen and Armelagos 1984).

[279] It could be problematic that the Breitinger/Bach formulas – although being in principle being the best to use for the compiled data – are based on post-secular data which could result in deviations in the height estimations of an earlier living population. To control for a possible distortion Pearson's models were employed in addition. This is the only suitable alternative to utilize other than Breitinger and Bach for the estimation of skeletal heights, because these are the only ones which are based on pre-secular trend data. Thus, in particular if the height of especially small individuals (males below 160 cm) is reconstructed Pearson might be more efficient: Correspondingly, there is also the risk of overestimation of female heights due to Bach formula's (Rösing 1988). The whole dataset was recalculated by using the Pearson formulas.

[280] The decision to use the formulas by Breitinger and Bach to reconstruct male and female heights is based on detailed deliberations: on the one hand Breitinger and Bach give the most accurate results (lowest mean of differences in stature) for the relevant spectrum of centimeters (Formicola 1993); on the other hand several other aspects speak for them, like the comparability with the height data based on cremations reconstructed by Rösing.

FIGURE 27
DEVELOPMENT OF THE OVERALL GENDER EFFECT
IN EUROPE, 8th century B.C to 18th century A.D.
BASED ON HEIGHT DATA RECONSTRUCTED BY BREITINGER/BACH IN
COMPARSION TO THE SAME HEIGHT DATA RECONSTRUCTED BY PEARSON



Which determinants have an explanatory power for the long run development of the mean gender factor in height dimorphism in pre- until early modern historic Europe?

Panel estimation was applied to clarify this question: four WLS regression models are presented in the following.[281] In the basic model (Model 1 in Table 16, col. 2 and 3) solely regional and temporal variables were included; these are dummies for the major European regions, and the periods under study.[282] It has an adjusted R^2 of 0.19. In this case the regional dummy for Mediterranean Europe was statistically negatively significant on the 1%-level, which means overall gender effect was significantly lower

[281] As in earlier papers in each model the constant refers to Central-Western European conditions of the Migration Period/early medieval period.

[282] As done before in the earlier papers, those were employed to control for unobserved inter-temporal heterogeneity.

there, and thus Mediterranean women actually did comparably well in comparison to their contemporaries in the rest of Europe.[283] As one would have expected due to the finding by Gustafsson and Lindenfors (2004), and Gustafsson et al. (2007), also in our data, the gender effect in North-Eastern Europeans is not stronger than in the regions with a lower overall mean height. In the second model (Table 16, col. 4 and 5) various different determinants are added to the regional and temporal dummies. These are factors which are shaped by, and could influence the cultural and socio-economic background and thus the gender effect such as cattle share as proxy for the agricultural specialization, land *per capita*, plague, war and prosecution, and the practize of three-field-rotation and use of iron plough indicating enhanced agricultural technology.[284] The extended model does explain little less: it has an adjusted R_2 of 0.15. None of the variables (including the dummy standing for Mediterran Europe) are neither statistically nor economically significant.[285] If we reduce the model (Table 16, col. 6 and 7) to the the regional and periodical dummy, as well as land *per capita* and cattle share the adjusted R_2 becomes much higher: the model can explain 25%. The Mediterranean Europe – dummy becomes statistically significant on the 10%-level. In a forth model (Table 16, col. 8 and 9) we control for a possible Roman impact, finding it to have a

[283] Compared to the reference value 'Central-Western Europeans living in the Migration&early medieval Period'.

[284] For a detailed description of these variables, see earlier chapters.

[285] If we only include land per capita and cattle share (as the presumably most important determinants) in the model (not shown), the latter variable becomes statistically significant on the 10%-level. But the adj.R^2 is only 0.12 in this case. We have to keep in mind that the in particular the estimation of the dependent variable is probably a bit rough and could contain some measurement error. Thus, it is not surprising that the coefficients are statistically insignificant.

TABLE 16
REGRESSIONS:
DETERMINANTS OF THE GENDER EFFECT IN THE THREE PARTS OF EUROPE

1	2	3	4	5	6	7	8	9
Constant	0.97	*0.00*	1.79	0.00	1.79	0.00	1.75	*0.00*
early prehistory	0.08	*0.37*	-0.07	0.74	-0.05	0.77		
late prehistory	0.03	*0.70*	-0.03	0.77	-0.03	0.81		
Antiquity	0.05	*0.38*	0.10	0.23	0.10	0.16		
Middle Ages	0.07	*0.36*	0.17	0.37	0.19	0.12		
high Middle Ages	-0.13	*0.17*	0.07	0.80	0.10	0.64		
Modern	-0.16	*0.21*	0.32	0.38	0.33	0.27		
Mediterranean	-0.19	*0.00*	-0.30	0.13	-0.32	0.08	-0.35	0.01
North-East	0.03	*0.57*	-0.04	0.68	-0.04	0.69	0.01	0.94
Plague			-0.00	0.97			-0.00	0.96
war&prosecution			-0.02	0.74			-0.02	0.82
three-field-rotation& iron plough			0.03	0.88			0.13	0.26
log land per capita			0.25	0.17	0.25	0.13	0.22	0.04
cattle share			-0.01	0.28	-0.01	0.20	-0.01	0.10
cattle plague			0.01	0.88			0.00	0.97
Roman bath&technology							0.14	0.08
Adj.R^2	0.19		0.15		0.25		0.24	
N	56		45		45		45	

P-Values in columns 3, 5, 7, 9 in italics. Weighted Least Squares Regression: number of cases adjusted for aggregated observations using square roots. Constant refers to a hypothetical height value for the Early Middle Ages, and Central-Western Europe. Statistically siginifcant coefficients marked grey underlayed.

note: Included are only absolutely definitely sex determined observations, and the centuries with N_m, as well as N_f > 10.

statistically positive influence (on the 10%-level) on gender effect, and thus increasing female gender discrimination. Higher land *per capita* is also negative for females, as the gender effect increases. In contrast, cattle share has a significantly negative impact on the gender effect (on the 10%-level), that is if overall a higher supply of animal protein is available, also females profit from this good.

4.4.4.2. Masculinity Index

In the compiled dataset of this study the MI for all observations is 191. Regional differences (see table 15[286]) show a MI of 229 for Central-Western Europe; the lowest level is represented for North-Eastern Europe with a value of 163; and the MI for Mediterranean Europe is not much higher with 167 (see also figures 28, 29, and 30).

Explanation for the extreme high female deficit (in combination with the quite stable overall height dimorphism discussed above) could be that discrimination is manifested especially in femicide (killing the baby girls or letting them starve to death before they have grown up), but those girls who were seen as being worth enough to keep alive, and therefore reached the adult age, were treated comparably good during growth.[287] A relation between the masculinity index and the gender effect is shown in Figures 28 ff., resulting in more beneficial conditions for the females surviving until adulthood in all the three major regions, but statistically insignificant.

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[286] If less than 10 heights per gender and century-region-unit could be reported this unit was coded as missing value.

[287] The fact that women are not more robust than men is supported by the finding that the standard deviation (SD) of female and male height in the data is similar in the course of the centuries, no matter which kind of reconstruction model is used. According to WLS-regression (not shown here) female heights even have a significantly higher SD, it does not matter whether cremations are included or not: SD in female heights of the overall, definitely sex determined data are 0.32 cm more than the mean male SD of 3.17 cm.

FIGURE 28

RELATION OF THE MASCULINITY INDEX (MI) AND DEGREE OF GENDER EFFECT
IN MEDITERRANEAN EUROPE
8th century B.C to 18th century A.D.

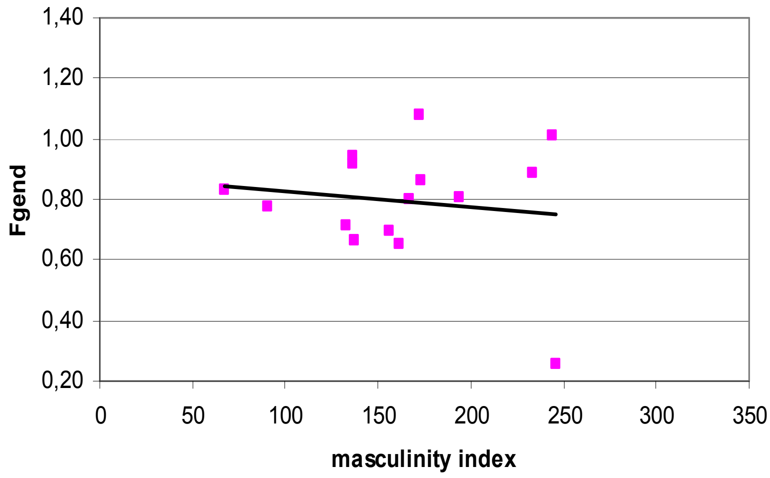


FIGURE 29

RELATION OF THE MASCULINITY INDEX (MI) AND DEGREE OF GENDER EFFECT
IN CENTRAL-WESTERN EUROPE
8th century B.C to 18th century A.D.

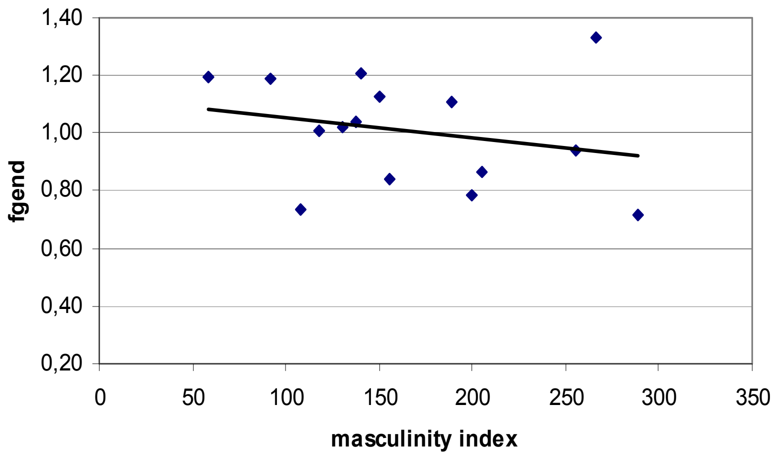
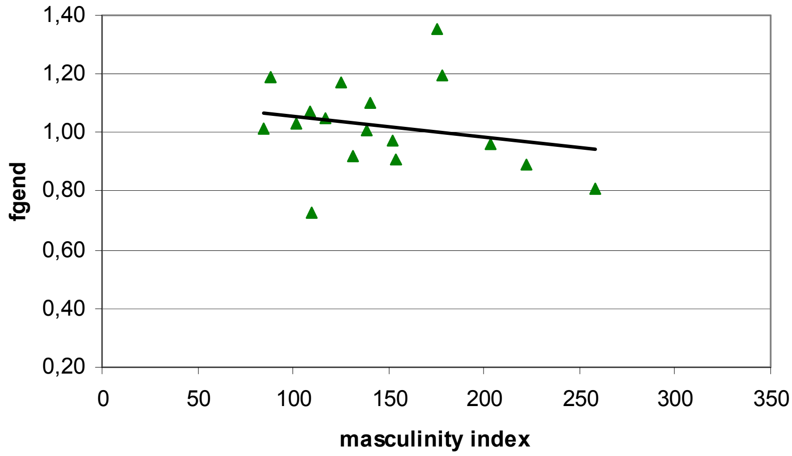


FIGURE 30
RELATION OF THE MASCULINITY INDEX (MI) AND DEGREE OF GENDER EFFECT IN NORTH-EASTERN EUROPE
8th century B.C to 18th century A.D.



4.4.5. Conclusion

For the first time the possibilities of anthropometric height data and its informative value was used for an overview on the development of female discrimination in the long run in pre-historic, ancient and early historic Europe, which allows verification of archaeological and historic data.

Height dimorphism between males and females, like height itself, is determined by genes and biological basics (sex) and environmental factors influencing nutritional status. However, this dimorphism can be modified by gender dependent cultural practices. In recent research the sex effect was found to be rather constant, whereas the gender effect could change height dimorphism over time. Based on these findings it is possible to study skeletal material in terms of the relative status of females in pre-modern Europeans.

The vague picture of the status of females one gets according to written sources and archaeological material from excavations of prehistoric and ancient sites was clarified by the anthropometric data under study: Remarkably no significant change in gender effect took place in the course of pre-historic to early modern periods.

Anyhow, in the course of time Mediterranean females lost their relative good status, whereas overall North-Eastern and Central-Western females could strengthen their status in the long run over the 8th century B.C. until the 18th century A.D.: The data shows that the status of pre-modern surviving females improved during the time from a low level in the North-Eastern, as well as the Central-Western case, whereas in Mediterranean Europe the trend moves in the opposite direction.

Nevertheless, overall Mediterranean women did comparably well. The gender effect is statistically significantly lower there in comparison to the rest of Europe.

4.4.6. Excursus: **How did the females' status develop according to archaeology, iconography, and ancient written sources**

European pre-modern societies generally were organized patriarchalically. With an expanding 'urban mentality' females became confined to the household, restricted their options even more. Differences in the male and female position were already found for the Iron Age. For this period Bonfante (1994) interprets the status of Etruscan woman as comparably good, however Amann (2000) found the status of Etruscan woman to be not much better than the position of females in other contemporary societies. This example shows the general problem that the available information for recent times can be interpreted differently by different authors. Also the "Celtic"[288]woman did not do any better in comparison to contemporaneous existing Indo-European societies.[289] What might have had a positive impact on lowered discrimination of Celtic females was that in case of their death (even if married) her family was enabled to make claim of a part of her property.[290]

For daughters being subordinate to Roman law the discrimination was stronger, since Roman females automatically switched to the husband's family after the wedding. Nevertheless, for Romans there was no strict separation between the genders, neither in

[288] This generic term is problematic, because very different regions and centuries are subsumed, based on a 'cultural material' basis. Anyhow it is interesting how close the contact e.g between the continent and the British Isles was during the pre-Roman Iron Age.

[289] Wegner (2001); the position of women after wedding depended on the kind of marriage – whether she became main wife or secondary wife –, whereas the men was always "the one and only". Furthermore, in general females had no heriditary rights (Brandt 1995).

[290] Anyhow it is unknown to what extent the law was practiced; furthermore, the known laws are passed on from Irish and Welsh Celts which anyhow stem from the 8th century onwards, which is more early medieval, and thus presumably it is not completely transferable to pre-Roman period. Furthermore it is questionable whether there had been differences in the law of Gallic continent Celts (due to different living conditions like living in 'urban'-kind settlements, and trading with other 'nations', in contrast to widespread farms on the Britannic Islands (Wegner 2002, 28 ff.).

public nor in private domains (as in ancient Greece).[291] Roman women were not (completely) barred from the male world, such as the women in ancient Greece.[292] Anyhow, although some Roman women worked in different public occupations (Fantham 1994; Setälä 2002), had own property and had transactions, Spencer-Wood (2006, 307) concludes that according to the majority of inscriptions and texts that "the emphasis [laid] on women's domestic roles … rather than women's diverse public roles in active practice".[293] Likewise, the female position[294] was unequal to the position of men, although 'not extremely suppressed' by Roman law (Amann 2000; Saller 1994).[295] In the course of the early Roman Empire equality before the law in the making of wills was phased in. From the third century A.D onwards, additional to the dowry the *donatio propter nuptias* was introduced: donations and gifts which had to be provided by the husband and his families to provide the additional endowment for the wife to guarantee her living conditions after divorce or death of the husband (Gestriich et al. 2003,105 ff.). This should have had a positive impact on female status. Despite recent research is concluding that the position of Roman women was not as bad as the purely juridical approach would suggest (Amann 2000); women certainly were not seen as equal to

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[291] Although women were not allowed to be active in politics, they could move and act freely in the public. Correspondingly Roman houses show no areas separated for men and women.

[292] But of course males predominate public professions (see corpus inscriptorum Latinarum).

[293] Furthermore, written sources emphasize that women's most virtuous task is reproduction and proper child rearing. This view also can be found in the works by Tacitus, for instance - although not as an 'unequivocal and misogynistic' statement (Pölönen 2002, 102).

[294] The determined role and character attributes of females are commemorated in women's funerary monuments all over the Roman Empire: "her inactivity bring s him status" (Fantham at al. 1994, 369 ff.).

[295] For example, the consideration of females in Roman wills was seen as disadvantaged by scholars until recently (like e.g. Champlin 1991). But Pölönen (2002) comes to the conclusion that sons were not especially favored over daughters in terms of division of passed on properties, because firstly not only heritage, but also dowries have to be taken into account; and secondly disinheritance "was not automatically a discriminative strategy … [because furthermore] heres sustained financial burdens … [like] paying for the funeral." (Pölonen 2002, 179).

men, but had a subordinate role. Hence, for example schooling was predominantly for males (Deißmann 1989).[296] Also, only males were supported with *annona /frumentaria*, a regular grain donation to support Roman citizens (Garnsey 1998).[297] Furthermore, what is probably most important: the *pater familias,* the mother was not the decisive person.[298] The right of the *patria potestas* gave the sole male head of the family the right of deciding upon the life and death of the family members (see Spencer-Wood 2006).[299] Additionally, females had to stay under male control and custody for their whole life according to Roman law[300]. Although it is questionable as to how far the law was actually carried out in everyday day life, it certainly had its impact.[301] Generally Fantham at al. (1994) conclude that "the conservative ideal of Roman womanhood [was kept] inherited from the Republic" also during the period of high and late *imperium Romanum*.

In contemporaneous Germanic tribes patriarchy also existed, although women seem to have had some exclusive functions, especially in medicine (and also other

[296] E.g. Klasen (2002) and many others found inferior education/literacy in females as indicator of discrimination, being related to dimorphism.

The idea that also middle-class girls should get (some) secondary schooling additionally to the strictly controlled practising of domestic duties was established in the German region, for instance, not before the turn to the 19th century AD (Doff 2004, 78).

[297] *Annonae* may not only be an indicator for the unequal status of female, but also an incentive to discriminate females in terms of support baby girls (chance of) survival.

[298] Becoming even more strict under the reign of Augustus: for instance, adultery was defined by law, but sexual access was still legal for a married free man as long as he had no contact with a married women other than his own wife, whereas it was forbidden for wives to have contact with anyone else but her husband (digest 48.5.1.): see Fantham (1994, 300).

[299] This resulted in a further common characteristic of gender specific discrimination: female infanticide (see above).

[300] This demand can be found in the 'twelve table law' (dating in the 5th cent. B.C.), and was part of law until the reforms of Diocletian (AD 285-305).

[301] The absence and death of many men of all classes especially due to the long Civil Wars periods resulted in some responsibility of women to maintain the family, which gave many women a new relative independence.

important fields of that time such as fortune-telling) (Amstadt 1994). However the question is whether this had a general positive impact for the position of average females.

In early medieval Europe, in terms of political power of women, no real difference arose in comparison to former periods: for example the position of a Merovingian queen derived from the marriage with the king (Sasse 1996).[302] Overall, during the Migration Period and early Middle-Ages, a person (whether male or female) had no rights as a single individual (at least within the Teutonic region).[303] This peculiar understanding of a person – in which everybody had to be in connection with others to exist in full sense – resulted in the fact that members of a group (in general the family) had to take care for the 'honor' of the fellows (Nitschke 1989, 679). But women and men had different tasks in fulfilling the preservation of dignity and honor. In general the Germanic customs resemble the ancient Roman structure: on the one hand, rights laid within the function of the father, or after his death the son - including decisions over wife (respectively mother) daughters and. sisters ('Muntgewalt'), which even comprised of the right to sell them.[304] On the other hand, the honor of a family increased with size; thus the woman was then of special importance[305], and it is known, for example from Alamannic, Bavarian, Saxon, and Frank law that women were higher valued than men

[302] And even in the case of her only possible participation in 'public' reign doing the regency for a under-age son the queen had only limited power and control.

[303] Instead e.g. a single person needed oath assistants ('Eideshelfer'); but also during this period a large difference is made between genders, as women had to bring al long many more assistants compared to men.

[304] Rooting in early medieval society, and proved especially from the 14th century onwards the jus primae nocti was as a male power display in European culture, which also shows the inferior position of females (Wettlaufer 2000).

[305] Not only because of her ability of childbearing, but also to make bond to other families of higher honor by marriage.

(in terms of 'Wergeld').[306] Therefore, it is to be supposed that women were held in high repute during that time; but then again it is known that the female position in terms of marriage rights (including adultery punishment) was inferior and subordinate.[307] Thus, again, the status of women cannot really be decided from the ancient written sources.

Similarly this question subsists for the 11th and 12th century A.D. when women seem to gain more independence due to edicts regarding the status of their husband's heiress. Moreover, during that time, until the beginning of the 16th century, women flourished as authors, patronesses or clients, but these were rare and belong to convents; institutions which were primarily reserved to peerage (Arnold 1989). The life of females was characterized by a greater variety then the conventional historiography perceived, due to their considerable participation in religious movements (Mogge-Grotjahn 2004, esp. 18 ff.; Weinmann 1997). Anyhow, men dominated the society, and in everyday female life many rules restricted women's framework of action. From early to high medieval ages the legal position and rights of women were broadening. Partially merchants and craftswomen were organized into their own guilds (Ennen 1991).

For the Renaissance, according to the new educational ideal of humanism the female theoretically had the same legitimization like the male, but although she therefore had a wider range of opportunities for individual development, she functioned as "silhouette of masculinity"[308]: The most common supposition is that traditional customs and rules existed which limited the female self-reliance, particularly the self-

[306] see Nitschke (1989, 681 f.): with reference to concerning passages in the Leges Alamannorum etc.; in the Lex Baiuwariorum it is elucidated that honor was not guaranteed institutionally to women: if she stole several times or fought armed like a man she lost her honor and was treated like males.

[307] It makes no difference whether primary wife ('Kaufehe') or secondary wife ('Friedelehe'): females were "throughout … more or less" regarded as the husband's property: see Weber-Kellermann (1996, esp. 17).

[308] In contrast to Burkhardt (1988) completely gender equalization was barely perceptible.

reliance of wives (Nitschke 1989, 697; King 1998; Mogge-Grotjahn 2004). This means that the female position remained quite constant (with her 'main task' being fertile), being classed as inferior (combined with the problem of dowries), and 'as usual' resulting in the preference of males. But on the other hand, it is known that during this period new chances arose for females – not only for those from nobility, but also within the bourgeoisie – to get an education, and even gain scientific influence.[309] Schools were founded;[310] but many people seem to have "had grave reservations about educating their daughters" (Hardwick 2004, 345). Although the initial idea of regular elementary schooling for females was to teach them obedience and virtuousness, education also allowed females to read literature other than the bible, and free themselves.[311] The *donne nobili* 'arose' and drifted away from her "real" destiny.[312] The idea that females seem to gain a better position in societies' view is also recognizable due to archaeological findings.[313] Furthermore, an increased number of females worked in public 'industries', cooperating in guilds, and gaining authority while supervising family manufactures, including dealing with money in contrast to official regulations. Additionally, in the case of the non-elite society, women's working and financial contribution to the family economy was extremely important. Hardwick (2004, 345) states that the vibrant commercial economy of elite society furthermore "depended to a substantial degree on the capital provided by women's dowries and the ties of kinship". This would suggest that females were appreciated for all they brought along. Although

[309] see Arnold (1989, 723 f.) with references.

[310] From the booming trade cities female teachers are commonly known.

[311] Especially in 'Italian' cities a fertile intellectual and cultural climate was nourished fostering humanism, sciences and art.

[312] Indicated e.g. by her refusal to breast feed her own child.

[313] see e.g. the change in inhumations of females closer to the important places in Christian cemeteries near the Church: Ulrich-Bochsler (1997).

they worked hard similarly to men, they were paid much less, and still restricted in many ways. It seems that because men were afraid of females becoming strong competitors, what finally culminated in the 'war against females' as King labels the witch hunting (King 1998, 184. Correspondingly, Hardwick (2004, 355) finds that "gender issues were of paramount importance, and nowhere was this dynamic clearer than in the prosecution of witches"[314]: In contrast to the Middle Ages, when half the accused witches were males, in early modern times approximately 80% of the defendants were females (Opitz 1995; Baten and Woitek 2001).

Overall, even though men still had the absolute authority and control over women[315] – the presence of women materializing in the cultural life phased in gradually (Segler-Meßner 2004). Similarly King (1998) concludes that 'the Renaissance woman' broke out from her traditional role (despite all resistance) obtaining the opportunity of individual development.

From the 18th century A.D. onwards – in the same way to the increased separation of private and public spheres – ideology was readjusted to the idea of dualism (Dölling 1991).

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[314] An intense debate is going on what caused this dimension of prosecution. One aspect is a decreased deference of females in different situations on life, like against husband supervision, or employers (Hardwick 2004, 356), because indeed some rethinking was induced during this period – culminating in Locke's alternative conceptualization in understanding gender relations. According to Amstadt (1994, 154 f.) the obsessive belief in witches and its inhuman excesses were initiated by the church in order to introduce posteriority and devaluation of women and their knowledge (especially their pre-eminence in know-how of healing power). This did not take a negative effect until the end of the medieval ages when the decisive change took place that remedies/drugs were sold in pharmacies by specialized men: women got adhered the bad reputation to be witches more and more, because their medical knowledge was not tolerated or accepted by the male competitors, because the men were afraid of rivals. Thus it is no puzzle why despite the overall enhanced position of females the phenomenon of witch-hunt had its historical peak during late medieval times and early modern times.

[315] Although early modern Europe 'brought' comparably many female rulers, authority was equated with masculinity (it does not matter whether family or politics).

It can be concluded that according to the “traditional” sources men had the dominant position over all periods.[316] It seems that in the Roman Empire, during the Migration Period and in the Renaissance the position of the women was comparable good, but in general the overall position of females was unequal to the position of males.

[316] As indicated by the fact that institutionally secured reign is carried out solely by men (Hermann-Otto 2000), and only very sporadic exceptions of single politically important women exist (like the Celtic Boudica leading their people in the rebellion against the Roman occupation, or the Roman Fulvia being military leader against Octavian’s land confiscations).

5. GENERAL CONCLUSION

Final mean height of humans is influenced by their nutritional status during growth, and thus, by a complex combination of living conditions. Since it can be assumed that the situation, which is relevant for the children in a population, can be transferred to the contemporary living adults, mean height can be used as indicator for the nutritional status and welfare, i.e. the biological standard of living, for the whole population. Therefore, higher longitudinal growth and final height of humans are widely recognized to be a good proxy for favorable conditions in terms of diet, diseases and work load, whereas poor height outcome is recognized as a proxy for inadequate nutritional status.

This correlation between height and nutritional status is valid for the present, but also for the past. The difference, however, between the present plus the last centuries against the earlier centuries, is the fact that for the former very different material exists to determine welfare, whereas for the long run information on the height of the population is the only, at least the best quantificable source. The reason, on the one hand, is that written sources for the past are problematic since texts by ancient authors or inscriptions in general cannot be taken as objective and exist only sporadically; and that usual economic data, like GDP or price development, for most times and regions are not available. On the other hand, nutritional status via human height can be determined even for pre-historical times utilizing bone remains. Here a large amount of information exist (for this study data on about 18000 individuals have been compiled), the data are widely distributed in time and region, belong to all social classes, and include information on both men and women. The latter is an additional advantage, since it allows us not only to investigate the nutritional status in general, but also gender effects, which is often even not possible for the last centuries since these data mainly stem from recruitment lists.

Of course, the method using bones for height determination has restrains, due to the degree of preservation, measurement errors, and uncertainties in the equations to reconstruct the height from the bones. However, effects of preservation already are taken into account in the height determination methods, measurement errors should be low since the data used have been measured by trained archaeologists, and we prepared new algorithms to unificate the data from different conversion methods. Moreover, the height data can be seen as representative due to their large amount and the random collection from a high number of cemeteries from all over Europe.

Restraints for the explaining variables result from the fact that data are available only for a small section of the potential determinants. Thus, we have combined different influencing factors into one available determinant. Moreover, the information on these determinants often stems from archaeological sources, and correspondingly in general data are not so precise.

Caveats are the temporal resolution, which is hundred years, with an additional small uncertainty due to the assessment of the age of death of the individuals. Furthermore, dating of graves in archaeological context can be problematic. However, we excluded uncertain dated individuals in this study. In the present data set, with the temporal resolution of 100 years, negative and later positive effects of events like wars or epidemics could be balanced, and thus not be significant for the explanation of the height development. Therefore, if both the spatial and the temporal resolution could be improved, this would have the advantage that such relatively short, but essential determinants could be investigated better.

Despite these restrains the positive aspects of the method clearly dominate: the analysis of bones is of special interest for archaeological periods. Skeletal data contribute powerfully to the knowledge on former living conditions. And the data are adequate enough to draw reasonable conclusions and to check hypotheses, whose accuracy could not be controlled for before.

The knowledge that skeletal data are a useful information source was adapted to the development of mean height of European population from the eighth century B.C. to the 18th century A.D. Since for this time no other really useful data are available, this provides a first attempt to fulfill the long outstanding, repeatedly criticized desideratum of a long run study on the nutritional status in pre- and early historic Europe.

Therefore, we venture to present the following conclusions about the Europeans in the time span of 2500 years:

- No decisive change in the nutritional status took place in the very long run until the 17th century A.D. This finding confirms the idea of missing secular trend prior to industrial revolution.
- Nevertheless, the Europeans experienced in-between periods of better and worse conditions.
- In contrast to the common imagination the period of Roman occupation brought a negative impact on the affected regions.
- In the long run overall temperature shifts have no statistically significant impact on mean height.
- Higher cattle share, as an indicator for high quality protein proximity and therefore consumption, has a positive impact on mean height.

- Cattle share and thus milk consumption were comparably low in the Mediterranean Region. However, if we control for cattle share no significant regional differences in mean height occur.
- Higher urban rate as indicator for dense, inadequate, and unhealthy living conditions was a major detrimental determinant of nutritional status.
- Higher population density has no statistically significant negative impact on mean height, in particular if we include the centuries B.C. with their very low population densities.
- Mean height of females and males moved more or less parallel over the centuries.
- In the 2500 years of the study period all over Europe no real change took place in the status of females, but the results vary. In regional comparison, overall status of females was comparably well in Mediterranean Europe. In the overall data the Roman influence was negative for female status.

Here the first step was made in order to study the development of nutritional status in pre- and early historic Europeans, but hopefully once further research in the different related fields will enable an extension of the study (also with an improvement of the explaining variables). Or as Björn and McKenzie (2007, 370) concluded their attempts to probe climatic proxies in the past: “Most of the past is still hidden in fog, but there is hope that future research will be able to lift it”.

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