Population trend in the Merovingian era in Western and Southern Germany

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Abstract – According to the common knowledge which is widespread among Early Medieval archaeologists, the number of grave fields and the number of graves in the burial sites are far higher in the 7th century than in the 6th century. However, the last supra-regional quantification of this phenomenon was conducted more than fifty years ago (Donat & Ullrich, 1971). This article aims to produce a more exact broad-based quantification of the population growth for Western and Southern Germany with the aid of modern, detailed dating systems. It finds that the population triples in the period from ca. 530 AD to 700 AD. This population growth is slightly higher than that of the Linear Pottery Culture in the Rhineland – a pioneering, agrarian-oriented population in this region which is well researched archaeologically – and slightly lower than in eastern Central Europe at the time of the booming Great Moravia. In modern times it roughly corresponds to the population growth in North America from 1950 to 2015 (**Fig. 43**). Within the period from about 530 to 670 AD, which can be assessed well because good sources are available, the growth in both the size of the grave fields (**Fig. 4, Fig. 5**) and their number (**Fig. 8, Fig. 11**) is linear, not exponential or logistic. The size of the grave fields does not follow a general norm, but is grouped into size classes: there are very small grave fields (approx. 1 farm), small ones (approx. 2 farms), medium-sized ones (approx. 5 farms) and large grave fields (approx. 7 farms); only a very small number of burial sites represent even larger communities (**Fig. 37, Fig. 38**). The growth in size of the individual grave fields is limited by a social upper growth limit (carrying capacity), which leads to the foundation of new communities when it is reached, i.e. the establishment of new grave fields (and settlements). The detailed analysis of the 34 grave fields investigated reveals that fewer than half the sites exhibit individual, significant deviations from the general trend in certain decades (**Fig. 16-Fig. 34**). In particular, the times the grave fields begin and cease to be used are sometimes individual. Deviations from the general growth model described which are common to all grave fields do not become apparent, however – especially not for the 6th century AD – which points to natural disasters or high-impact waves of plague with supra-regional effects. This does not negate the existence of the plague in Southern Germany, but its ability to spread and its lethality in this thinly populated, rural area should be scrutinised.

[A complete German version of this essay can be found in the Suppl. Mat.]

Key words – archaeology; Germany; Early Middle Ages; Merovingian era; Dark Ages; population growth; Justinianic plague; LALIA; Franks; Alemanni

Titel – Die Bevölkerungsentwicklung zur Merowingerzeit in West- und Süddeutschland

Zusammenfassung – Nach dem unter Frühmittelalter-Archäologinnen und -Archäologen verbreiteten Allgemeinwissen ist die Anzahl der Gräberfelder und die Anzahl der Gräber auf den bestehenden Bestattungsplätzen im 7. Jahrhundert erheblich größer als im 6. Jahrhundert. Die letzte überregionale Quantifizierung dieses Phänomens liegt jedoch mehr als fünfzig Jahre zurück (Donat & Ullrich, 1971). Der hier vorgelegte Beitrag unternimmt für den Raum von West- und Süddeutschland den Versuch, das Bevölkerungswachstum auf breiter Basis und unter Hinzuziehung moderner, detaillierter Chronologiesysteme exakter zu quantifizieren. Danach verdreifacht sich die Bevölkerung im Zeitraum von ca. 530 n.Chr. bis 700 n.Chr. Dieses Bevölkerungswachstum ist etwas höher als jenes der Bandkeramik im Rheinland – also einer archäologisch gut untersuchten, auf Landwirtschaft orientierten Pionierpopulation – und etwas niedriger als im östlichen Mitteleuropa zur Zeit des boomenden Großmährischen Reiches. Es entspricht in der Moderne in etwa jenem in Nordamerika in den Jahren 1950-2015 (**Abb. 43**). Innerhalb des aufgrund der Quellenlage gut beurteilbaren Zeitraums von ca. 530-670 n.Chr. verläuft das Wachstum sowohl der Gräberfelder (**Abb. 4, Abb. 5**) als auch deren Anzahl (**Abb. 8, Abb. 11**) linear, nicht exponentiell oder logistisch. Die Größe der Gräberfelder folgt keiner übergreifenden Norm, sondern ist gruppiert: es gibt sehr kleine Gräberfelder (ca. 1 Hof), kleine (ca. 2 Höfe), mittlere (ca. 5 Höfe) und große Gräberfelder (ca. 7 Höfe), nur sehr wenige Bestattungsplätze stehen für noch größere Gemeinschaften (**Abb. 37, Abb. 38**). Das Wachstum der einzelnen Gräberfelder wird durch eine soziale Wachstumsobergrenze (Carrying Capacity) gedeckelt, deren Erreichen jeweils zu Ausgründungen führt, d.h. zur Anlage neuer Gräberfelder (und Siedlungen). Die Detailanayse der 34 untersuchten Gräberfelder legt offen, dass weniger als die Hälfte der Plätze in einzelnen Jahrzehnten individuelle, signifikante Abweichungen vom generellen Trend aufweist (**Abb. 16-Abb. 34**). Insbesondere der Beginn und das Ende der Gräberfelder erfolgen z.T. individualisiert. Es zeichnen sich jedoch keine – insbesondere nicht für das 6. Jahrhundert n.Chr. – gräberfeldübergreifenden Abweichungen vom beschriebenen Wachstumsmodell ab, die auf überregional wirksame, naturbedingte Katastrophen oder hochwirksame Pestzüge schließen lassen. Die Existenz der Pest in Süddeutschland wird dadurch nicht negiert, aber ihre Ausbreitungskraft und Letalität in diesem dünn besiedelten ländlichen Raum sind zu hinterfragen.

Schlüsselwörter – Archäologie; Deutschland; frühes Mittelalter; Bevölkerungswachstum; Dark Ages; Iustinianische Pest; LALIA; Franken; Alemannen

Introduction

Estimating absolute population numbers and densities on the basis of archaeological sources is and will remain difficult. It ultimately involves the hardly reliable possible estimation of how much of what existed in the past has meanwhile been recorded archaeologically and prospected or excavated. If one wishes to compare different regions and eras, there is the additional problem that the quantities of discovered sites, graves or houses etc. which are now documented in the archaeolog-

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ical archives and publications very much depend on the one hand on the different customs of the people back then – e.g. solid post-built houses vs. simple huts or sleeper beam construction, deep inhumations vs. surficial interment of the deceased. On the other hand, our archives contain the effects of the different preservation conditions in each case, of the modern, source-dependent different probabilities of finding them (e.g. Siegmund, 1998, 5-13), and of the regionally different preferences of state archaeology (e.g. Siegmund, 2008). Against this background it is difficult to make reliable statements about the diachronic developments of the population density (e.g. Zimmermann, 1996; Chamberlain, 2006; Nikulka, 2016). Focusing on the Early Middle Ages, there is thus a marked difference between what is now Western and Southern Germany in the 6th and 7th centuries AD with a socially binding custom of burial and grave goods – especially the inhumation graves with ostentatious grave goods which are sunk deep into the ground (e.g. Koch, 1996; Stork, 1997) – and what is preserved and the likelihood of finding graves in what is now Northern Germany, for example. In the latter region, the dead together with their grave goods were often cremated at this time and their remains not infrequently left near the surface – either uncovered or covered only with a small mound – where they were soon exposed to natural erosion (Siegmann, 2004).

In my view, the diachronic studies of Andreas Zimmermann's team in Cologne are relatively good estimates of the prehistoric population densities in Germany (see in particular Wendt et al., 2012; re. critical analysis e.g. Herzog, 2012; Ehmig, 2012), because they focus on eras with well-preserved archaeological finds and use a uniform methodology. They therefore probably provide results which can be compared at least with each other. But they also do not eliminate the source-critical problem of the very different records. According to Wendt et al. (2012), for the Early Middle Ages in Western Germany, the regional population density is estimated to be 7.7 to 10.3 inhabitants per square kilometre (people/km^2) (Wendt et al., 2012, 266-292, esp. 291 "*Franken*"). My own estimate on a similar factual but different methodological basis, in contrast, produced an estimate of at least 3.3 and a maximum of 4.3 people/km^2 (Siegmund, 1993), which shows how strongly such absolute estimates diverge.

On the other hand, things are on a much more certain footing with the estimate of the relative population trend, i.e. in relation to the question of the relative growth (or decline), as long as one works within a space-time frame within which the same or similar observation and preservation conditions prevail. This is precisely what this article is attempting to do for the Merovingian era in Western and Southern Germany. For the Early Middle Ages, it is the grave fields and graves which are better preserved and form the basis of such estimates thanks to the fact that they can be dated well (Siegmund, 2018). Settlements from this period on the other hand are recorded in a comparatively unsystematic way, much more rarely excavated, and can be dated with considerably less precision than the graves (Siegmund, 2000, 243-245 & 402-403).

Previous findings on the population trend in the Early Middle Ages

Earlier studies, which from today's perspective took their starting point from research findings which were narrow and are now outdated, had already shown that for the Merovingian era, the number of discovery sites increases greatly as one moves from the 6th to the 7th century (e.g. Rütten & Steeger, 1932; Stoll, 1938a, 1938b; Böhner, 1969; Böhme, 1974).[1] Moreover, the chronological differentiations when evaluating the grave fields repeatedly indicated that the number of graves in the grave fields (i.e. the size of the grave fields) increases from the 6th to the 7th century (e.g. Fremersdorf, 1955, 135; Neuffer-Müller & Ament, 1973, 151; Koch, 1977, 190-193). For active Early Medieval archaeologists, it is thus a kind of common, general knowledge that there were more graves in the 7th century than in the 6th century; or expressed in terms of the material goods: there are far fewer graves with shield-on-tongue buckles (Schilddornschnallen) than with three-piece and multi-piece belt fittings. Although the growth hypothesis basically became common knowledge among experts, general and comparative syntheses remained rare apart from single findings; a more exact quantification of the phenomenon is lacking.

The most recent general synthesis on population growth is fifty years old: Peter Donat and Herbert Ullrich (1971) published a research synthesis on the population sizes in the Early Middle Ages and their growth. Taking archaeological and anthropological data as their basis, they discussed suitable methods, the problems and limits of the data available, and estimated how large the respective local communities were. According to their findings, the Early Medieval grave fields point to settlement communities of around 10 to 30 inhabitants, and also include a few larger burial communities of 70 to 90 or 130 to 210 inhabitants, which then each encompassed more than one settlement community (Donat & Ullrich, 1971, 249 Tab. 3). Although later studies corrected various details of these figures (Steuer, 1988; Siegmund, 1993; Schreg, 2006; Wendt et al., 2012), the methods proposed by Donat and Ullrich are still applied and most of their estimates validated with respect to their order of magnitude.

Using a detailed analysis of six grave fields which were used for a long period of time, Donat and Ullrich showed that the local communities grow from the 6th to the 7th century; they estimated the general scale of this growth to be a factor of 2.8 (Donat & Ullrich, 1971, 252 Tab. 4 and Fig. 1). The two authors emphasised the limited database and the preliminary character of their estimate. They additionally pointed out that not only the grave fields themselves grow in size, but the number of grave fields increases as well, but did not quantify the latter phenomenon. From today's point of view, it must be said that the archaeological chronologies on which Donat and Ullrich based their work must be considered to be outdated (Nieveler & Siegmund, 1999).

A valuable study on this topic was recently presented for the Rhine-Maas region in the Netherlands; it is based on settlements, i.e. on the number of settlements in a region whose archaeology has been the subject of good investigations over a long period of time and comprehensively surveyed, and the reconstructed number of houses (van Lanen et al., 2018; van Lanen & Groenewoudt, 2019). For this diachronic study from the start of the Roman era until 1000 AD, the Merovingian era from ca. 525 to 725 AD is a period which is not further differentiated such that it can be compared en bloc with the time before and after it. Comparisons show that the population in this region in ca. 525-700 AD was a factor of 4.77 lower than in the (heavily populated) middle Roman Imperial period (ca. 70-270 AD). After the Merovingian era and into the Carolingian era (ca. 725-900 AD), the population in this region increased by a factor of 2.45 (van Lanen et al., 2018, 57, Tab. 7).

There is thus no modern synthesis as yet on the question of the population trend in the Early Middle Ages for Western and Southern Germany, where the sources available make it possible, on the basis of the number of graves and modern chronology models, to also trace trends within the Merovingian era. According to the present state of our knowledge, two different phenomena must be observed in parallel for a more exact estimation of the population trend in the Early Middle Ages: the normal trend of the local settlement and burial communities, which manifests itself in the trend for the number of persons buried per time interval, and the number of grave fields and their dating in comprehensively surveyed regions. This is because a hypothetically stable population can seemingly dwindle on the local level by establishing new settlements together with new grave fields, or lead to a reduction in the number of sites by concentrating previously scattered, smaller burial sites at one common site, for example – without the actual head count in a region having changed. Only an overview of both phenomena allows reliable statements to be made.

The wider background to the issue

The current hypotheses which have been presented on an Early Medieval growth in population are in stark contrast to the general picture of a decline and fall which is traditionally portrayed for this era. According to the *"Decline and Fall of the Roman Empire"* (Gibbon, 1776-88), various smaller-scale societies formed in Central and Western Europe, and many elements of the previous civilisation were abandoned or greatly diminished (e.g. Fried, 2008, esp. 11-57; Wickham, 2009). This period, formerly often called the *"Dark Ages"*, is today interpreted as an important time in the transition from the Roman civilisation to the kingdoms of the European Middle Ages (e.g. Hodges & Bowden, 1998). The extrinsic living conditions in this era were difficult: In addition to the well-known politico-social and economic problems, the climate became increasingly adverse from around 300 AD (Büntgen et al., 2011); as a consequence, there was a reduction in farming activities, reforestation occurred (Bunnik, 1995). The 6th century AD in particular is repeatedly presented as a time of severely negative environmental influences, the years between ca. 530 AD and 660 AD have recently been classified as the *"Late Antique Little Ice Age"* (LALIA), with average annual temperatures around 1.5 degrees lower than the average of the last 1,500 years (Büntgen et al., 2011, Fig. 3; Büntgen et al., 2016, Fig. 2). The discussion centres around large volcanic eruptions in the years 537, 540 and 547 AD (Büntgen et al., 2016; general: Newfield, 2018).

Reliable information in the written sources proves that in the middle of the 6th century – starting in 541 AD in the eastern Mediterranean, from 543 AD onwards in Southern France as well – several waves of the plague swept through Europe. The population reduction this triggered is estimated to be about 40 % (Grupe, 1986, 27 Fig. 1; Herlihy, 1987, 10; Gutsmiedl-Schümann, 2010, 112-113). The incidence of the Early Medieval plague in Germany as well was demonstrated for the first time at the grave field in Aschheim near Munich, where it was possible to detect the plague bacterium *Yersinia pestis* by means of ancient DNA (Staskiewicz, 2005; Wiechmann & Grupe, 2005). Later, researchers successfully obtained further proofs of plague dead, at a total of six grave fields in the east of Southern Germany so far (as of 2023) (Harbeck et al., 2013; Keller at al., 2019; cf. Haas-Gebhard, 2017).

Basing his work on a larger collection of demographic data, Bernd Hermann (1987, 64 f.) applied the regression equations of Bocquet and Masset (1977) to show that the population declined in the Early Middle Ages. The recent results of Andreas Zimmermann's research team confirm this: compared to the prospering Roman provinces in the Rhineland in the 2nd and early 3rd century AD, the population density fell from 14.4 (10.8–17.9) people/km^2 (Zimmermann, 1996; Wendt, 2008, 22) to around 9.0 (7.7–10.3) people/km^2 in the 7th century (Wendt et al., 2012, 290) – a decline of around 38 percent.

On the other hand, apart from the aforementioned population growth, other individual observations also indicate that the Early Middle Ages were not characterised only by decline and disasters, but by living conditions which tended to be good: The people were significantly taller – usually taken as an indicator of good living conditions – in the Early Middle Ages than in the times before and after (Siegmund, 2010, Figs. 7-8). Büntgen et al. (2011, Fig. 2C) show that the number of trees felled increased from the middle of the 5th century until ca. 850 AD, which points to more building activities being undertaken in Central Europe.

A more exact description, quantification and possibly also a temporal localisation of the Early Medieval population growth (or decline) would help us to obtain a more exact assessment of the consequences of the social changes and the extrinsic conditions (climate, geological disasters, plague) outlined, and to describe the resilience of the Early Medieval societies.

The space-time window investigated in more detail

The grave fields reveal much more archaeological information about the Early Middle Ages in Western and Southern Germany than the settlements. The custom of that time relating to burials and grave goods produces conditions which are good for preservation and discovery: In the 6th and 7th centuries AD, the dead were generally buried in deep inhumation graves accompanied by ostentatious grave goods – esp. jewellery, pieces of costumes, weapons, food and drink together with the associated earthenware and glass vessels. When discovered accidentally, these goods lead to subsequent recovery, find notifications and professional excavations. The new burial customs developed gradually and over several generations in the course of the 2nd half of the 5th century AD and became socially binding at the beginning of the 6th century – around 530 AD at the latest (e.g. Ament, 1992; Quast, 1997; Siegmund, 2000, 97-99; Theune, 2004, 203-234). An accurate assessment of the numbers for the period before 530 AD is therefore difficult: What is certain is that during the 5th century, a large proportion of the people of that time followed burial customs for which archaeological evidence is sometimes difficult to find (e.g. Ament, 1992; Siegmund, 1989; Siegmann, 2004). Part of this article will examine to what extent the numbers after the lower limit of the investigation window set here – from 480 AD onwards (*"Clovidian times"*) – are reliable.

After the middle of the 7th century on the other hand, first the quantity of grave goods declined and a short time later the people moved their burial sites from the cemeteries outside the settlements to the vicinity of the newly established churches in the settlements, i.e. to the churchyards (Theune-Grosskopf, 1997; Schreg, 2006). In these churchyards, the dead were buried without any grave goods with a few exceptions, which means they can be dated with less precision than before. Moreover, these churchyards were then used over a long period of time without changing in size, i.e. the graves of the late 7th and 8th century were largely disturbed and destroyed by later burials. The churchyards are accordingly not a source which is as useful and representative as the grave fields which preceded them. The fact that during the transition from graveyard to churchyard other transitional forms were also used – think of farmstead burial – makes the situation regarding archaeological sources after ca. 660/70 AD even more complicated (cf Theune-Grosskopf, 1997, Fingerlin, 2004; Steuer, 2004; Lobinger, 2014, for example).

With some exceptions, churches and churchyards began to be founded in the Rhineland in the decades around 600 AD, in Southern Germany somewhat later in the course of the 7th century (Böhme, 1993, 520 Fig. 9). The first churches initially attracted only small numbers of burials however; it was not until the last third of the 7th century, roughly from 660/670 AD onwards, that the churchyards successively became the preferred place of burial (e.g. Theune-Grosskopf, 1997).

For the reasons set out, the Early Medieval burial sites from ca. 480 AD until ca. 700 AD can be easily tracked, the time frame of ca. 530-670 AD providing good, intercomparable data, whereas the situation regarding sources before and after this time span is much less reliable. Within the suitable time frame, a relatively rapid cultural change took place which makes it possible to use the grave goods to develop relatively finely meshed local or regional chronologies and to date the grave assemblages to *"stages"*/*"phases"*/*"horizons"* of roughly 15 to 40 years as a rule (e.g. Nieveler & Siegmund, 1999; Siegmund, 2018, with additional lit.). Counting the number of dated graves per year or decade provides an insight into the relative population trend.[2]

What do archaeological chronologies date?

During the 20th century, great progress was made on dating grave goods from the Merovingian era. While the early chronologies developed from the 1930s to the 1970s aimed at an appropriate assignment of the grave assemblages to centuries, then half-centuries, the 1980s and 1990s saw the development of chronology systems for Western and Southern Germany (overview: Nieveler & Siegmund, 1999, 3-4) which are more detailed and therefore allow phenomena such as decline or growth to be understood more exactly. The absolute chronology in Western Europe is based mainly on the coins found in the graves, in addition to the relatively small number of graves dated using dendrochronology. Thanks to the overall large numbers of coins which can be dated absolutely, a reliable network of data has been created which makes it easy to identify individual outliers (ancient pieces).

In Great Britain, where it is a very rare exception for the Early Medieval graves to contain coins which can be dated absolutely, a large-scale chronology project in the 2000s obtained large numbers of ^{14}C datings from bones and compiled a separate Early Medieval chronology on the basis of a comparison of the find combinations and ^{14}C data ordered per correspondence analysis (Bayliss, Hines, Høilund Nielsen, McCormac & Scull, 2013). Comparing the absolute dating of similar types of find in Great Britain with their parallels on the continent shows that very similar results are obtained in respect of the absolute dating, i.e. the continental coin chronology and the British ^{14}C chronology correspond to each other (Bayliss, Hines, Høilund Nielsen, McCormac & Scull, 2013, 479-492).

But what exactly is actually dated? This is a question whose answer, given the level of detail of the datings, which are often shorter than the lifespan of an individual, is important for the understanding of connections with historically fixed events, for example. In short: the datings do not record the time of death or burial, but the (early) adulthood of the buried individuals. In more detail: It is not the individual finds that are dated, but the assemblages which are typical of the time. An estimate is made of the point in time at which the individual objects of the grave assemblages were most probably all present together in the living culture. The resultant relative chronologies describe the sequence of find combinations which are typical for the time. Only in exceptional cases were the coins used for the absolute dating placed in the grave as *"Charon's obol"* (i.e. quite specifically as an offering for the burial); instead they are part of the jewellery or the purses as a rule, i.e. they are acquired and used under the same conditions as the rest of the grave goods. The grave goods overall are mainly personal possessions. They were chiefly obtained after childhood and adolescence in (early) adulthood, i.e. primarily around 20-30 years of age. In the Merovingian era, most of those who reached adulthood died as mature adults, with deaths peaking around 45 years of age or in the decade of their life spanning 40–50 years of age (e.g. Kunter & Wittwer-Backofen, 1996, 655 Fig. 522: mean value of e_{20}+20: 44.1 years).[3] The absolute datings therefore refer to the probable age of the grave assemblages which the individual mainly acquired when 20-30 years of age. However, the calendrical time of death of the individual who owned this assemblage – given most people died aged 40-50 years of age – is around 20 years after the absolute datings stated on statistical average. For all questions relating to the scale of the relative population growth, this time shift is of no consequence, but it does play a role when we link archaeological data with historically fixed events.

Let us visualise these considerations: A grave assemblage dated using the methods normally used in west European Early Medieval archaeology to *"ca. 530 AD"* was probably buried ca. 550 AD. Notable discrepancies then arise when bones of the buried person are ^{14}C dated or woods used for the coffin are dendrochronologically dated, because these methods date the time of burial, not (like the coins) the period in which the assemblage was put together. Moreover, one must bear in mind that exceptional disasters such as major wars, famines or epidemics in which many people in a population died within a short time, shorten the usual period of *"plus 20 years"* between the actual age of the assemblage and the time of death, i.e. shift it closer to the usual archaeological dating of the assemblage.

"Population": Number of persons buried

When graves are counted, it is the number of persons buried which is recorded, not the number of the living. But to make it easier to visualise the results, here is a model calculation. In the Early Middle Ages, the average proportion of those aged 0-9 years in the 525 Early Medieval grave fields collated by Peter Caselitz is 18.9 % (Caselitz, 2021, 32 Fig. 5; cf Lohrke, 2004, 52 Tab. 3). According to the considerations in Caselitz (2021, 34-37), who followed the demographic models of the UN (so-called Model UN 36), the true proportion of children aged 0-9 years should be 44 %. After the child mortality has been corrected to 44 %, the average life expectancy at birth becomes 33.1 years. The life expectancy of those who reached adulthood (e_{20} + 20 years) is roughly 43.3 years (Caselitz, 2021, 32 Tab. 5; Kunter & Wittwer-Backofen, 1996, 665 Fig. 522; Panhuysen, 2005, 159 Tab. 6.10 and 218). It is thus possible to determine as a rough approximate value that 1 deceased per year represents a living population (incl. 44 % non-adults, following Caselitz, 2021, 35 Fig. 6) of 38.6 persons (17.0 non-adults, 21.6 adults). To stay as close as possible to the actual primary information available, I still use the number of people buried per year, not the living population which can be estimated therefrom, in my arguments below.

More graves = more people?

All those who live will die. The general population trend is therefore reflected in the number of dead. A growth in population therefore ultimately goes hand in hand with more dead per year, and a population decline with fewer dead per year. The above-mentioned disasters – e.g. years with famine caused by a large volcanic eruption, years with pandemics or wars with far-reaching consequences – would likewise also result in a greater number of dead. An increase in the number of dead is therefore ambiguous, for example from the decade 530/540 to the decade 540/550 AD: It can be down to the growth of a population which lives well and is increasing, but also to a pandemic, for example. The difference between the two phenomena can be seen from the time which follows: If the main cause of the growing numbers is a general population growth, the numbers continue to increase in the years which follow. If the cause is a pandemic, for example, there will be fewer living people and consequently fewer dead immediately afterwards. The detailed analysis of individual grave fields will show that there were also grave fields where the living population shrank (considerably) for a time in addition to the fact of a general population growth.

Objective

This article investigates the time-related different numbers of grave fields in comprehensively analysed regions, and the time-related different numbers of graves for comprehensively analysed grave fields for the time frame from ca. 530 to 670 AD. These data are used to estimate the relative population development in the Merovingian era.

Material and methods

The study is based on two datasets. Both sets were collected criteria led and with a claim of being complete. One dataset covers all regions in Western and Southern Germany for which a comprehensive survey of all grave fields from the Merovingian era is available and in which these grave fields and their establishment and end are dated on the basis of a recognised, modern chronology model. The objective of this collection is to be able to make statements about the number of grave fields.

A second dataset was compiled of all completely or almost completely excavated grave fields whose graves are again dated on the basis of a recognised, modern chronology model and which were used over a longer period of time – because trends can only be determined given a certain minimum utilisation time. Grave fields which were used over only a short period of time, and those which did not begin to be used until around 600 AD or in the 7th century, were not included in the collection.

Dating models whose temporal resolution only achieves the level of a whole or a half century were classified as being too coarse for our purpose and not considered.

The data on the regions including the references can be seen from the table in **Fig. 1**. The dataset on the number of dated graves per decade is included in this article as Open Data (**Suppl. Mat. 1-2**).

Dataset for the grave fields

In accordance with the criteria stated, it was possible to collate data from seven comprehensively surveyed regions with a total of 916 grave fields. From these data it is possible to deduce how the number of grave fields developed within the time frame considered for two time intervals (**Fig. 1**). The regions considered are different in size, which is why the absolute numbers cannot be compared with each other, but the relative trend as a function of time can.

Dataset for the graves

The second dataset contains the number of burials per relative chronology phase for 34 suitable grave fields with a total of 8,909 dated burials (**Suppl. Mat. List 1; Fig. 6**). All graves were dated in accordance with the regional chronology accepted as valid for this region or the respective local chronology, as could be retrieved from the relevant publications. With graves which could be dated less accurately, whose dating spans two phases of the chronology, 50 % was added to each of these two phases. Graves which span more than two phases are deemed to be undatable. However, in all cases where a systematic spatial development of the grave fields (*"chorologic"* / *"topochronological"* analysis) is observed and allows to fix burials without grave goods too, all such graves with a high degree of probability belonging to a certain phase are also considered to be dated graves.

The absolute years (i.e. the phase boundaries) which are associated with the respective regional and local chronologies (e.g. Nieveler & Siegmund, 1999, 8 Fig. 1.4; Siegmund, 2016, 119 Fig. 122) do not coincide. It is therefore necessary to process the raw data. This was done by converting the number of dated graves per phase into *"graves per decade"* with the aid of the absolute duration of these phases. This number is assigned to the middle decade or both middle decades of the phase in question (**Suppl. Mat. List 2**, numbers in bold). The still empty cells (decades) between the phase mid-points are filled by interpolation with the arithmetic mean from the two neighbouring cells i.e. decades (**Suppl. Mat. List 2**, numbers not in bold). Any large jumps in the values between two phases are thus smoothed, which can be seen as an advantage or a disadvantage of this procedure.[4]

Parametrisation of the population trend

The tables and diagrams compiled here from the raw observations already provide valuable insights into the relative trend within the Merovingian era. For more detailed comparisons, it is useful to additionally use those parameters which are used in demography for the abstract description of population growth or decline. Parametrising the observations makes it possible to compare the numbers for the Merovingian era with the values of other eras and the present day, to which I return in the discussion. So as not to deflect the text flow from the real issue, the three relevant models – geometric growth (parameter λ, lambda), exponential growth (parameter r) and logistic growth (parameters k and C) – including the respective parameters, their calculation and their mathematical relationships with each other, are explained in more detail in the *"Demographic Parameters"* glossary (**Suppl. Mat. 3**), but are not discussed in detail here. Those who are interested can consult this glossary whenever such information appear below (see also: Chamberlain, 2006).

Number of graves and living population

This essay uses the number of grave fields per unit of time and the number of graves per time interval in its arguments almost throughout. Using the equation proposed by Acsádi & Nemeskéri (1970, 65 f.; also: Donat & Ullrich, 1971; 1976), the size of the living population can be estimated from the number of graves per unit of time. The parameter e_0, the life expectancy at the time of birth, is needed for this, however. This parameter depends to a very great extent on the infant mortality: A population with high infant mortality has a low life expectancy e_0 at birth, one with a low infant mortality has a higher life expectancy, possibly without there being any difference in relation to the adults. The average observed infant mortality in the Merovingian grave fields is around 29.2 % (Caselitz, 2021, 32 Tab. 5a; Lohrke, 2004: 21.7 %). This it at odds with hypotheses which are usually advanced by anthropologists in particular, who assume the child mortality in prehistoric populations to be around 45 % or even 60 % as a rule (Acsádi & Nemeskéri, 1970, esp. 235; Langenscheidt, 1985, 80-83). It has thus become the practice to use the phrase *"too few children aged 0 to 5 years of age"* or *"too few children aged 0 to 1 year of age"* (e.g. Rösing, 1975, 30 ff.) and also, with a view to the UN model life tables, for example, to make a projection of and supplement the *"missing"* children with corresponding effects on e_0. Opinions such as those of Alfred Czarnetzki (Czarnetzki et al., 1982, esp. 10; Czarnetzki, 1987, 201), which have rejected this practice pointing to the much lower child mortality which is presumed to have actually existed in the Merovingian era (no towns, more hygienic conditions than in the Middle Ages, very low population density, etc.), are voiced repeatedly (Kölbl, 2004; Meier, 2011), but have not yet gained broad acceptance in the research. The scientific debate on the lack of children aged 0 to 5 years of age is still ongoing and not yet settled. So as not to add an additional, considerable uncertainty to this text, a calculation of the living population (with one exception) is not undertaken, and the argumentation is consistently based solely on the number of graves.

Data management and statistics

The two datasets were recorded in a spreadsheet (MS Excel) and are enclosed with this publication as Supplemental Material. All statistical calculations were done using R (Version 4.3.1; R Core Team, 2023); graphics were made with the help of the R package ggplot2 vers. 3.4.4 (Wickham, 2016). The two maps were produced with QGIS vers. 3.34 in the WGS 84 system, base map: ESRI Gray (light) and ESRI Satellite.[5] All hypotheses on differences were tested for their statistical significance (depending on data: chi-squared test; Kruskall-Wallis test), a p-value of $p \leq 0.05$ being used as the limit value in each case.

Results

The number of grave fields increases

For Western and Southern Germany, seven larger regions with comprehensive surveys of the Early Medieval grave fields are available; in each of these studies all sites are recorded, provided with references and in particular dated with a useful accuracy. When these studies are combined, 240 grave fields exist around 500 AD, 451 grave fields in the middle of the 6^{th} century, and 916 in the middle of the 7^{th} century. The data for the individual regions are listed in **Fig. 1**.[6]

Region (reference)	Late 5^{th}/early 6^{th} c. ≈ 480-510/30 AD	Mid to 2^{nd} half 6^{th} c. ≈ 530-580/90 AD	Mid 7^{th} c. ≈ 630-670 AD
Northern Rhineland (Nieveler, 2006)	89	184 λ= .01017 λ= .02033	254 λ= .00272 λ= .00411
Southern Rhineland (Bienert, 2008)	121	176 λ= .00433 λ= .00866	468 λ= .01185 λ= .01794
Main-Tauber region (Koch, 1967)	6	13 λ= .01111 λ= .02222	38 λ= .01374 λ= .02079
Breisgau (Hoeper, 2001)	6	20 λ= .02222 λ= .04444	41 λ= .00750 λ= .01135
Runder Berg (Quast, 2006)	10	32 λ= .02095 λ= .04190	61 λ= .00647 λ= .00980
Hegau (Theune, 1999)	3	13 λ= .02143 λ= .04286	21 λ= .00440 λ= .00665
Lech Valley (Trier, 2002)	5	13 λ= .0152 λ= .03048	33 λ= .01099 λ= .01663
Sum mean annual growth rate (min-max)	**240**	**451** λ= .01256 (0.00837-0.01675)	**916** λ= .00926 (0.00736-0.01115)

Fig. 1 Number of grave fields in seven comprehensively surveyed regions in Western and Southern Germany. The geometric growth rate λ (*"lambda"*) is calculated once after the beginning and the end of the respective time intervals, and once after the middle of the respective time intervals. Owing to the unavoidable dating spans, this table calculates the annual growth rate λ as the mean of the lowest given growth (time span in years = end of the most recent phase minus the beginning of the earlier phase) and the presumed highest growth value (time span = mid-point of the most recent phase minus mid-point of the earlier phase).

The new burial tradition of inhumation graves with grave goods which first became the norm in the late 5th century and beginning of the 6th century means that the observed frequencies of the grave fields for the first time interval *"Late 5th/ early 6th c."* i.e. *"480-510/30 AD"* are probably too low, which is why the estimate of the growth in the interval which follows is correspondingly too high. The observations for the trend from ca. 530-580/90 to ca. 630-670 AD with an annual growth of about λ= .00926 (i.e. approx. 0.93 %) are considerably more reliable, on the other hand. The fact that the growth in the preceding interval, which can be estimated with less certainty from an archaeological point of view, turns out to be much higher at approx. λ= .01256 (i.e. approx. 1.26 %) than in the undermentioned later, more reliably estimated time interval, means that the starting figure of 240 grave fields on which this is based is quite probably an underestimate of the actual number – as is also generally assumed to be the case (e.g. Ament, 1992; Quast, 2006, 111-113).

When the issue is population growth, the exact form of this growth is very important, i.e. whether the observations indicate growth which is more likely *"geometric"* (linear), exponential (*"intrinsic"*) or logistic in nature. This question can only be answered when more than two reliable observation points along the time axis are available, however. For two of the regions listed in **Fig. 1**, the numbers of grave fields are available with high temporal resolution: for the Northern Rhineland and for the Lech Valley. These two regions are used below to help examine which type of growth occurs (**Fig. 2-Fig. 5**).

Northern Rhineland	n sites	Absolute growth
Phase 3, c. 470-515 AD	59	-
Phase 4, c. 515-565 AD	102	+ 43
Phase 5, c. 565-585 AD	154	+ 52
Phase 6, c. 585-615 AD	174	+ 20
Phases 7/8, c. 615-675 AD	224	+ 50
Phases 9/10, c. 675-740 AD	251	+ 27
515/565-615/675 AD		+149

Fig. 2 Number of grave fields per time interval in the Northern Rhineland (as per Nieveler, 2006). The annual growth rate from phase 4 to phases 7/8 is λ = .01152 (.00913 to .01391).

Lech Valley	n sites	Absolute growth
500-520/525 AD	5	-
520-540/545 AD	4	- 1
540-565/570 AD	7	+ 3
565-590/600 AD	13	+ 6
590-620/625 AD	16	+ 3
620-650/655 AD	24	+ 8
650-675/80 AD	33	+ 9
675-700/710 AD	30	- 3
700-720/25 AD	17	- 13
520/40–660/75 AD		+29

Fig. 3 Number of grave fields per time interval in the Lech Valley, Bavaria (as per Trier, 2002 Tab. 1). The annual growth rate λ from 520-540 AD to 650-680 AD is .02275 (.02097 to .02453), i.e. it is approximately double that in the Northern Rhineland.

The line graphs shown in **Fig. 4** and **Fig. 5** put the number of graves into the middle of the time spans stated by the respective authors. In both cases there is linear (geometric) growth within the time frame of relevance here – 530-670 AD; i.e. in both test regions there is a continuous increase in the number of grave fields. It is not important here that the growth rate is lower in the Rhineland and higher in the Lech valley; neither is it important that the figures for the Northern Rhineland are ultimately more reliable than those for the Lech Valley because the sample is large. What is important is that neither exponential growth (cf. **Fig. 12**) nor logarithmic growth (cf. **Fig. 13**) is present in either region, at least not within the time frame of ca. 530 to 670 AD.

Thus the calculation of a growth rate λ for the data in **Fig. 1** assuming linear growth is justified. Since source-critical reasons mean there are significant doubts about the initial figure for the late 5th century, we use the figures collated in **Fig. 1** to calculate the growth in the number of grave fields only for the core interval: the middle third of the 6th to the middle third of the 7th century. If we base our time span on the maximum interval (530-670 AD, i.e. 140 years) we obtain a λ of .00736; if we base our time span on the midpoint of the estimation interval of the initial phase and the end phase in each case (i.e. 92.5 years), we obtain a λ of .01115; the mean of the two estimations is .00926. For comparative purposes, we also determine the value of r (exponential growth) therefrom, and obtain r = 0.00636 (0.00506 to 0.00766); the doubling time is 109 years (90.5-137 years).

To illustrate the result, the above-mentioned mean of the two estimates, i.e. λ = .00926 is used as the basis of the calculation. Eighty years later,

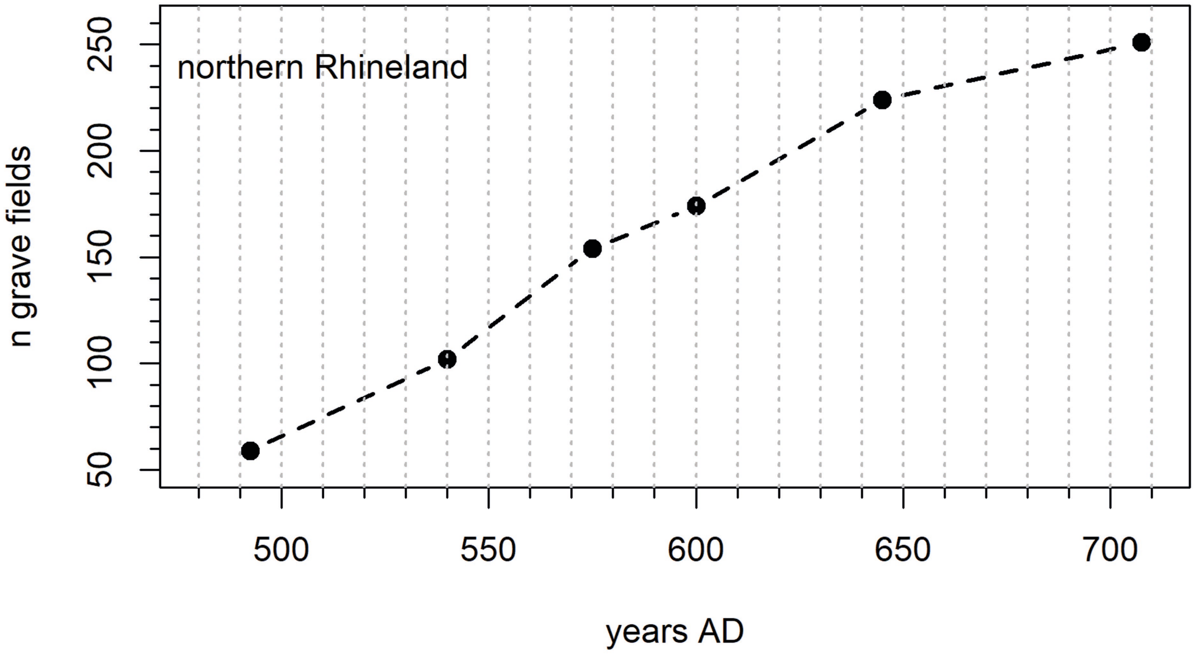


Fig. 4 Trend for the number of grave fields in the Northern Rhineland (as per the figures in NIEVELER, 2006).

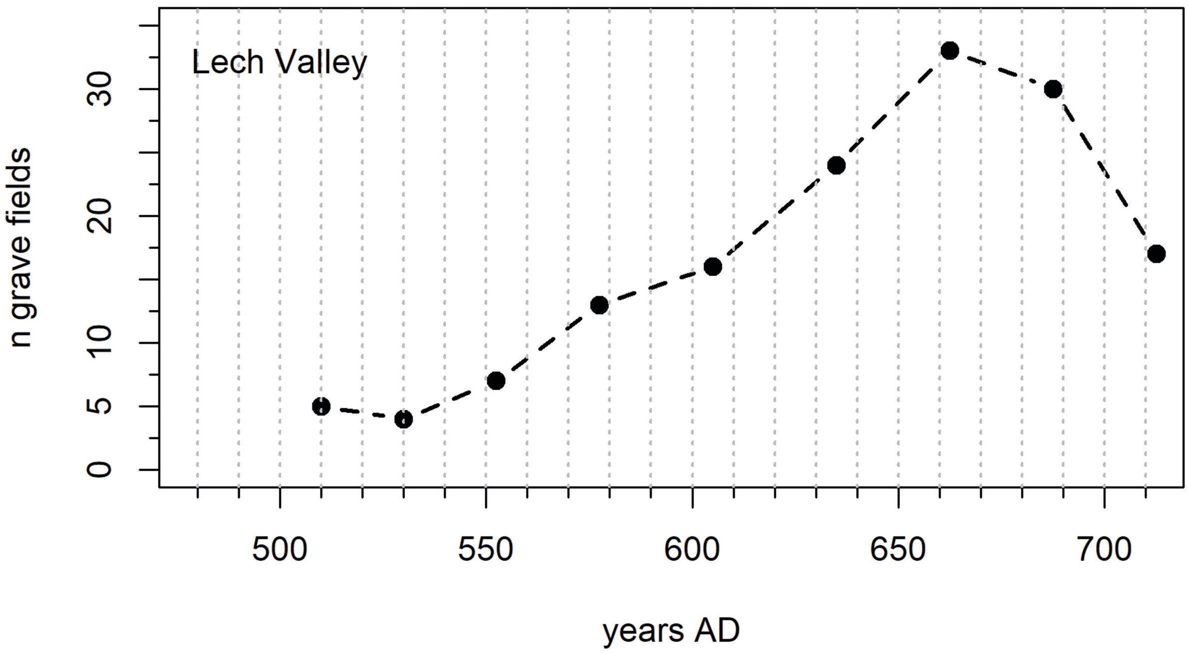
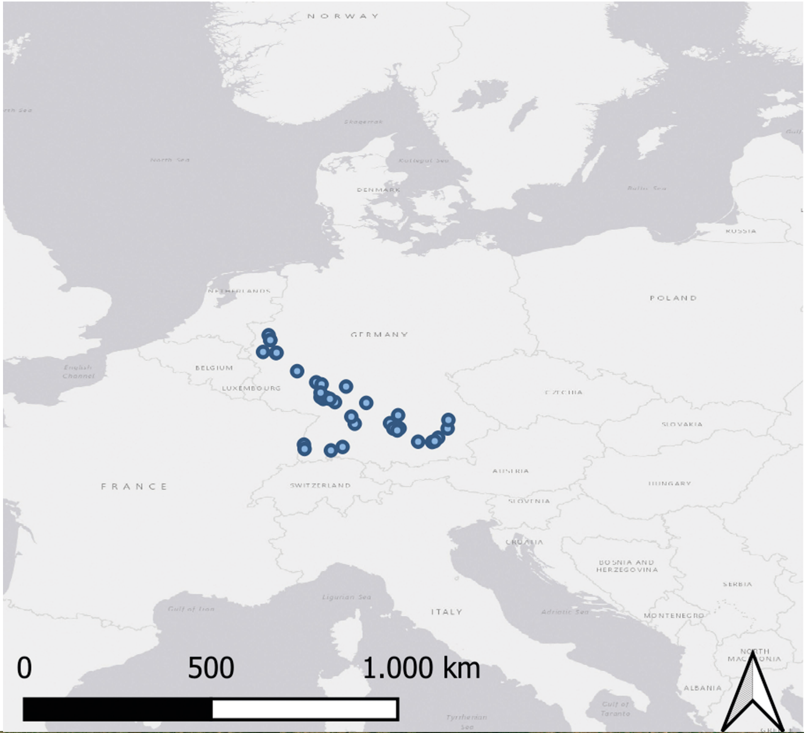
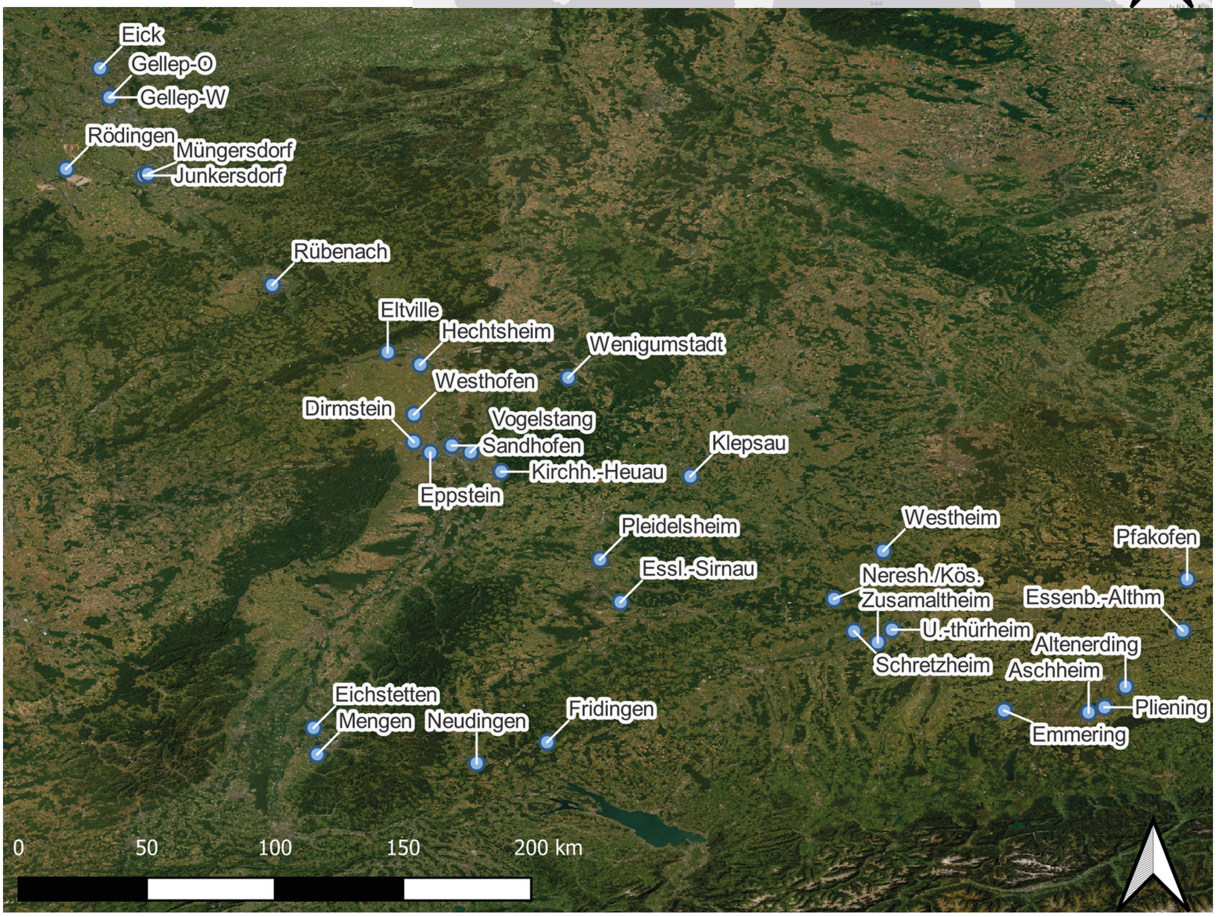


Fig. 5 Trend for the number of grave fields in the Lech Valley (as per the figures in TRIER, 2002, Tab. 1).

Fig. 6 (a, b)
Maps showing the distribution of the 34 grave fields used here which are (largely) complete and were in use for a longer time. Base map (WGS 84): ESRI Gray (light) resp. ESRI Satellite.





1 grave field in the 530s has become approx. 1.89 grave fields in the 610s (i.e. the global maximum of the number of graves), and 130 years later in the decade 660/70 AD (i.e. the time the transition

Decade	Graves/year
480-490 AD	4.49
490-500 AD	9.57
500-510 AD	12.23
510-520 AD	17.37
520-530 AD	20.81
530-540 AD	33.57
540-550 AD	37.63
550-560 AD	41.11
560-570 AD	45.75
570-580 AD	52.39
580-590 AD	52.67
590-600 AD	54.16
600-610 AD	57.56
610-620 AD	58.43
620-630 AD	55.77
630-640 AD	50.53
640-650 AD	46.49
650-660 AD	42.05
660-670 AD	38.30
670-680 AD	29.90
680-690 AD	25.00
690-700 AD	22.05

Fig. 7 Number of graves per year. The table shows the sum of all 34 suitable grave fields with modern, sufficiently detailed chronology models. Grey: Time intervals in which the nature of the sources means the data are less reliable.

from the row grave field to the churchyard is traditionally assumed to have taken place) it has become a total of 2.45 grave fields.

When a starting value of 451 grave fields in the 530s and a growth rate of λ = .00926 is used as the basis of an interpolation into the past, linear growth over the whole period results in approx. 242 grave fields in the 485s. This comes very close to the observed number of 240 grave fields (**Fig. 1**). From this we can deduce that the number of grave fields extant around 485 AD, i.e. the grave fields which archaeology can discern, is plausible. Similarly, if the numbers are extrapolated into the 695s, 1,120 grave fields would then be expected, i.e. 204 sites more than the 916 grave fields observed here for the period 630-670 AD. This is not implausible given the many new cemeteries/settlements in the late 7th century, but given the uncertainty in the sources available which was explained in the introduction it cannot be evaluated for a robust comparison between expected and actual values.

A detailed look at the growth rates in **Fig. 1** shows that the growth is significantly lower in some regions (i.e. Northern Rhineland, λ= .00342 corresponding to approx. 0.34 %), and considerably higher in others (e.g. Main-Tauber region, Lech valley, approx. 1.7 % and 1.4 % respectively). The question remains unanswered as to whether the grave fields themselves increase more strongly in size but their number less so in some regions

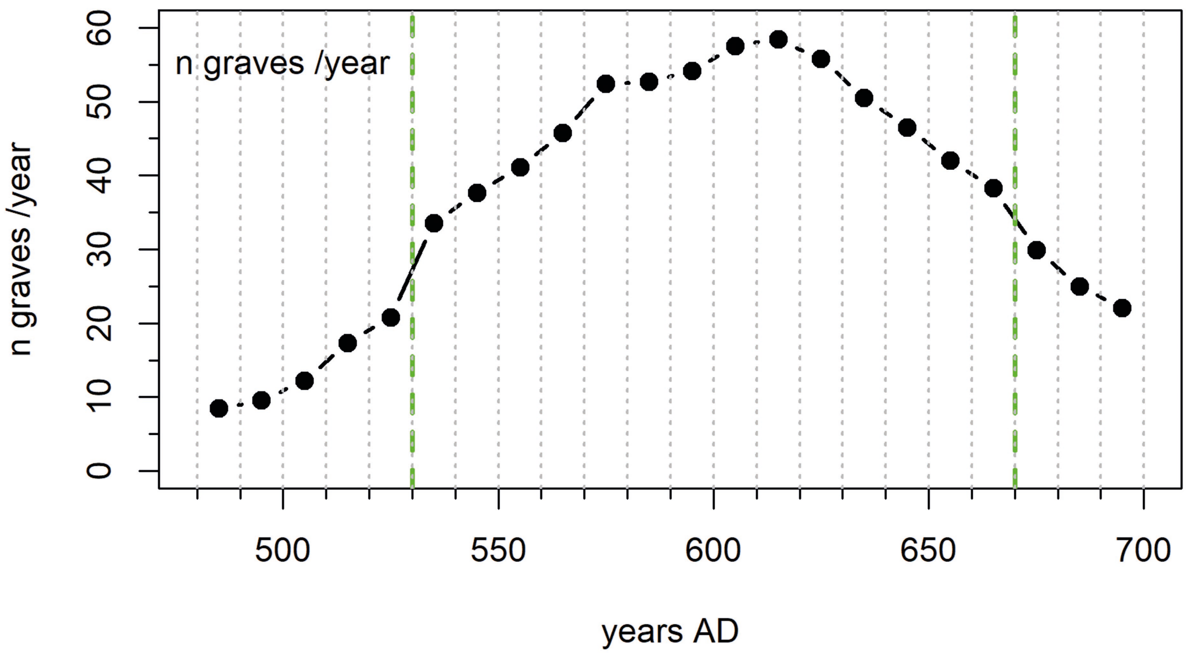


Fig. 8 Line plot with number of graves per year, sum of all 34 grave fields. The two vertical green lines mark the intercomparable time frame ca. 530-670 AD for which good sources are available.

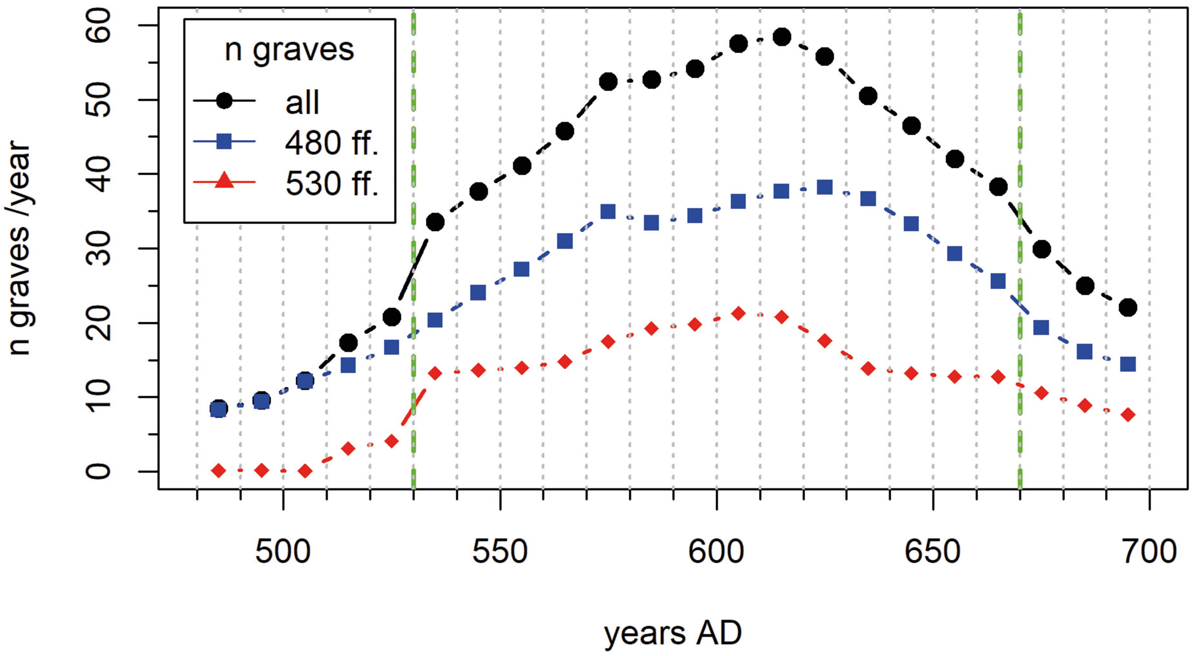


Fig. 9 Number of graves per year, shown for the total sample (black) and differentiated into those grave fields which were established as early as the late 5th century or *"around 500"* (blue), and those that were established around 530 AD (red).

such as the Rhineland, whereas the grave fields increase less strongly in size but their number increases all the more in the Main-Tauber region or the Lech Valley, i.e. the increase in the overall number of graves is the same. Alternatively, historical processes can be the cause of the (not slight) differences between the regions, for example less growth in the ancient settlement areas (Rhineland), more growth in areas where hitherto hardly populated regions were being settled. However, this requires us to first study the other dimension, the number of graves.

530 ff: The number of graves increases

Using the criteria described, it was possible to include 34 grave fields with their dated burials (**Fig. 6-Fig. 7**); the respective local chronology was used for ten of these grave fields (see **Suppl. Mat. List 1**), while for the others one of the four standard chronologies was used (Koch, 1977; Siegmund, 1998; Müssemeier et al., 2013; Koch, 2001). There are no indications of systematic differences in the dataset which are down to the chronology system used in each case.

The results for the 34 grave fields evaluated which were utilised over a longer time interval with detailed chronologies are shown in **Fig. 7** and **Fig. 8**.[7]

In the sample, the number of graves per year in the decade 480/490 AD is around 4.5 and reaches its maximum at approx. 58.4 graves in the decade 610/620 AD. After 530/540 AD, the increase to approx. 52.4 graves initially in the decade 570/580 AD is considerable and mostly linear, before a marked levelling off occurs. After the maximum at around 610/620 AD, there is a decrease in the number of graves to around 22.1 graves/year, this decrease again being very considerable and largely linear.

It is expedient to note the following in anticipation of what follows: When described with the parameters customarily used in demography (**Fig. 10**), the jump between the 525s and 535s (**Fig. 8**) is twice as high as the so-called population explosion in Africa in the 2nd half of the 20th century (**Fig. 43**). Such a growth rate is extremely unlikely as an actual population growth, which supports the usual interpretation in research into the Merovingian era that it is more likely a big change occurred in the customs relating to interment and grave goods which had hitherto been practised.

Within the overall picture visible in **Fig. 8**, the grave fields established as early as the 5th century

	λ, lambda (geom. growth)	R (expon. growth)
480/90–610/20 AD	.04525	.01484
- 520/30–530/40 AD	.06132	.04782
- 530/40–570/80 AD	.01402	.01113
- 530/40–610/20 AD	.00926	.00693

Fig. 10 Demographic parameters for the number of graves/year from 34 grave fields.

and then utilised for a long time differ from those that started only approx. with the beginning of the middle third of the 6th century (**Fig. 9**).

According to **Fig. 9**, the grave fields established as early as the 5th century increase quite uniformly in size through into the years around 575 AD and reach their maximum size around 625 AD after a dip around 585-595 AD, to then – again quite uniformly – decrease in size until 695 AD. In contrast, the grave fields newly established in the 530s increase more steadily until their maximum in the 605s AD and already decrease in size in the 625s, quite dramatically initially. The clear dip in the whole curve in the 585s and 595s is therefore essentially down to the necropolises which were established as early as the 5th century. We stay with the overall picture (black dots and line) so as not to get caught up in too much detail too early.

Now that the general picture has been explained and illustrated with **Fig. 7** and **Fig. 8**, the trend shall be parametrised in more detail (**Fig. 10 pp**). First the time interval of the grave field growth is considered in more detail, i.e. the time until the maximum in the 615s AD.

The comparison of the two growth rates in **Fig. 11** primarily emphasises the significant difference between the two models: for the interval 535s to 575s with a higher growth rate, the difference between the model and the observations becomes larger and larger from the 585s onwards. In the decade 610/20 AD, the observed number of graves per year – 54.8 – compares with the expected number – 71.2 graves. Referring to the time frame 535s to 615s with a lower growth rate, the model is overall closer to the observations, the difference between observations and model being noticeably large in the 565s and particularly in the 575s (575: observed 52.4 to expected 46.0).

The extrapolation of the two geometric growth models from the decade 530/40 AD backwards to the decade 480/90 AD is also interesting: For the stronger growth of λ = .0140 (red line), a hy-

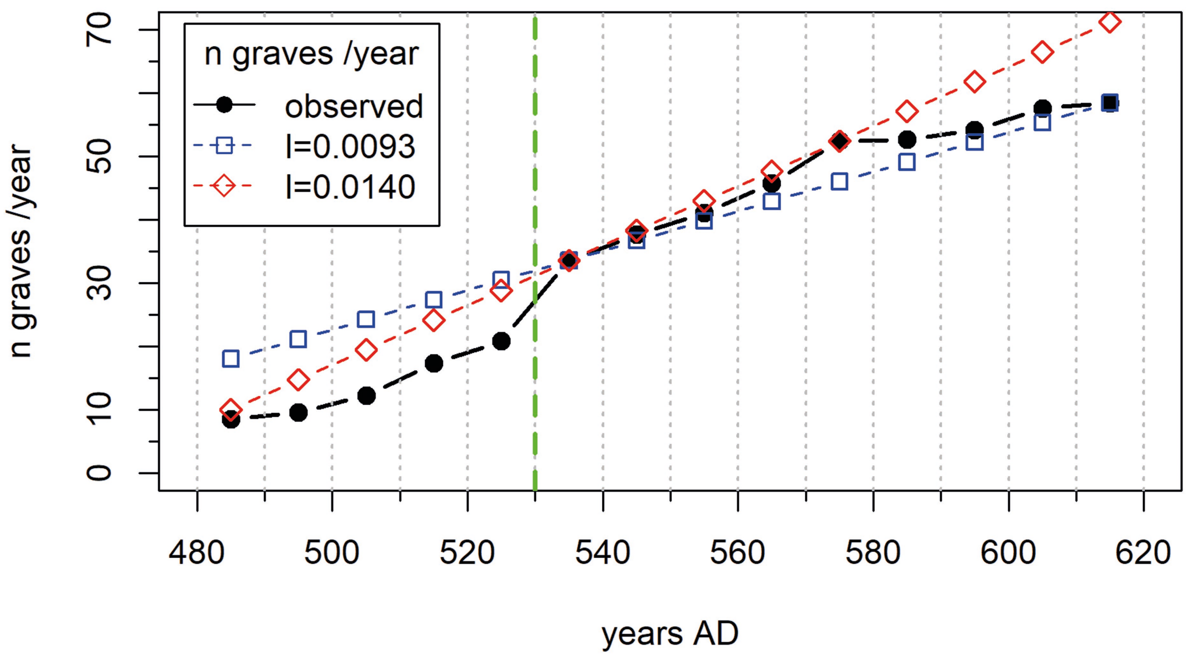


Fig. 11 Observed frequencies (black) and expected frequencies according to the model of geometric growth from the decade 530/40 AD, once in relation to the maximum in the decade 610/620 AD (blue symbols; λ = .0093), alternatively in relation to the first maximum in the decade 570/580 AD (red symbols; λ = .0140).

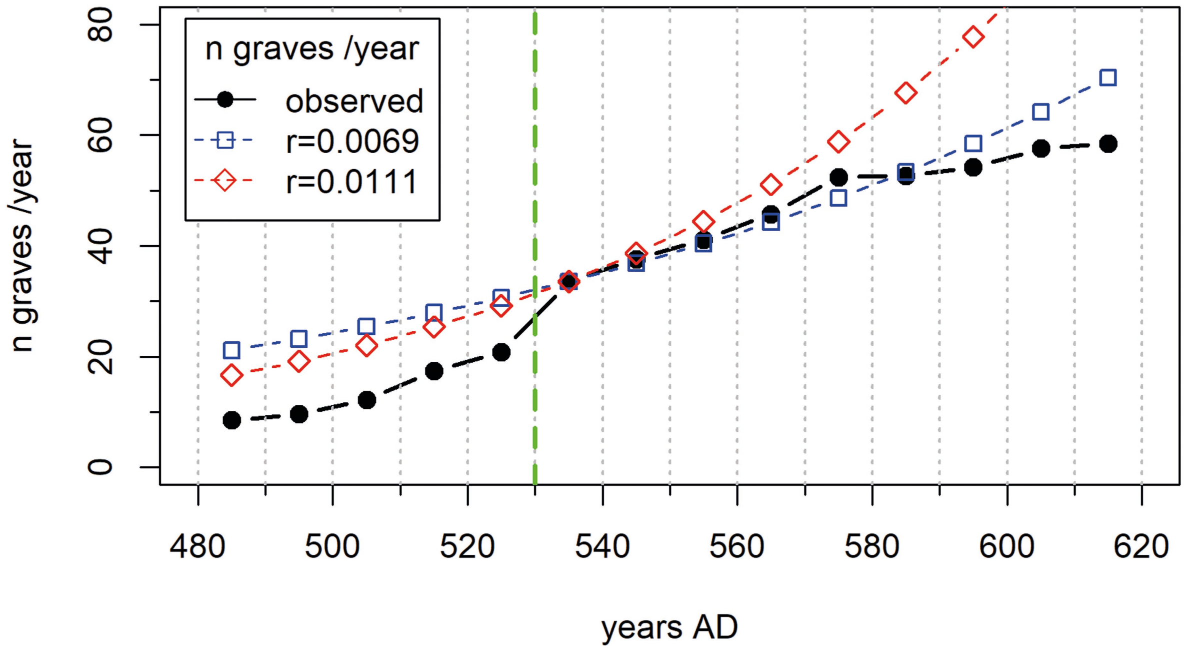


Fig. 12 Comparison of the observed frequencies (black) with the model of exponential growth from 530/40 AD onwards, once with reference to the interval 535s to 575s (red symbols; stronger growth), once with reference to the interval 535s to 615s (blue symbols; lower growth).

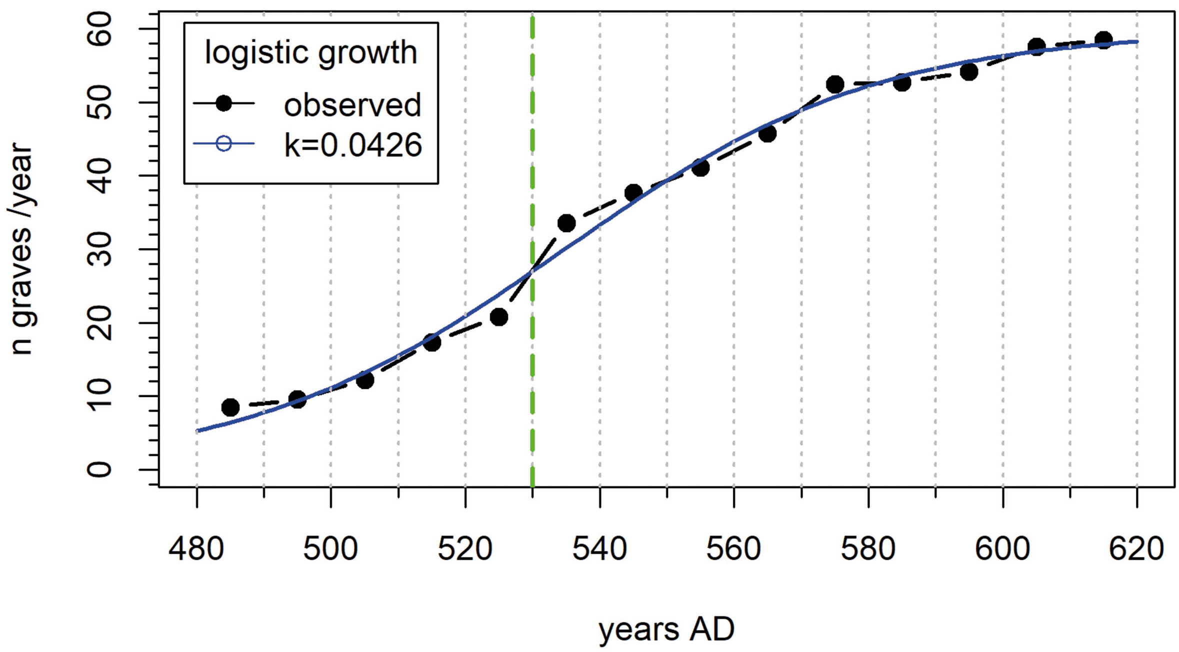


Fig. 13 Line plot of the observed frequencies (black) and model of logistic growth (blue line) from 485 to 615 AD with k = .0426 and C (carrying capacity) = 59.75.

pothetical value of 10.0 (for an observed value of 8.5) results for the start of the line; for the lower growth figure of λ = .0093 (blue line) which aims at the situation 610/620 AD, a value of 18 graves/year is expected. Regardless of which model is followed, these figures and the progression of the three lines up to and including 525 AD highlight the considerable lack of graves before the 530s, i.e. graves are lacking because of different burial customs and chances of discovery in the sources available to archaeology.

The comparison between the observed values and the model of exponential growth (**Fig. 12**) shows that in the space-time window considered here there is no exponential growth, because if this were the case, much higher values would have been observed in the decades around and after 600. If the parameter estimate is based on the interval 535s to 575s, approx. 103 graves per year would be expected in the decade around 615; if the basis is the longer interval 535s to 615s, at least 70.4 graves per year would still be expected in the decade around 615, compared with an observed number of 58.4.

Fig. 13 illustrates that the numbers observed between 480/90 and 610/20 AD are in good agreement with the assumption of logistic growth, i.e. an S-shaped growth curve with low growth at the start becoming stronger, which approaches an upper growth limit of just under 60 graves/year towards the end, and is zero again there (parameters: k = .0426, C=59.75).

When this estimate of logistic growth is based on the narrow interval 535 to 615 AD, a growth rate of k = .0312 and an upper growth limit of C = 63.0 with (likewise) strong deviations between expected and actual values in the 575s and 595s are obtained.

However, the growth in the number of grave fields which continues past 615 AD shows that an upper growth limit was not in fact reached, at least not at around 59-63 graves per year, which is why the model of logistic growth is discounted and not pursued further here.

Interim summary: the models of exponential growth and logistic growth are discounted. For the time being, the model of geometric growth provides the most suitable model for all grave fields for the interval 535s to 615s with λ = .0093, or alternatively also λ = .0140 on the basis of the time interval 535s to 575s.

615 ff: The number of graves decreases

From the decade 610/620 AD onwards, the data depict negative *"growth"*, i.e. a decrease; it starts

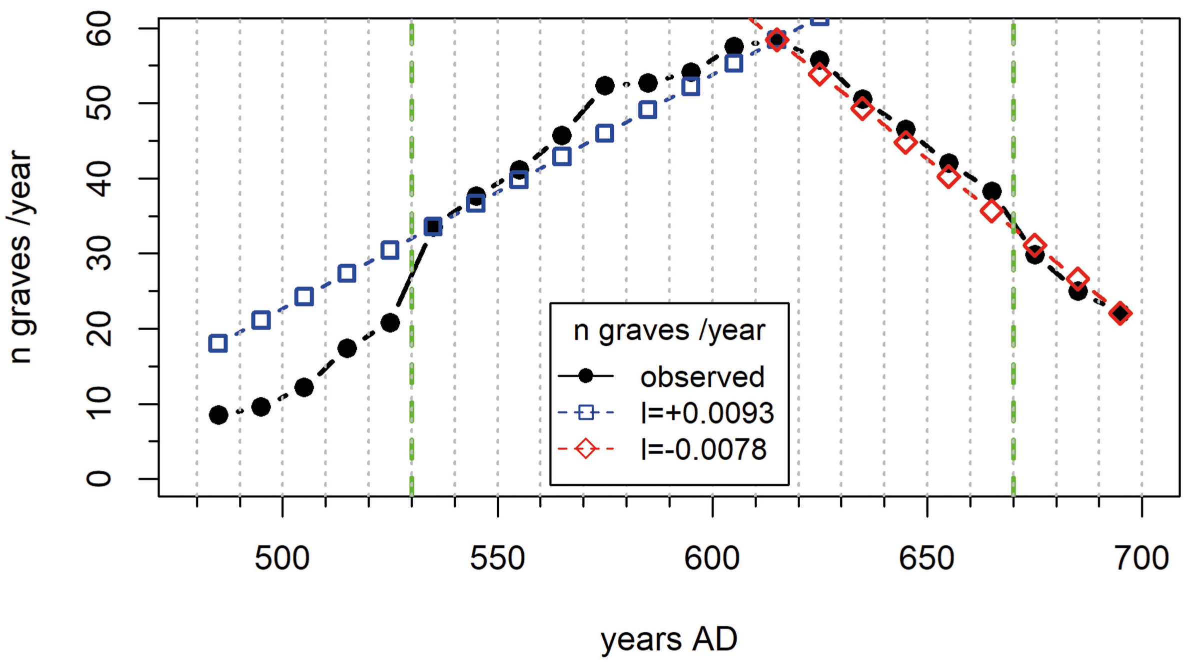


Fig. 14 Line plot for the whole time interval showing the geometric growth in the 535s ff. (blue) and the geometric decrease from 625 to 695 AD (red).

immediately at the maximum around 615 AD with 58.4 graves/year and decreases quite uniformly to 22.0 graves/year around 695 AD. This corresponds to a geometric growth of λ = - 0.0078 (**Fig. 14**). This is a somewhat surprising finding for experienced Merovingian researchers because it means that the decrease in the number of graves around 610/20 AD indicates a much earlier start than the time from 660-670 AD onwards which is usually considered for this, i.e. the time after which the successive transition from row grave field to churchyard took place. We will return to this as well in the discussion. The overall trend has thus now been shown and parametrised for the interim with the most suitable parameters which are customarily used in demography.

Synthesis: the interplay of the two growth rates, the carrying capacity and the social interpretation

The curve in **Fig. 14** is characterised by strong growth in the 6th century, which is followed by very low growth after a first maximum in the decade 570/580 AD right up to the absolute maximum in the decade 610/620 AD. As was demonstrated above, such a curve is in good agreement with the hypothesis and the mathematical model of logistic growth. Logistic growth is characterised by the fact that it runs against a natural upper limit of the carrying capacity. Animals, plants – and humans as well – require a minimum quantity of resources (space, food etc.) to survive, and at some stage the limits of growth resulting from the maximum quantities of resources available are reached as the population grows. For the Merovingian era grave fields, the curve in **Fig. 14** indicates that this was first the case around 575 AD and subsequently led to a slight stagnation, and was associated with a continuous decrease after the next maximum at 615 AD. This has been proved to be not correct, however, because the number of grave fields continues to increase substantially – as shown.

For the Rhineland, the studies undertaken by Andreas Zimmermann and his team (esp. Wendt et al., 2012) have shown that the population density of all prehistoric and protohistoric populations remained far below the actual carrying capacity of this region for a pre-industrial, agrarian population. Hence the growth curve described here does not signal a carrying capacity which is limited by nature or economic activity, but a social process which leads to the grave fields no longer growing in size after 610/620 AD, although – at least until 660/670 AD – their number does continue to increase.

The findings so far are summarised for the further analysis:

- In the period 535–615 AD, the 34 grave fields undergo geometric growth with a growth rate of λ = +.0093. Alternatively, the data for the interval 535–575 AD also allow higher growth with λ = +.0140 to be considered.
- In the period 615–695 AD, the 34 grave fields undergo geometric decline with λ = -0.0078.
- Parallel to the growth in size of the existing grave fields, there is an increase in the number of grave fields in the period 535-665 AD, and this increase is geometric with λ = +.0093 (.0074-.0112; **Fig. 1**).

In addition, the data available show that the mean of all 34 grave fields collated here is 9.4 burials per year around 535 AD (median 9.3). At the start of the period considered, around 485 AD, this mean is 4.3 burials per year (median 4.4). In the first maximum of the grave field size in the decade around 575 AD, the mean size of the grave fields is 14.7 burials per year (median 12.0), and in the later absolute maximum in the decade about 615 AD it is 16.1 burials (median 10.8); this value is never exceeded after this.

Two extrapolations for the period 535-615 AD are derived from these key data: what are the as-

Decade	n graves λ +.0093	n graves λ +.0140
535	9.4	9.4
545	10.3	10.7
555	11.1	12.0
565	12.0	13.3
575	12.9	14.7
585	13.8	16.0
595	14.6	17.3
605	15.5	18.6
615	16.4	19.9
625	17.3	21.2
635	18.1	22.6
645	19.0	23.9
655	19.9	25.2
665	20.8	26.5
675	21.6	27.8
685	22.5	29.1
695	23.4	30.5

Fig. 15 Extrapolated increase in the number of burials per grave field from the decade 530/40 AD onwards according to two different growth models. The values in the row for the decade 535 AD are the starting values of the two model calculations.

sociated frequencies on the basis of the parameters stated? The result is collated in the table in **Fig. 15**.

The calculation model shows that according to the model with λ = +.0093, an average grave field has grown from 9.4 burials to 12.9 burials when the first maximum is reached around 575 AD, i.e. a plus of 3.5; when the growth is not disturbed until 615 AD, the number of burials reaches 16.4 per decade, i.e. a plus of 7.0 burials. However, the actual trend in **Fig. 7** shows that there is no undisturbed growth, that – increasingly from 575 AD onwards – new grave fields are founded, i.e. people migrate from existing burial communities including the establishment of new grave fields. This conservatively calculated growth in the number of graves does not sufficiently explain this.

Hence the model with a λ of +.0140 shall also be examined; this model is based on the (stronger) observed growth in the number of grave fields in the time interval 535-575 AD: Around 575 AD, the number of burials reaches 14.7, a plus of 5.3 burials and thus the order of magnitude at which the grave fields newly established as early as the end of the 5th century start. If two of these new settlement populations each with 5.3 burials per decade were to join forces, they would even exceed the mean population size with which the grave fields in the 535s started. In other words: taking the model with λ +.0140, there would be a sufficient number of people in a local population to maintain the existing population while at the same time a founding generation migrated to a new burial site.

This model calculation shows that the geometric growth with λ = +.0093 represents a lower limit, and that the actual growth was larger, with λ = +.0140. With approx. 15 burial per year, the local communities had reached a size where it seemed advantageous not to grow further, but to found new settlements by migrating. More than 16.1 burials per year – the maximum value of the 615s – was reached only in exceptional cases. In other words: This value is a kind of social carrying capacity of the burial communities in the Merovingian era in Western and Southern Germany. With the model of the stronger growth with λ = +.0140, this state is usually reached in the decade 585 AD. New settlements are founded now at the latest, a situation which can be easily identified by the dip in the frequencies for the decades around 585 and 595 AD. In other words: The model with geometric growth of λ = +.0140 is the one which is in good agreement with the observed data, whose background population is sufficient even for the proven foundation of new settlements, and which provides a good explanation for the dip in the data of the 585s and 595s.

A further phase of increased migration to new settlements can be observed after the maximum of the 615s. This is because the relatively substantial decline in the number of burials per decade from the 625s onwards is long before the time from ca. 660/70 AD onwards when the cemeteries were successively abandoned in favour of the churchyards (which are not covered by our sample).

The resulting hypothesis that the growth rate of λ = +.0140 is the more probable one is examined again below. If the starting population of a medium-sized grave field with 9.4 burials per year were to undergo geometric growth with a λ of +.0140 in the 535s, there would be 26.5 burials per year in the decade around 665 AD. The actual mean value of the sizes of the grave fields in the decade 665 AD is 10.6 burials, the difference between the actual value and the model is therefore 15 burials, which corresponds to a population of approx. 1 further, new grave field given a social carrying capacity of approx. 15-16 burials/year. Thus numerically, the (stronger) growth model states that 1 grave field population in the middle third of the 6th century becomes 2 grave field populations in the middle third of the 7th century – which corresponds almost exactly to the actual growth in the number of grave fields (**Fig. 1**).

I now cross-check according to the model with λ = +.0093: According to this model, approx. 19.9 burials per decade would take place in the decade 660/70 AD; subtracting the 10.6 burials per year as the actual value would leave 9.1 burials per year. Although this is sufficient for 1 further grave field, it is around 1/3 lower than the expected value. For comparison I use the growth in the number of grave fields as per **Fig. 1** in the period from ca. 530-580/90 AD to ca. 630-670 AD as the basis, where the ratio is 1 : 2 (451 => 916 grave fields). Overall, the model with the stronger growth of λ = +.0140 is far closer to the observed growth in the number of grave fields. I therefore base the following on the model with a λ of +.0140.

This means that our growth rate of .0140 into the 7th century provides a good description of the sum from the increase in the number of grave fields as well as the number of graves. Up to the maximum of the grave field sizes around 615 AD, the population has thus approximately doubled (a factor of 2.1 to be more precise), almost tripled (a factor of 2.8) by the time of the transition from grave field to churchyard from ca. 665 AD onwards, and more than tripled (a factor of 3.2) by the end of our time frame in the 695s. This means that the old estimate by Donat & Ullrich (1971, 252 Tab. 4 and Fig. 1) is confirmed as far as the order of magnitude is concerned, this time on a significantly broader base of materials and more exact chronology.

Grave fields which deviate from the usual pattern

The sample of 34 grave fields on which this article is based has so far been considered as a collective so as to be able to identify regularities and patterns. Having achieved this, we now take a look at the individual grave fields. To this end we first need to explicitly state what the expected, *"normal"* development of a grave field is in order to be able to measure deviations from this and to test this for statistical significance. The obvious thing would be to make the geometric growth of $\lambda = +.0140$ which was determined here the benchmark. However, as has been shown, this growth is subject to a complex interplay between the reaching of a local social carrying capacity and the foundation of new settlements, and a great deal of effort is required to model this. I therefore select a simpler but statistically just as robust solution: The figures of the total cohort according to **Fig. 7** and **Fig. 8** are used as the basis to reflect what is usual. It is thus possible to compare two series of frequencies, one series corresponding to the figures of the total cohort, the other series to the individual grave field investigated in each particular case. A suitable method is the chi-squared method, where the overall picture gives the *"expected frequencies"* and their difference to the actually observed frequencies is determined. The method ultimately provides the parameter chi-squared, which allows a statistical statement to be made as to whether the deviations between observed and expected values are still consistent with randomness or are significant, i.e. they can no longer be explained by randomness alone with certainty. A so-called chi-squared test of goodness of fit is carried out for each of the 34 grave fields.[8]

As shown, the change to the universal, socially binding custom concerning grave goods which is typical for the Merovingian era falls into the time around 530 AD. Of the 34 grave fields investigated here, 20 (59 %) were already in use before that time, some since the 485s, 14 (41 %) start approx. with the 530s, on the other hand. Just as different as the start is the end of the grave fields: some decline – probably with a shift towards the churchyard – already in or even before the 660/70s, others are in use until the end of the time frame investigated here. In order to not overload the investigation with details, I focus here on the period 530 AD to 670 AD, in which a good intercomparison of all grave fields can be undertaken.

This approach shows that:

- 18 of the 34 grave fields (53 %) completely follow the usual pattern explained above: Dirmstein, Eichstetten, Eick, Emmerich, Eppstein, Essenbach-Altheim, Gellep-West, Junkersdorf, Kirchheim-Heuau, Klepsau, Mainz-Hechtsheim, Mannheim-Sandhofen, Mannheim-Vogelstang, Neresheim/Kösingen, Pleidelsheim, Rödingen and Zusamaltheim;
- 3 of the 34 grave fields (9 %) are just within what is usual, i.e. there is no statistical significance in the overall finding, but there are clear anomalies: Aschheim, Neudingen and Pliening;
- 13 of the 34 grave fields (38 %) show a statistically significant deviation from the usual pattern: Altenerding, Eltville, Esslingen-Sirnau, Fridingen, Gellep-Ost, Mengen, Müngersdorf, Pfakofen, Rübenach, Schretzheim, Wenigumstadt, Westheim and Westhofen.

I would like to dispense with an individual presentation and discussion of the 18 grave fields which follow the usual pattern. For each of the others, I compile a table (**Fig. 16** to **Fig. 33**) which shows in which decades significant deviations occur. The aim here is not to examine these grave fields individually in more detail, because this has already been done adequately in the primary publications listed. It is rather to create the basis for an overview of whether overall characteristic patterns of deviations emerge again.

These tables follow the same pattern: the left-hand column gives the decade in question; the figure for the burials counted for this decade and this grave field is entered under *"observed"*; the bottom line with the total states the total number of graves in this grave field that lie within the time interval considered here; *"expected"* states how many graves would have to exist in that particular decade if the grave field were to follow the usual pattern entirely (*"expected value"*); the right-hand column lists the chi-squared value: at the very bottom is the total value for the table, in the cells above the cell chi-squared, i.e. the contribution of the individual decade to the total value.

In a table with 14 rows i.e. decades, a total chi-squared value greater than 22.36 represents a statistically significant deviation (shown in bold in the tables). In the individual cells, small chi squared values represent small deviations which are consistent with randomness; values larger than 3.84 represent a statistically significant de-

Aschheim			
Decade	Observed	Expected	Chi-squared
530-540	11.2	8.3	1.0
540-550	11.2	9.6	0.3
550-560	11.2	10.5	0.0
560-570	13.9	11.5	0.5
570-580	16.5	13.0	0.9
580-590	16.5	12.9	1.0
590-600	16.7	13.0	1.1
600-610	17.0	13.8	0.7
610-620	17.2	14.1	0.7
620-630	12.6	13.3	0.0
630-640	7.9	11.7	1.2
640-650	3.3	10.8	5.2
650-660	3.3	10.1	**4.6**
660-670	3.3	9.2	**3.8**
Total	161.8		21.0

Fig. 16 Aschheim: observed number of graves per decade and compared to the expected frequencies.

Gellep Ost necropolis			
Decade	Observed	Expected	Chi-squared
530-540	28.3	20.3	3.1
540-550	28.4	23.5	1.0
550-560	28.6	25.7	0.3
560-570	28.7	28.2	0.0
570-580	35.0	31.8	0.3
580-590	39.5	31.5	2.0
590-600	44.0	31.8	4.7
600-610	44.0	33.8	3.1
610-620	36.5	34.5	0.1
620-630	29.0	32.6	0.4
630-640	22.1	28.6	1.5
640-650	15.2	26.3	**4.7**
650-660	8.3	24.7	**10.9**
660-670	8.3	22.4	**8.9**
Total	395.9		**41.1**

Fig. 18 Gellep Ost necropolis: observed number of graves per decade and compared to the expected frequencies.

viation between observed and expected values. Chi squared values of approx. 3.0 and above may already be considered to be *"suspect"*, however. In the respective tables, significant and *"suspect"* values of chi-squared are highlighted in bold. Where there are significant deviations, the observed values have a coloured background: grey for observed values higher than expected, yellow for values lower than expected.

Grave fields with deviating end

Some of the grave fields which deviate have too few graves especially towards the end of the period under consideration, which is probably down

Eick			
Decade	Observed	Expected	Chi-squared
530-540	2.8	4.2	0.5
540-550	2.8	4.9	0.9
550-560	3.6	5.3	0.6
560-570	4.3	5.8	0.4
570-580	9.7	6.6	1.5
580-590	9.3	6.5	1.1
590-600	8.8	6.6	0.7
600-610	8.8	7.0	0.5
610-620	9.5	7.1	0.8
620-630	10.2	6.8	1.8
630-640	7.1	5.9	0.2
640-650	3.9	5.5	0.4
650-660	0.8	5.1	**3.6**
660-670	0.5	4.6	**3.6**
Total	82.0		16.6

Fig. 17 Eick: observed number of graves per decade and compared to the expected frequencies.

Schretzheim			
Decade	Observed	Expected	Chi-squared
530-540	10.0	9.5	0.0
540-550	10.0	11.0	0.1
550-560	14.5	12.0	0.5
560-570	19.0	13.2	2.6
570-580	21.5	14.8	**3.0**
580-590	24.0	14.7	**5.9**
590-600	24.0	14.8	**5.7**
600-610	20.0	15.8	1.1
610-620	20.0	16.1	1.0
620-630	11.9	15.2	0.7
630-640	3.7	13.3	**6.9**
640-650	2.9	12.3	**7.2**
650-660	2.0	11.5	**7.8**
660-670	1.2	10.5	**8.2**
Total	184.7		**50.8**

Fig. 19 Schretzheim: observed number of graves per decade and compared to the expected frequencies.

Fridingen			
Decade	Observed	Expected	Chi-squared
530-540	1.5	3.2	0.9
540-550	2.3	3.7	0.6
550-560	3.0	4.1	0.3
560-570	2.4	4.5	1.0
570-580	1.8	5.1	2.1
580-590	1.8	5.0	2.1
590-600	3.2	5.1	0.7
600-610	4.5	5.4	0.1
610-620	4.5	5.5	0.2
620-630	5.9	5.2	0.1
630-640	7.2	4.5	1.6
640-650	8.6	4.2	**4.7**
650-660	8.3	3.9	**4.9**
660-670	8.0	3.6	**5.5**
Total	107.3		**24.7**

Fig. 20 Fridingen: observed number of graves per decade and compared to the expected frequencies.

Pfakofen			
Decade	Observed	Expected	Chi-squared
530-540	5.3	9.4	1.7
540-550	5.3	10.8	2.8
550-560	6.8	11.8	2.2
560-570	8.2	13.0	1.7
570-580	9.7	14.6	1.7
580-590	9.7	14.5	1.6
590-600	11.5	14.6	0.7
600-610	13.2	15.5	0.3
610-620	15.0	15.8	0.0
620-630	17.0	15.0	0.3
630-640	18.9	13.1	2.5
640-650	20.9	12.1	**6.3**
650-660	20.9	11.4	**7.9**
660-670	19.6	10.3	**8.4**
Total	182.0		**38.1**

Fig. 22 Plakofen: observed number of graves per decade and compared to the expected frequencies.

to a late foundation of a new settlement at a different site or even a large-scale out migration of the population (**Fig. 16-19**).

With other grave fields, the deviation is exactly the opposite towards the end of the period, i.e. they have significantly more burials than expected – presumably because the usual migration to new settlements had not yet taken place or there was even an influx of people **(Fig. 20-22)**.

Grave fields with deviating start

Other deviating grave fields have too few burials especially at the start of our observation period, i.e. they start later than usual or their growth (in

Pliening			
Decade	Observed	Expected	Chi-squared
530-540	1.8	3.1	0.6
540-550	2.2	3.6	0.5
550-560	2.6	4.0	0.5
560-570	3.0	4.3	0.4
570-580	3.0	4.9	0.7
580-590	3.1	4.8	0.6
590-600	3.2	4.9	0.6
600-610	3.3	5.2	0.7
610-620	3.3	5.3	0.8
620-630	4.9	5.0	0.0
630-640	6.6	4.4	1.1
640-650	8.3	4.0	**4.5**
650-660	8.3	3.8	**5.3**
660-670	7.3	3.4	**4.3**
Total	60.8		20.7

Fig. 21 Plining: observed number of graves per decade and compared to the expected frequencies.

Eltville			
Decade	Observed	Expected	Chi-squared
530-540	5.0	13.1	**5.0**
540-550	6.2	15.2	**5.4**
550-560	7.3	16.6	**5.2**
560-570	12.6	18.2	1.7
570-580	18.0	20.6	0.3
580-590	23.3	20.4	0.4
590-600	23.3	20.5	0.4
600-610	25.7	21.8	0.7
610-620	28.0	22.3	1.5
620-630	28.0	21.1	2.3
630-640	23.4	18.4	1.3
640-650	18.8	17.0	0.2
650-660	18.8	16.0	0.5
660-670	17.4	14.5	0.6
Total	255.7		**25.5**

Fig. 23 Eltville: observed number of graves per decade and compared to the expected frequencies.

Wenigumstadt			
Decade	Observed	Expected	Chi-squared
530-540	0.6	5.0	**3.9**
540-550	1.2	5.8	**3.6**
550-560	1.8	6.4	**3.3**
560-570	2.4	7.0	**3.0**
570-580	2.4	7.9	**3.8**
580-590	8.0	7.8	0.0
590-600	8.0	7.9	0.0
600-610	10.8	8.4	0.7
610-620	10.8	8.5	0.6
620-630	9.5	8.1	0.3
630-640	8.2	7.1	0.2
640-650	10.1	6.5	2.0
650-660	12.0	6.1	5.7
660-670	12.0	5.5	7.5
Total	97.8		**34.6**

Fig. 24 Wenigumstadt: observed number of graves per decade and compared to the expected frequencies.

relation to their later state) is unusually weak in their initial decades **(Fig. 23-24)**.

Or they have *"too many"* burials at the beginning or their growth is significantly below average in relation to the starting population.

Westheim			
Decade	Observed	Expected	Chi-squared
530-540	15.3	8.5	**5.6**
540-550	20.7	9.8	**12.2**
550-560	20.7	10.7	**9.3**
560-570	16.5	11.8	1.9
570-580	12.2	13.2	0.1
580-590	8.0	13.1	2.0
590-600	8.0	13.2	2.1
600-610	8.8	14.1	2.0
610-620	9.6	14.4	1.6
620-630	10.4	13.6	0.7
630-640	10.4	11.9	0.2
640-650	9.0	11.0	0.4
650-660	7.6	10.3	0.7
660-670	7.6	9.3	0.3
Total	164.8		**39.0**

Fig. 25 Westheim: observed number of graves per decade and compared to the expected frequencies.

Westhofen			
Decade	Observed	Expected	Chi-squared
530-540	12.0	4.5	**12.7**
540-550	15.0	5.2	**18.8**
550-560	10.8	5.6	**4.7**
560-570	6.6	6.2	0.0
570-580	5.3	7.0	0.4
580-590	4.0	6.9	1.2
590-600	4.0	7.0	1.3
600-610	4.0	7.4	1.6
610-620	4.0	7.6	1.7
620-630	3.4	7.2	2.0
630-640	2.7	6.3	2.0
640-650	4.1	5.8	0.5
650-660	5.5	5.4	0.0
660-670	5.5	4.9	0.1
Total	86.9		**47.1**

Fig. 26 Westhofen: observed number of graves per decade and compared to the expected frequencies.

Grave fields with deviations more in the middle of the period investigated

Other grave fields follow none of the deviation patterns described, and have to be classified as individual cases **(Fig. 27-33)**.

Altenerding			
Decade	Observed	Expected	Chi-squared
530-540	26.0	29.6	0.4
540-550	19.5	33.2	5.6
550-560	19.0	36.2	8.2
560-570	28.0	40.4	3.8
570-580	38.0	46.1	1.4
580-590	45.5	46.3	0.0
590-600	56.0	47.6	1.5
600-610	59.5	50.7	1.5
610-620	54.0	51.1	0.2
620-630	51.0	48.6	0.1
630-640	61.5	44.1	**6.9**
640-650	56.0	40.6	**5.8**
650-660	37.5	36.8	0.0
660-670	33.0	33.1	0.0
Total	484.5		**35.5**

Fig. 27 Altenerding: observed number of graves per decade and compared to the expected frequencies.

Mengen			
Decade	Observed	Expected	Chi-squared
530-540	17.8	25.3	2.2
540-550	22.9	29.2	1.4
550-560	24.0	32.0	2.0
560-570	25.2	35.1	2.8
570-580	26.3	39.5	**4.5**
580-590	27.4	39.2	**3.5**
590-600	37.0	39.5	0.2
600-610	46.6	42.0	0.5
610-620	56.2	42.8	**4.2**
620-630	51.2	40.5	2.8
630-640	46.2	35.5	**3.2**
640-650	41.2	32.7	2.2
650-660	36.2	30.7	1.0
660-670	33.9	27.9	1.3
Total	492.1		**31.7**

Fig. 28 Mengen: observed number of graves per decade and compared to the expected frequencies.

Rübenach			
Decade	Observed	Expected	Chi-squared
530-540	31.4	35.5	0.5
540-550	38.0	40.9	0.2
550-560	46.8	44.9	0.1
560-570	55.5	49.2	0.8
570-580	64.3	55.5	1.4
580-590	48.3	55.0	0.8
590-600	48.3	55.5	0.9
600-610	43.6	59.0	**4.0**
610-620	38.9	60.1	**7.5**
620-630	46.9	56.9	1.7
630-640	55.0	49.8	0.5
640-650	63.0	45.9	**6.3**
650-660	63.0	43.1	**9.2**
660-670	47.5	39.1	1.8
Total	690.5		**35.7**

Fig. 30 Rübenach: observed number of graves per decade and compared to the expected frequencies.

Overview of deviations: all decades, all grave fields
To keep track of everything given the many details, a count was also made for all the grave fields of how often a chi squared value of 3.0 (*"suspect"*) or 3.8 (significant) was exceeded in individual cells (**Fig. 34**, left-hand column). It is thus possible to illustrate in summary which decades stand out more often overall, i.e. whether and when, if appl., time-related effects affecting all grave fields are present.

As shown in the *"All"* column of the table in **Fig. 34**, it is mainly the three decades 530 ff. and the three decades 640 ff. that stand out, while deviations in between with frequencies from 0 to 3 tend to be rare given the 34 grave fields investi-

Müngersdorf			
Decade	Observed	Expected	Chi-squared
530-540	5.0	5.8	0.1
540-550	5.4	6.7	0.2
550-560	11.1	7.3	1.9
560-570	16.7	8.0	**9.4**
570-580	21.3	9.1	**16.6**
580-590	14.1	9.0	2.9
590-600	6.8	9.0	0.6
600-610	6.8	9.6	0.8
610-620	7.3	9.8	0.7
620-630	7.7	9.3	0.3
630-640	6.1	8.1	0.5
640-650	4.5	7.5	1.2
650-660	0.0	7.0	**7.0**
660-670	0.0	6.4	**6.4**
Total	112.7		**48.5**

Fig. 29 Müngersdorf: observed number of graves per decade and compared to the expected frequencies.

Esslingen-Sirnau			
Decade	Observed	Expected	Chi-squared
530-540	6.7	5.4	0.3
540-550	6.7	6.2	0.0
550-560	3.9	6.8	1.3
560-570	1.0	7.4	**5.6**
570-580	1.0	8.4	**6.5**
580-590	1.3	8.3	**5.9**
590-600	1.6	8.4	**5.5**
600-610	7.3	8.9	0.3
610-620	13.0	9.1	1.7
620-630	13.0	8.6	2.3
630-640	12.8	7.5	**3.6**
640-650	12.5	6.9	**4.5**
650-660	12.5	6.5	**5.5**
660-670	11.0	5.9	**4.4**
Total	104.2		**47.4**

Fig. 31 Esslingen-Sirnau: observed number of graves per decade and compared to the expected frequencies.

Neudingen			
Decade	Observed	Expected	Chi-squared
530-540	10.3	8.1	0.6
540-550	9.2	9.3	0.0
550-560	8.0	10.2	0.5
560-570	14.0	11.2	0.7
570-580	20.0	12.6	**4.3**
580-590	18.9	12.5	**3.2**
590-600	17.7	12.6	2.0
600-610	13.4	13.4	0.0
610-620	9.0	13.7	1.6
620-630	7.6	12.9	2.2
630-640	6.2	11.3	2.3
640-650	4.8	10.5	3.1
650-660	7.7	9.8	0.5
660-670	10.5	8.9	0.3
Total	157.1		21.3

Fig. 32 Neudingen: observed number of graves per decade and compared to the expected frequencies.

gated. During the frequency dip in the 575s and 585s which is already visible in **Fig. 8**, and is probably due to an increasing number of new settlements after the first maximum, there are 5 and 4 anomalies respectively.

If the grave fields which have been shown above to deviate are examined again in relation to the disasters put forward by scientists in particular (plague, LALIA, crop failure; cf. Introduction), especially for the 6th century, it is hardly possible to discern a clear time horizon with an event which is extensive and large scale. There are suspect cases, however: The grave field at Altenerding, where aDNA analysis has proved that some people there died from plague (Keller et al., 2019), has too many deaths in the three decades after 540 AD – which fits with the plague findings. The two grave fields at Westheim and Westhofen start over three decades with relatively large numbers of graves and then do not continue to grow as expected from the 560s onwards – and could thus indicate plague-induced growth which is likewise too low. Esslingen-Sirnau and Mengen have too few graves in the 560s ff. and 570s ff. from an overall perspective, this is a reliable finding which provides four further candidates for special events with each one roughly in the 560s. Rübenach and Unterthürheim have too few graves in the years ca. 600-620, but given the large distance between the two sites there is probably no common reason for this. From a source-critical point of view, one must always consider that the 34 grave fields investigated here have not always been excavated completely, but sometimes only *"almost completely"*, i.e. that to a small extent graves and possibly specific time intervals, of course, can be missing – which is the case in Rübenach (partly disturbed by a road construction in the past), for example.

Overall there is no indication of serious extrinsic events which have affected the whole of Western Germany or the whole of Southern Germany over a clearly defined time interval. It is more the case that the observations are probably related to anomalies with local to regional dynamics, as recently presented in detail by Rainer Schreg (2020) for the Eastern Alb region.

Unterthürheim			
Decade	Observed	Expected	Chi-squared
530-540	2.5	5.3	1.5
540-550	9.3	6.1	1.7
550-560	9.3	6.7	1.0
560-570	10.6	7.3	1.4
570-580	11.8	8.3	1.5
580-590	11.8	8.2	1.6
590-600	7.5	8.2	0.1
600-610	3.2	8.8	**3.5**
610-620	3.2	8.9	**3.7**
620-630	5.6	8.5	1.0
630-640	7.9	7.4	0.0
640-650	7.9	6.8	0.2
650-660	6.7	6.4	0.0
660-670	5.5	5.8	0.0
Total	102.7		17.3

Fig. 33 Unterthürheim: observed number of graves per decade and compared to the expected frequencies.

Differentiation of the number of graves according to time of establishment and region

The 34 grave fields were then differentiated according to the time they were established and the region. Those grave fields that were established as early as the late 5th century do not differ between the 535s and the 665s from those that were established in the 520/530s as far as their anomalies are concerned (**Fig. 9**). However, the two right-hand columns in **Fig. 34** indicate that there could be differences between the grave fields in Western Germany and Southern Germany, because the latter seem to exhibit more deviations from the usual course in the decades 570/80 and 580/90 AD. To examine this

Decade	All	Est. late 5th cent.	Est. ca. 530 AD	Western Germany, *"Frankish"*	Southern Germany, *"Alemannic"*
530-540	6	2	4	4	2
540-550	4	3	1	2	2
550-560	5	3	2	2	3
560-570	4	2	2	1	3
570-580	5	2	3	1	4
580-590	4	1	3	0	4
590-600	3	0	3	1	2
600-610	3	2	1	2	1
610-620	3	3	0	1	2
620-630	0	0	0	0	0
630-640	5	3	2	0	5
640-650	11	6	5	3	8
650-660	11	6	6	4	7
660-670	11	5	6	4	7

Fig. 34 Trend in the number of graves per grave field: Number of significant deviations per decade. Every cell chi squared of 3.0 and above is counted as a significant deviation.

further, I plot the core period investigated here differentiated according to region (**Fig. 35**).

Fig. 35 and **Fig. 36** allow two slightly different trends along the time axis to be identified: In Western Germany, the number of graves increases more strongly than in Southern Germany after the 530s through to the 575s, and then remains nearly constant through into the 615s. In Southern Germany, the increase in the number of graves is smaller and follows a linear course without the

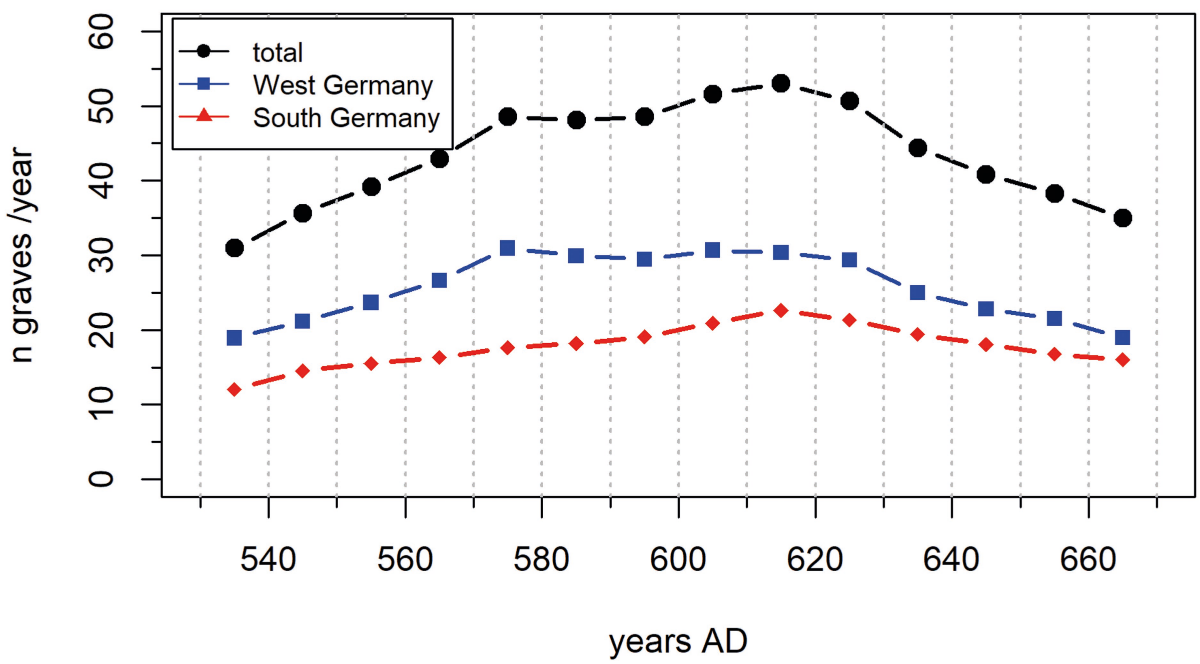


Fig. 35 Graves per year in the interval 530-670 AD, differentiated according to grave fields in Western Germany and in Southern Germany.

Region (reference)	Late 5th/early 6th c. ≈ 480-510/30 AD	Mid to 2nd half 6th c. ≈ 530-580/90 AD	Mid 7th c. ≈ 630-670 AD
Northern Rhineland (Nieveler, 2006)	89	184 λ= .01515	254 λ= .00342
Southern Germany	30	91 λ= .03970	194 λ= .00910

Fig. 36 Recapitulation of the numbers from **Fig. 1**: Northern Rhineland in contrast to the summed figures for Southern Germany (*"Alemannic"*)

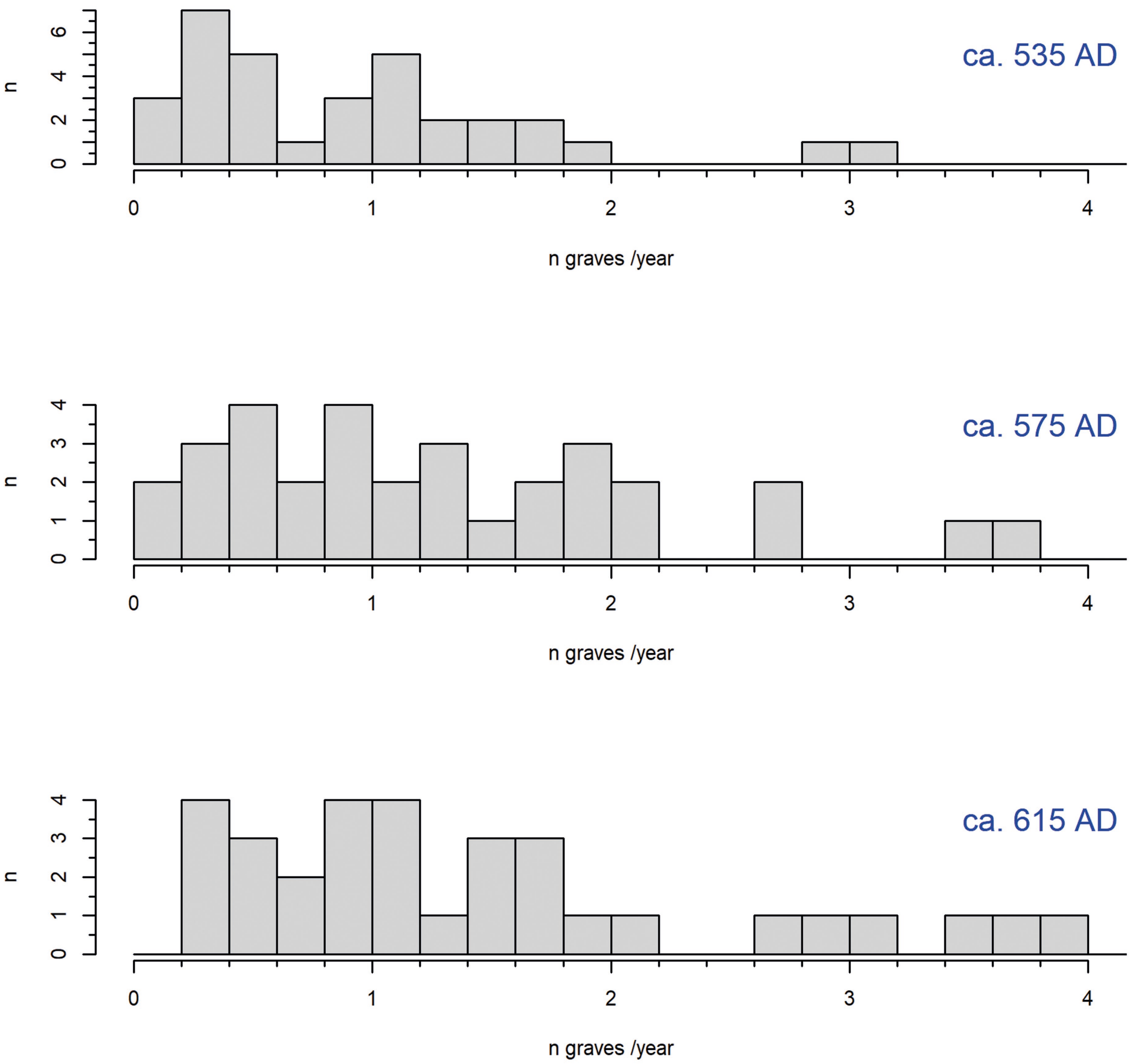


Fig. 37 Number of graves per year in the individual grave fields for the time intervals around 535, 575 and 615 AD. There are more than 4.0 burials ca. 535 at: no gf; ca. 575 at: Rübenach and Altenerding; ca. 615 AD at: Mengen and Altenerding.

peak in the 575s until the maximum in the 615s. Both curves mirror the different trends of the regions (**Fig. 36**): In the northern Rhineland, the increase in the number of grave fields from the 530s to ca. 665 AD is only small in comparison. In Southern Germany, the increase in the number of grave fields is considerably larger right from the start, i.e. the smaller increase in the number of graves (in the large grave fields) goes hand in hand with an increased number of new grave fields, whereas in the Rhineland the new cemeteries apparently occur in greater numbers only after the 575s. This also explains the slightly different deviations (**Fig. 34**) from the general growth model which is particularly emphasised here, which covers both Western and Southern Germany.

Interim summary for deviating growth curves
More than half of the grave fields investigated here follow the growth curve for the whole sample shown here in **Fig. 7** and **Fig. 8** without any statistically significant deviation. Several different types of significant deviations can be observed for almost 40 % of the grave fields, i.e. more individual rather thn universal deviations: In four cases, the decline at the end is significantly stronger than usual (**Fig. 16** to **Fig. 19**), in three cases it is smaller than usual (**Fig. 20** to **Fig. 22**). Significant deviations are present in the first decades of the time frame investigated in a total of four cases (**Fig. 23** to **Fig. 26**). Significant deviations in the middle of the time frame investigated are present in eight grave fields (**Fig. 28** to **Fig. 33**), but they are again not uniform, but more individual. The grave fields which were established early (480s ff.) do not differ from those established in the 535s as far as the frequency of deviations in the time frame 530s to 665s is concerned (**Fig. 34**). Only one systematic difference is apparent: grave fields in Southern Germany more frequently have deviations in the middle (and towards the end) of the time interval under investigation here than do those in Western Germany (**Fig. 34**). This observation on the number of graves corresponds to the regionally slightly different trend for the number of grave fields: In Southern Germany, there are more new grave fields, while the grave fields themselves often grow slightly less strongly in size than in Western Germany (**Fig. 35**).

Size and development of the local burial communities

The 34 grave fields have so far been considered as a collective and the argumentation has been based on the summed frequencies. This was useful to initially be able to recognise and describe the general trend. Hereinafter we want to investigate how large the individual grave fields are, i.e. the individual number of graves per year, and examine their development. The number of burials per year is usually between 0.1 and 4.0, only a very small number of grave fields are larger. This is plotted in the histograms in **Fig. 37** for the time intervals around 535, 575 and 615 AD.

The histograms illustrate that a bell-shaped curve does not emerge anywhere, i.e. a general regularity in the size of the burial communities and a distribution which could be properly described by a mean value and a standard deviation or alternatively by a median and an interquartile range. On the contrary, there are a great many small and a few large grave fields. To be able to recognise a system if there is one, I repeat the histogram in a sectional enlargement with an upper limit of 2.2 burials/year (**Fig. 38**). If one uses the clusters and the *"valleys"* in these histograms to look for groups, a pattern of three size classes becomes apparent: small grave fields of up to around 0.8 graves/year, medium-sized grave fields with approx. 0.8 to 1.4 graves per year, and large ones with 1.4 to 2.2 graves per year. The system becomes clearer when the histograms are supplemented by a density curve and these curves are superimposed (**Fig. 39**). Small and medium-sized grave fields are separated by a minimum at around 0.7-0.8 graves in all time intervals; the separation between medium-sized and large grave fields is around 1.4 graves. In addition, a dual peak structure is indicated for the small grave fields with maxima at 0.2 graves and 0.5 graves per year in the time intervals around 535 and 575 AD.

The density curves in **Fig. 39** illustrate that the frequency shifts slightly between the groups in the course of time: the quantity of small grave fields decreases, the number of large and very large ones increases; all four groups exist in all time intervals, however. The grouping which can primarily be recognised by means of the density curve in Fig. 39 is used to count the corresponding frequencies and display them in a table (**Fig. 40**).

For illustrative purposes, I use the mean values of the particular group to calculate the corresponding living population.[9] I follow Caselitz (2021, 32 f. Tabs. 5-6) here and change the proportion of children from the 29.2 % observed on average to a corrected 44.4 %, and set the average life expectancy at birth to 26.87 years (Caselitz, 2021, 41 f. Tabs. 8c-d). This estimate is for illustrative

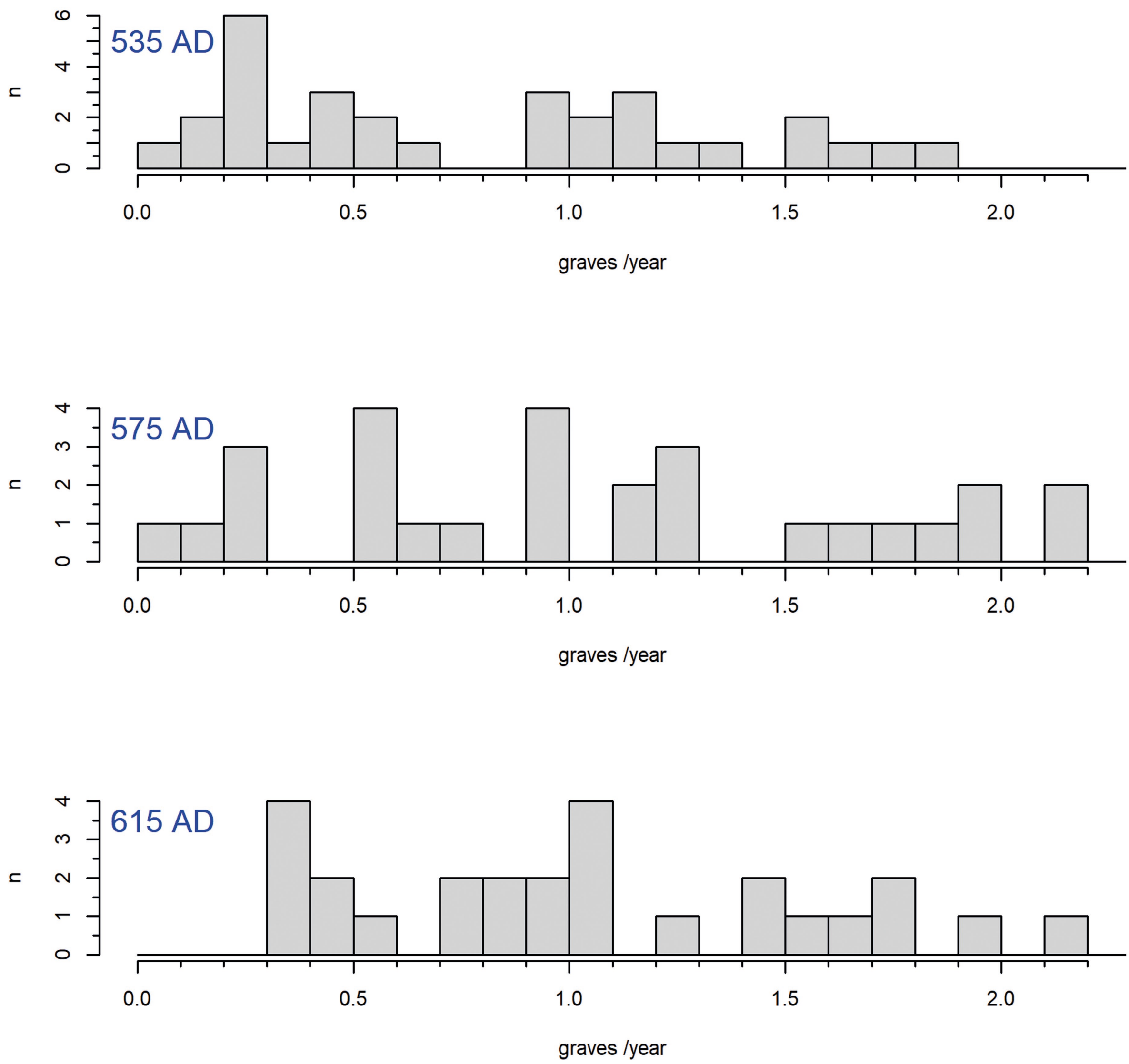


Fig. 38 Number of graves per year in the individual grave fields for the time intervals around 535, 575 and 615 AD. There are more than 2.2 burials around 535 AD at: Gellep-Ost (2.83), Rübenach (3.14); around 575 AD at: Rödingen (2.61), Mengen (2.63), Gellep-Ost (3.50), Junkersdorf (3.70), Rübenach (6.43); around 615 AD at: Eltville (2.80), Mannheim-Vogelstang (2.95), Rödingen (3.17), Junkersdorf (3.59), Gellep-Ost (3.65), Rübenach (3.89), Mengen (5.62) – and Altenerding across all time intervals.

purposes only, the further analysis is based on the much more reliable number of graves per year. The line at the bottom with the grey background in Fig. 40 shows the result: It becomes apparent here that seven living people are the *"standard configuration"* of a farm/a settlement (cf. Siegmund, 1993). Very large grave fields are rare and are possibly already characteristic for places with central functions (Krefeld-Gellep) or for burial communities of several settlements (Altenerding?).

Now that the size of the local communities has been described and it has been possible to work out five size classes, their development is to be investigated further in more detail. This is done by determining the growth rate between the 535s and the first maximum in the 575s (**Fig. 41** to **Fig. 42**).

The medium-sized and large grave fields grow in size from the 535s through to the first maximum in the 575s with a geometric growth rate λ of around 0.01 – i.e. completely within the overall trend already detailed.

The very small grave fields deviate significantly from this, their average growth in size is about four and a half time stronger. As the dis-

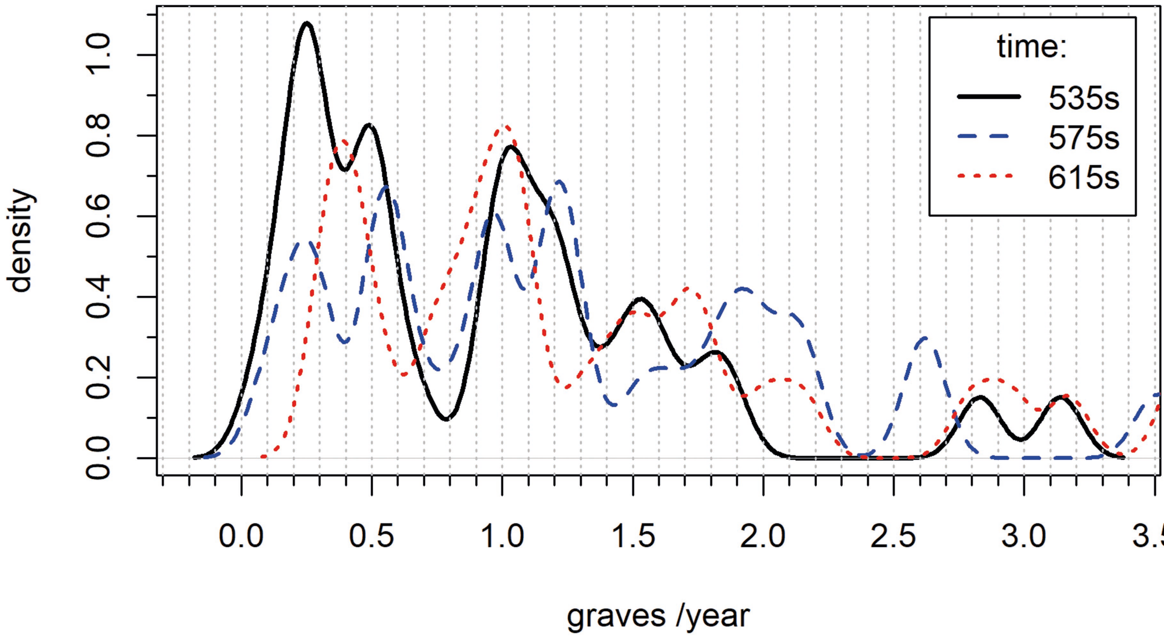


Fig. 39 Number of graves per decade, plotted as a density curve. Same data as in Figs. 37 and 36, but presented in a different way.

cussion below will confirm, this growth rate of about 0.045 is in a range which is higher than the population explosion in Africa in the years 1950-2000. This means it is highly probable that the very small grave fields do not simply increase in size organically from within the community itself, but through an influx from outside. Around 575 AD, the previously very small grave fields have reached the size of the small grave fields.

In the range between the very small and the medium-sized grave fields, the growth of the small grave fields is heterogeneous: for some it is as low as the medium-sized ones (clearly visible in the median shown in **Fig. 41**), but for others it is just as strong as that of the very small ones with a growth rate which is more likely down to an influx of settlers than endogenous growth.

Looking at the average number of graves in the years around 575, 615 and 665 AD in comparison, it can be seen that the grave fields which had formerly been very small have now become small grave fields, the grave fields which were formerly medium-sized have now grown into large grave fields. It also becomes clear that the numbers after the first maximum in the 575s remain largely stable for the formerly very small, small and medium-sized grave fields, i.e. they cease to grow. Evidently 1.3 to 1.6 graves/year – corresponding

Decade	Very small up to 0.4	Small up to 0.8	Medium-sized up to 1.4	Large up to 2.2	Very large, >2.2
Around 535	9 *0.22*	7 *0.51*	10 *1.11*	5 *1.66*	3 *2.99*
Around 575	5	6	9	8	6
Around 615	3	6	9	8	8
Living population	6.8	15.8	34.4	51.4	92.6

Fig. 40 Frequency of the grave fields in the different size classes. The cells contain the number at the top, below this (small, in Italics) the arithmetic mean of this group. Bottom line with grey background: Approx. living population of this group (according to the mean value).

Fig. 41 Geometric growth in the size of the grave fields from the 535s to the 575s, differentiated according to the five size classes. *"Boxplot"*: the horizontal bold line indicates the particular median, the grey box encloses 50 % of the observations in the particular size class.

to 40-50 living people – form a local social upper growth limit.

The formerly large grave fields on the other hand grow in stages right through until the 615s to become very large grave fields, but then fall back to their starting level. This decrease is also large and can be explained by new settlements rather than by a biological dynamic. The very high standard deviations for the large and the very large grave fields here indicate that their development is very individual, less regular than for the very small to medium-sized grave fields.

To make these numbers more illustrative and to better present the fundamental pattern without all the details, I convert the stated values into living people, as in the table in **Fig. 40** and assume 7 living people as the basic configuration of 1 farm according to the figures there (this agrees well with 15.8 living persons = 2 farms) for very small grave fields. Accordingly, the aforementioned re-

Size class	Graves/year around 535	λ 535-575	Graves/year around 575	Graves/year around 615	Graves/year around 665
Very small	0.22 ±.08	.04475 ±.03245	0.61 ±0.37 *+177 %*	0.64 ±0.33 *+191 %*	0.55 ±0.45 *+150 %*
Small	0.51 ±.08	.02318 ±.03683	0.95 ±0.74 *+86 %*	1.28 ±0.75 *+151 %*	0.99 ±0.73 *+94 %*
Medium-sized	1.14 ±.14	.00944 ±.01272	1.51 ±0.52 *+33 %*	1.57 ±0.75 *+38 %*	0.99 ±0.71 *-13 %*
Large	1.66 ±.16	.00899 ±.01490	2.29 ±1.04 *+38 %*	3.01 ±1.81 *+81 %*	1.71 ±1.08 *+3 %*
Very large	2.99 ±.22	.01455 ±.01047	4.96 ±2.07 *+66 %*	3.77 ±0.17 *+26 %*	2.79 ±2.77 *-7 %*

Fig. 42 Parameters for the development in the size of the grave fields. Each cell contains the mean value ± standard deviation. Figure below (in italics): Size in % compared to the starting value in the 535s.

sults can also be expressed as follows:

- In the 535s, very small grave fields correspond to approx. 1 farm, small grave fields correspond to approx. 2 farms. They expand to the size of 2-4 farms until the 575s, at least partially through an influx of new settlers. Afterwards they cease to experience any significant growth.
- In the 535s, medium-sized grave fields correspond to approx. 5 farms. Right through until the 575s, they grow in size to approx. 6-7 farms, then no longer experience any significant growth.
- In the 535s, large grave fields correspond on average to approx. 9 farms. They grow somewhat steadily right through until the 615s to approx. 12 farms, with no further growth afterwards.

Thus, initially very small and small communities reach their social carrying capacity with approx. 4 farms, medium-sized communities reach it with approx. 7 farms. For formerly large communities this upper growth limit is 12 farms.

Discussion

Synopsis and classification of the results

I attempt to summarise the most important findings. It must always be borne in mind that although the dataset covers the time from the late 5th century to around 700 AD, reliable information is only available from the same, good sources in the time frame 530-660/70 AD.

- The number of grave fields doubles from the middle third of the 6th century to the middle third of the 7th century (**Fig. 1**). This growth is linear (geometric) (**Fig. 3, Fig. 4**).
- The number of graves increases in the 535s until the 575s, likewise geometrically (not exponentially, not logistically) with a growth rate of $\lambda = .0140$ (corresponding to $r = 0.01113$) (**Fig. 11**).
- From the 615s onwards, the number of graves declines, again geometrically, with $\lambda = -.0078$ (**Fig. 14**). This is not an actual population decrease, because the number of grave fields continues to increase.
- Taken together, these growth parameters state, using slightly simplified and rounded numbers, that the population in the decade 530/40 AD had doubled by the decade 610/20 AD – the maximum of the grave field sizes – and had trebled by the end of the time frame investigated here in the decade 690/700 AD. These figures include the information on the growth in the number of graves as well as the number of grave fields.
- The search for deviations from the general trend described among the individual grave fields reveals that more than half of them follow the general trend without significant deviations. For others, deviations are present primarily in the three decades at the beginning or the three decades at the end (**Fig. 16 to Fig. 33**). Within the time frame from the 535s to the 665s, there are no supra-regional significant deviations which would point to a large-scale disaster or its effects (e.g. volcanic eruptions and their consequences for the climate, LALIA, plague etc.) (**Fig. 34**).
- In addition to Altenerding, where the plague or the bacterium Yersinia pestis has been scientifically proven by aDNA, the four cemeteries of Esslingen-Sirnau, Mengen, Westheim and Westhofen show deviations from the usual course of growth in the middle of the 6th century AD, which could be related to the effects of the plague.
- The two regions Western and Southern Germany differ in respect of how the growth progressed: In Western Germany, the number of graves increases more strongly, the increase in the number of grave fields is smaller; in Southern Germany, the number of grave fields increases more strongly, but the number of graves slightly less so (**Fig. 35, Fig. 36**).
- The sizes of the burial communities differ, there are very small, small, medium-sized, large and very large grave fields (**Fig. 37, Fig. 38**).
- Their growth in size follows different patterns: very small and small grave fields grow so strongly between the 535s and the 575s that this cannot be endogenous growth alone: there is also an influx from the outside. Over the course of time, the number of graves for the local burial communities trebles at most, afterwards (i.e. from the 615s at the latest) the social carrying capacity of these communities is reached.
- The size of the medium-sized and large grave fields increases by around 35 % to 80 % at most, but not so much as to double their numbers of graves. In the 615s at the latest, these communities have reached their social upper growth limit as well.

This investigation thus bears out the well-known, albeit older, hypotheses (e.g. Donat & Ullrich, 1971; Böhme, 1974) that the population grew in the early Middle Ages. For the Dutch Rhine-Maas region, Lanen et al. (2018, 57 Tab. 7; 2019) had presented and detailed a population growth of 48 % from the 5th century (450-525) through into the Merovingian era (ca. 525-725 AD), and from then of about 145 % through into the Carolingian era (725-900 AD) – albeit on the basis of other sources. The picture developed here with the aid of the graves has a finer temporal resolution and makes a far stronger population growth likely, which was around 300 % within the Merovingian era alone (here approx. 530–700 AD).

Likewise with a very different methodological basis (Galeta & Pankowská, 2023a), Patrick Galeta and Anna Pankowská (2023b) investigated the population growth from the 6th to the 14th century in the region which is now covered by the Czech Republic, Slovakia and Hungary with the aid of 59 grave fields with approx. 12,800 burials. They conclude the annual growth rates (exponential growth) there were between 0.67-1.19 % (corresponding to r = 0.0067-0.0119), with the (high) value of 1.19 % for the favourable phase of the Great Moravian Empire (9th century-beginning of the 10th century).[10] Compared with this, the (geometric) growth rate λ of 1.4 % (corresponding to r = 1.113 %) which is presented and detailed here for the Merovingian era is slightly lower.

The archaeological observations explained here agree with many other observations, e.g. with environmental data. Pollen analyses show that the intensive Roman farming practised right through until the early 3rd century is followed in the years 220–550 AD by a time in which the forest cover increases. It declines again from around 550 AD and farming intensifies (Bunnik, 1995, 337-340). A large collection of data on tree felling in Central Europe shows that the felling of trees decreased considerably ca. 170–450 AD, whereas afterwards in the period 450–850 AD the felling of oaks increased considerably again (Büntgen et al., 2011, Fig. 2 C).

Without being able to enter into a detailed debate here, I would like to point out that the age composition of the population in the Merovingian era fits with the hypothesis of a strong population growth. Strong population growth is only possible when relatively few children die and relatively large numbers of people reach reproductive age. According to the material collated by Brigitte Lohrke (2004), the average proportion of children's graves in grave fields which were first used in the early 6th century is 17.9 %, for those grave fields which started in the late 6th century it is 19.7 %, and for the grave fields of the 7th century it is 21.8 % (Lohrke, 2004, 52 Tab. 3). In his study of the demography of the Merovingian era, Peter Caselitz (2021, 34 ff.) adjusts the age distribution to the UN model 36, which in his view corresponds best to the early Middle Ages, and means that he determines there are far too few children aged one or under. It may be the case that there are too few children aged one or under in the Early Medieval grave fields, but in my opinion, the lack of children aged 7 and under (infans I) is chronically overestimated given the observed population growth (also Kölbl, 2004 on the basis of demographic simulations). Even when the lack of children aged one or under 7 in Caselitz (2021) is corrected, the proportion of adults, especially those aged 20-30 years of age, is higher in the Early Middle Ages compared to the Model UN 36 preferred by Caselitz, i.e. there are more young people of reproductive age than expected. I interpret the age composition of the Early Medieval population as an indicator which fits with the hypothesis of very strong population growth. I also associate people's comparatively tall height in the Early Middle Ages with the hypothesis of a healthy, thriving society (Siegmund, 2010, esp. 82 f. Figs. 7-8).

The Justinianic plague, which written sources state was present in Western Europe as well from 542 AD until at least into the 580s, has been a popular research topic ever since the first scientific proof of the plague bacterium Yersinia Pestis was obtained from the grave field at Aschheim near Munich (Wiechmann & Grupe, 2005), and this bacterium has meanwhile been detected in at least five grave fields in what is now Bavaria (Harbeck et al., 2013; Haas-Gebhard, 2017; Keller et al., 2019). A comment is required here about the development of the Early Medieval population. Based on all the descriptions of medieval waves of the plague, I expect a potent plague wave to cause a dramatic increase in the number of dead within a short period of time. Immediately afterwards, the remaining population is greatly reduced in number, i.e. in the decade which follows considerably fewer deaths than usual should be observed. From a differential diagnostic point of view, this time interval *"immediately afterwards"* is critical for the question *"disaster or population growth?"*. Our evidence of a generally sustained strong increase in the number of graves from 530 through into the 575s shows that such a pattern is not present in Western and Southern Germany, at least not on a supra-regional level. Neither does this pattern emerge for the grave fields at Aschheim (**Fig. 16**) and Unterthürheim (**Fig. 33**) investigated here, where the plague is proven to have struck. Only the grave field at Altenerding where the plague is proven to have struck exhibits a corresponding demographic effect (**Fig. 27**): higher numbers of graves at first in the 550s to 570s are followed by a marked stagnation, which is probably an effect of the epidemic.

Case	Population from .... to ...	r (exponential growth)	Doubling time	Reference
global 1.2 m bp-today	55,000-7,800 million	0.00001	70.119	Harper (2018), 6-13
Italy 14 AD-1850	6 million-10.6 million	0.00031	2236	Scheidel (2007) 5 f. & Note 132
Central Europe 5000 BC-1800 AD	2 people/km^2-43 people/km^2	0.00045	1548	according to data in Zimmermann (1996), 51 Fig. 1 and 57-59
globally 10,000 BC-1800 AD	4 million-990 million	0.00047	1484	Roser, Ritchie & Ortiz-Ospine (2019); Kremer (1993)
Switzerland 15,000 BC-birth of Christ	70-121,800 (267,400)	0.00050 (0.00055)	1,393 (1,261)	Stöckli (2016), 29-34 (2 models)
Western Germany 5000 BC-1800 AD	0.60 p/km^2-80.0 p/km^2	0.00072	963	Wendt, Hilpert & Zimmermann (2012), 308 Tab. 31
Germany 1500-1800 AD	9 million-22 million	0.00298	233	Pfister (1994), 10 Tab. 1
Europe 1950-2015 AD	549,375k-740,814k	0.00460	151	UN (2017) Tab. A.1
Europe 1650-1950 AD	500 million-2,500 million	0.00571	121	Khalatbari (2002)
Post-Great Moravian Empire ca. 10th-11th c. AD		0.00670	103	Galeta & Pankowská, 2023b, Tab. 2 (model e0 25-30)
Merovingian era 535-615 AD		0.00693	100	in this essay, lower limit
Egypt 1784-1907 AD	4.65 million-11.35 million	0.00725	96	Scheidel (2001), 212 Tab. 3.4 (*"mean"*)
global 1800-2015 AD		0.00932	74	Roser, Ritchie & Ortiz-Ospine (2019)
Linear Pottery Culture Rhineland I-XII, 5300-5020 BC	7-113 houses	0.00993	70	Nockemann (2017), 444 Fig. 6.73, until maximum in phase XII
Merovingian era 535-575 AD		0.01113	62	in this essay, probable model
North America 1950-2015 AD	172,603k-356,004k	0.01114	62	UN (2017) Tab. A.1
Great Moravian Empireca. 9th c. AD		0.01190	58	Galeta & Pankowská, 2023b, Tab. 2 (model e0 25-30)
Egypt 1800-1907 AD	2,488,950-11,287,359	0.01413	49	Kraus (2004), 217 Tab. 7.1
Vráble (Linear Pottery Culture Slovakia) 5290-5110 BC	34-586	0.01582	44	Furholt et al. (2020), 496 Tab. 6.1.1
Oceania 1950-2015 AD	12,648k-39,543k	0.01754	40	UN (2017) Tab. A.1
Asia 1950-2015 AD	1,404,062k-4,419,898k	0.01764	39	UN (2017) Tab. A.1
USA 1790-2020 AD	3,929,214 -328,239,523	0.01984	35	Wikipedia (2020)
modern global growth maximum 1962-63	3,201,178k-3,263,738k	0.01935	36	Roser, Ritchie & Ortiz-Ospine (2019)
Latin America 1950-2015 AD	168,918k-632,381k	0.02031	34	UN (2017) Tab. A.1
Africa 1950-2015 AD	228,670k-1,194,370k	0.02543	27	UN (2017) Tab. A.1; cf. Frankema & Jerven (2013) Tab. 9
Lengyel grave fields 4900-4800 BC	2.5/y-39/y	0.02750	25	Regenye et al. (2020), 57 Fig. 17

Fig. 43 Selected comparative data on the population growth in prehistoric times and the present. Please note that r (exponential growth) is the parameter used here, as is customary in demography.

It must be remembered that the project undertaken by Keller et al. (2019, Tab. 1) was unsuccessful despite their intensive search for the plague bacterium in 12 grave fields, and they only succeeded in finding relevant proofs in 4 grave fields (figures for Germany only). Far be it from me to deny the existence of plague in Early Medieval Southern Germany, but given a very low population density and the lack of or only a low impact on the population growth, the question is whether the lethality of the Early Medieval plague bacterium corresponds to that of the Medieval waves of the plague. I have my doubts. The methodological and factual debate among geneticists about which branch of evolution and hence which virulence the Early Medieval *Yersinia Pestis* found are more likely to belong to does not seem to have been settled either (e.g. Bos et al., 2012; Vogler et al., 2020).

Attention must be drawn to a further, methodological consequence of the present results: The popular life tables with their much used parameter e_0 – life expectancy at birth – are based on the starting hypothesis of a stable population (e.g. Hassan, 1981, 109; Chamberlain, 2006, 31). In the event of a strong decline or growth in population they lead to incorrect results for the average life expectancy. Given the doubling of the Early Medieval population between 530 AD and ca. 615 AD and the tripling by ca. 695 AD which has been proven here, one must question whether the parameter e_0 is still a suitable instrument to describe the life expectancy of the Early Medieval populations.

Furthermore, written records for modern time migrations e.g. from Europe to northern America show that it is young members of a population (young adults with small children) who emigrate as a rule (e.g. Chamberlain, 2006, 38 ff. Fig. 2.8). For our grave fields, the generation of the founders (*"immigrants"*) seems to be relatively young in the language of the life tables (i.e. low av. life expectancy because the older people are missing), whereas when a grave field is ceasing to be used, proportionately high numbers of older people are still buried at the old site, which indicates an apparently high life expectancy in the life tables. Moreover, this article proves that during the time the grave fields were in use, new settlements were established when the original ones reached their social carrying capacity, and these new settlements presumably likewise go hand in hand with such immigration/emigration demographies. A stable population is a methodological requirement for collating life tables, but the high population growth described here and the basically continuous immigration and emigration effects mean this criterion is not met here.

Comparison with growth rates of other eras

To be able to compare the population growth in the Merovingian era which has been presented in detail here with that of other eras, a selection of comparative data is collated in the Table in **Fig. 43**. Since it is easier for us to imagine the present as a rule, it includes some current data and data from the 20th century as well as some striking, well-investigated cases from prehistoric times. Since the discipline of demography usually works not with the geometric growth (λ) but with the exponential growth (r), the corresponding values of r are entered into the table for the Merovingian era as well. Parametrising the data as a growth rate has the advantage that apart from the factor of time, which must always be of equal measure, data such as people/square kilometre can also be used as the basis instead of absolute numbers of people. The doubling time, as a parameter derived from the growth rate, is also included in the table: the period of time in which a population doubles at the growth rate stated. It illustrates that even differences in the numbers which seem to be relatively minor have a large effect in practice when the growth is exponential.

The table makes clear that the growth rate of r = 0.00050 (alternatively r = 0.00055) determined by W. E. Stöckli (2016) for the prehistory of Switzerland lies within what is usual and plausible when very long periods of time are considered. The study by Wendt et al. (2012) of Western Germany from the Early Neolithic until around 1800 AD arrives at a similar, only slightly higher value.

Over short time intervals on the other hand the growth rates can be significantly higher. In the 20th century they were r = 0.01935 (global, 1962-63) to r = 0.025443 (*"population explosion"* in Africa, 1950-2015); a good value to take as a guide is also provided by the growth rate for the global population of r = 0.00932 for the time from 1800 to 2015. The value of r = 0.01113 determined here for the Merovingian era in the interval 535-575 AD puts its order of magnitude between the two values for two reliable studies on the Linear Pottery Culture (r = 0.00993 and 0.01582). The fact that, in prehistoric times, even higher growth was possible for short intervals is shown by an r of 0.02750 for Lengyel grave fields. Considering the data of modern times, the value for the Merovingian era in Western and Southern Germany is very close to the population growth in North America between 1950 and 2015.

Translation: Dr. Ulrich Greb/TechniText Translations

Notes

[1] Regarding the regions dealt with there, see now: Siegmund, 1998; Nieveler, 1995; Plum, 2003.

[2] According to the writing conventions usual in Early Medieval archaeology, years are often written as *"530/540 AD"*, for example, which means: ca. 530 to ca. 540 AD. To be able to use a more compact notation for the text and the tables, the forms *"535s"* and *"ca. 535 AD"* are also used here. The expression *"ca. 535"* thus means the same as 530-540 or 530/540 AD.

[3] e_0: life expectancy at birth; e_{20}: further life expectancy of those who reached the age of 20. For the sake of vividness, I often use the parameter „e_{20}+20" instead of e_{20}: average life expectancy at birth of those who have reached adulthood.

[4] The grave field at Altenerding with over 1,500 graves which have been carefully dated according to the cogent but special model devised by A. Pleterski, would dominate the dataset (Losert & Pleterski, 2003, esp. Fig. 616 & 616), because there are more than three times as many dated graves from Altenerding as from the next biggest sites. This would result in the values for the mean values and trend observations from Altenerding dominating the other sites, and it would primarily be the trend in Altenerding which was described here, not a general trend. For Altenerding, I have therefore simply divided all numbers per decade by two, whereby the number of graves in Altenerding becomes similar to those in Rübenach, Mengen and Junkersdorf in terms of order of magnitude. Thus, Altenerding remains relatively important in the dataset, but no longer *"drowns"* the other series.

[5] Many thanks to Michaela Schauer (Vienna) for creating these maps using the coordinates I provided!

[6] According to the table **Fig. 1**, there generally appear to be far more grave fields in Western Germany than in Southern Germany. This impression is wrong, it is based on regionally different research traditions: In Western Germany, it was customary following Kurt Böhner (1914-2007) to especially undertake comprehensive surveys of whole regions as well as individual large grave fields. In Southern Germany in contrast, following the Munich school centred around Joachim Werner (1909-1994), the custom was rather to work on grave fields, while the comprehensive survey of whole regions remained an exception. This means that only very localised regional surveys are available for Southern Germany.

[7] To avoid having very small numbers and also take account of the uncertainty in the datings, the data were compiled as *"graves per decade"* and are also documented in this way in the corresponding tables in the Suppl. Mat. In the entire evaluation, however, I argue with graves per year because this is the usual demographic parameter.

[8] As is usual in archaeology, a risk of error of $\alpha = .05$ is used.

[9] Calculated according to the equation in Acsádi & Nemeskéri, 1970, 65 f., but without the correction factor k.

[10] The estimate by Galeta & Pankowská (2023b, Tab. 2) has a standard error of 0.22 %, however, thus the true value is in the range 0.97-1.41 %. In addition, I take an e_0 of 25-30 years as my basis, the more restrained model of e_0 with 20-30 years results in a growth rate of 0.99 % (0.78-1.20 %); therefore overall, these are estimates with no certainty that they exceed the growth in Western and Southern Germany in Merovingian times.

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About the author

Frank Siegmund wrote his dissertation thesis (publ. 1998) on the typology and chronology of the Merovingian period in the Rhineland and his habilitation on early medieval ethnicity (publ. 2000). Overarching themes of later studies are social issues and the archaeology of living standard.

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Supplemental material

1. List of grave fields with number of dated graves (PDF)
2. Data as *.csv- and *.xlsx tables
3. Glossary: Demographic parameters