

Appendix A: Roman and early-medieval population estimates in the Rhine-Meuse delta (the Netherlands)

R.J. Van Lanen

The presented demographic reconstructions are based on a multitude of archaeological and historical data and are the result of a close collaboration with Roman and early-medieval period experts. The Roman reconstructions were compiled with help from Drs. T. de Groot (Cultural Heritage Agency of the Netherlands (RCE)), Dr. H. van Enckevort (municipality of Nijmegen) and Dr. S. Heeren (Vrije Universiteit). The early-medieval palaeodemographics would have been impossible to reconstruct without the help of Drs. C. van Rooijen (RCE) and Drs. J. van Doesburg (RCE). Overall demographic data were collected and analysed by R.J. van Lanen, M.A. (Utrecht University and RCE) and Dr. B.J. Groenewoudt (RCE).

For each archaeological (sub)period as defined in the Dutch Archaeological Basic Register (ABR http://cultureelerfgoed.nl/sites/default/files/downloads/dossiers/abr_website2.pdf) (Table 2 in the main text), the population estimates presented below are based on a variety of arguments and references. Only settlement sites that with certainty can be assigned to individual ABR subperiods were included in the analyses. Cited literature is referenced in the main text of this paper.

Method

Previously two different methods were used to estimate past population numbers in the study area: (1) the recruitment model (e.g. Bloemers, 1978 and Willems, 1986); and (2) the settlement-density model (e.g. Willems, 1986; Vossen, 2003; Vos, 2009; Vossen & De Groot, 2009). The recruitment model reconstructs past-population numbers based on Roman-army recruitment requirements that are mentioned in historical sources. The settlement-density model (SDM) bases demographic calculations on settlement numbers, number of houses per settlement, and average household size. In the present study we have decided to use the SDM because: (1) good-quality settlement data are available in the study area, allowing an evidence-based approach when reconstructing population dynamics; and (2) it is impossible to verify whether Roman army recruitment numbers are reliable, and these numbers merely may reflect target numbers.

We assume that both during the Roman period as well as during the Early Middle Ages the majority of the population lived in small rural settlements. Larger settlements were exceptional in the study area. We therefore separately estimated rural-population levels and population numbers of larger settlements.

Rural population

The rural population was calculated using the following equation:

$$Rp = (S_v + S_u) \times \delta \times \alpha \quad (1)$$

Rp	rural population
S_v	number of verified settlements
S_u	number of (probable) undiscovered settlements
δ	average number of houses per settlement (constant)
α	average number of individuals per house (constant)

In this approach rural demography (Rp), i.e. the number of people living in rural settlements, is calculated by adding the total number of verified settlements (S_v) to the probable number of undiscovered settlements (S_u) and by multiplying the outcome with the average number of houses per settlement (δ) and with household size (α) for each ABR period. Based on research by Bult (1983) and Deeben et al. (2006) we have assumed that around 50% of the settlements are still undiscovered. The average number of houses per settlement and household size were determined based on published archaeological-excavation data (see below and Table 3 in the main text).

Household size

The number of individuals per household has been the subject of discussion among archaeologists for years (e.g. Willems, 1986; Vossen, 2003; Heeren, 2009; Dijkstra, 2011). However, it is generally accepted that the average household size in the study area was ca. 6.5 individuals throughout the first millennium AD. This number is based on biological data concerning average family sizes and is considered to have remained constant during the preindustrial periods.

Number of houses per settlement

The ERP was characterized by small agrarian settlements. Bloemers (1978) reconstructed settlements commonly consisting out of a single farmstead only. The predominance of isolated farmsteads, so-called *Einzelhöfe*, during the ERP has been recorded for the western as well as for the eastern parts of the Netherlands (Van Beek, 2009; Dijkstra, 2011; Van Der Velde, 2011). In the study area, however, archaeological research at Tiel-Passewaaij and Wijk bij Duurstede-De Horden points towards settlements on average consisting of 1 to 2 houses per settlement (e.g. Heeren, 2009; Vos, 2009). For this reason we defined the average number of houses per settlement for the ERP as 1.5 (Table 3 in the main text). During the subsequent MRP, settlement size drastically increased. Bloemers (1978) and Dijkstra (2011) have reconstructed an average of 3 houses per settlements. The settlements at Tiel-Passewaaij and Wijk bij Duurstede-De Horden expanded to ca. 4 farmsteads during this period (e.g. Heeren, 2009; Vos, 2009). We conservatively defined the average number of houses per settlement during the MRP as 3 (see main text, Table 3). During the LRP settlement size (and numbers) decreases again. Based on excavations at Breda-West, Goirle-Huzarenwei and Tiel-Passewaaij the average number of contemporaneous houses per settlement varied between 1 and 2 and was equal to the ERP. Therefore we defined the average size of settlements during this period as 1.5 (see main text, Table 3). Research by Dijkstra (2011, p. 98) has shown that the number of houses per settlement during the Early Middle Ages (EMPA – EMPD) ranged from 3 to 5. Again, we conservatively defined the number of houses during the EMPA, EMPB and EMPC as 3. Research by Hamerow (2002, p.87), Van Beek et al. (2015) and Van Doesburg (in prep.) has shown that during the EMPD habitation clustered and larger rural settlements developed. To compensate for this phenomenon we defined the number of houses per settlement during this period as 5 (see the main text, Table 3).

Large settlements and military presence

Population numbers for the larger settlements in the study area were based on settlement size, building density, and average household size. Quantitative data from well-studied larger settlements, specifically from Roman Nijmegen and early-medieval Dorestad, served as a frame of reference for estimating population numbers of less-known contemporary larger settlements. We defined large settlements as habitation sites which are outliers in terms of their size, covering > 5 ha.

For the Roman period we also separately estimated military presence (number of troops). These estimates are partly based on historical sources. Each Roman *castellum* (fortress) was characterized by an associated civilian settlement (*vicus*). It has been suggested that the number of people living in a *vicus* may have been twice that of the number of soldiers (e.g. Sommer, 1984; 1991). Judging by the size and house-density of *vici* in the study area (e.g. Hazenberg, 2000; Ploegaert, 2006; Blom & Vos, 2007; Vos et al., 2012; Waasdorp & Van Zoolingen, 2015), this estimate is too high. Van Dinter et al. (2014, p. 29) for the western part of the Dutch *limes* concluded that the “.. assumption of 350 soldiers per fort and an equal number of people living in the surrounding vicus is rather a maximum estimate than an under-estimate”. Our calculations are based on this assumption. Excavation results from Köngen and Ladenburg (Germany) hint at a similar ratio between the number of Roman soldiers and *vici*-inhabitants (Hanel (2007, p. 413).

Total population numbers were derived by adding the estimates for rural population, larger settlements, and military presence.

Population estimates for each ABR subperiod

Based on these numbers we reconstructed and quantified palaeodemographic trends for each individual ABR-subperiod. To ensure maximum readability, integrated overviews of all reconstructed population numbers are provided in tables 4-7 in the main text.

Early-Roman period: 12 BC – AD 70 (ERP)

The ERP was characterized by the start of Roman occupation and the influx of Roman troops in the area. Nonetheless settlements remained predominantly rural during this period and consisted of isolated farms and small agglomerations of farms. Based on the work by Bloemers (1978) on the *civitas Cananefates*, Vos (2009) on the Kromme-Rijn area, Heeren (2009) on the *civitas Batavorum*, and Dijkstra (2011) on the estuaries of the Rhine and Meuse, we determined an average number of 1.5 houses per ERP settlement, and a household size of 6.5 (Table A.2).

Military presence

Roman-military presence during the ERP greatly fluctuated. In our calculations we have included the maximum number of soldiers during this period. Although from a historical perspective the ERP ends in AD 70 (after the army successfully quelled the Batavian revolt of AD 69-70), we included the Roman military presence between

AD 70 – 104 into our demographic calculations of the ERP. The reason for this approach is that military presence during these 34 years was a direct consequence of preceding ERP events and hence not characteristic for the largest part of the MRP. Around AD 70 circa 4,000 Roman soldiers (8 cohorts = 8 x 400 soldiers) of the 10th legion (*Legio X Gemina*) occupied the *castra* at Nijmegen (Driessen, 2007). In their tracks around 10,000 people settled in the nearby *canabae legionis*, which covered almost 100 ha (Willems et al., 2004). We calculated 10,000 people for the *canabae legionis* based on the fact that this settlement covered twice the surface area of the later Roman town at Nijmegen, (50 ha), and was characterized by a similar house-density level, therefore probably containing twice as many people.

Besides the large *castra* at Nijmegen the study area contained 14 smaller Roman fortresses, the *castella* (Table A.1). Although the chronological framework of each individual *castellum* differs, they all were in use after AD 70 and should therefore be included in the demographic calculations of both the ERP and MRP. In order to reconstruct the number of soldiers and *vici*-inhabitants represented by these *castella* we applied the 1-to-1 ratio as is explained above. Based on Van Dinter et al. (2014) we set the population numbers for each *castellum* at 350 soldiers and for each associated *vicus* at 350 civilians (Tables A.1 and A.3).

Table A.1 | Overview of *castella* and *castra* included in the demographic modelling for the ERP and MRP.

Name	Type
Arnhem Meinerswijk	Castellum
Nijmegen	Castra
Woerden	Castellum
Utrecht De Meern	Castellum
Utrecht Domplein	Castellum
Vechten	Castellum
Rijswijk Roodvoet	Castellum
Maurik Eckse Waarden	Castellum
Kesteren Lede en Oude Waard	Castellum
Duiven Loowaard	Castellum
Herwen De Bijland	Castellum
Randwijk	Castellum
Driel Baarskamp	Castellum
Huissen Hazebergh	Castellum
Rossum Kloosterwaard	Castellum

Large settlements

With the exception of the *Canabae Legionis* located at Nijmegen no large settlements are known dating to the ERP.

Middle-Roman period: AD 70 – 270 (MRP)

The MRP reflects the heydays of Roman occupation. For this period we have calculated an average of 3 houses per settlement, as was already suggested by Bloemers (1978). Although the number of houses per settlement in other studies have been suggested to have ranged between 4 and 5 during this period, recent research by Dijkstra (2011) for the Rhine and Meuse estuaries has shown that during this period numerous smaller isolated farmsteads were also present in (the western part of) the river area. Dijkstra (2011) therefore concluded that an average of 2.5 houses per settlement is more likely. However, research of the settlements at *Tiel-Passewaaij* and *Wijk bij Duurstede-De Horden*, both located in the study area, has shown that in these parts during the 2nd century 4 to 5 houses per settlement was not uncommon. In order to compensate for these discrepancies we conservatively applied an average of 3 houses per settlement during the MRP (see main text, Table 3).

Military presence

Military presence in the study area during the MRP was dynamic. For the population calculations we applied the maximum number of military occupation during this period. Military presence in the *castella* during the MRP was comparable to the final part of the preceding ERP, with a total of 14 smaller Roman fortresses being located in the study area (see main text, Figure 7). Each *castellum* was inhabited by a maximum of 350 soldiers and each accompanying *vicus* by an equal amount of civilians. Roman military presence at Nijmegen during the MRP was significantly lower than during the preceding ERP, consisting of no more than 1,000 soldiers LRP (Oral communication Dr. S. Heeren, 2016; Brulet, 2017). After the 10th legion left the region in AD 103-104, little is known about the occupation of the *castra*. It is however clear that in the wake of the 10th legion the *Canabae Legionis* was completely abandoned. Around AD 121 the *Legio IX Hispana* (9th legion), or at least a part of it, briefly appears to have stayed at Nijmegen, but for the period after AD 125 little additional information is available regarding military occupation of the *castra* (Bechert & Willems, 1995).

Large settlements

During the MRP large settlements developed (or were founded) as rural centres or *civitas* capitals in the study area. Based on archaeological research 5 large settlements could be identified (see main text, Table 5 and Figure 6). For each of these large settlements, population numbers were individually calculated based on published demographic reconstructions and on settlement size. The latter approach, which was applied in cases that the surface area of a settlement is known but no publications are available containing population estimates (e.g. Rossum and Wijchen), consisted of applying population density per hectare calculated using data from large settlements of which population estimates do exist.

Late-Roman period: AD 270 – 450 (LRP)

The study area during the LRP underwent a major demographic decline. During this last phase of the Roman occupation in this area not only the number of settlements appears to have been much lower, but in addition settlement size was significantly reduced to an average of 1.5 houses per settlement (see main text, Table 3).

Military presence

Little is known of LRP military presence in the Rhine-Meuse delta. Because of socio-economic and political instability in the Roman Empire numerous changes in defence policies occurred during this period. Additionally, after the fall of the Roman *limes* around AD 270 Roman occupation of the study area was not continuous. In order not to underestimate pressure on the landscape, we incorporated the maximum number of soldiers into the demographic reconstructions of the LRP. After the collapse of the *limes* most *castella* were abandoned and other military sites developed. Only a few of these late-Roman military sites are known. Therefore an estimate is only possible using available data on amongst other late-Roman *burgi* like Heumensoord, Goch, Wijchen (average 20-50 soldiers), Nijmegen (ca. 1,000 soldiers), Cuijk, Wijk bij Duurstede, and Vechten (with the latter three containing ca. 250 soldiers).¹ Using this approach we estimated the total Roman military presence during the LRP at 2,500 soldiers.

Large settlements

In the study area no large settlements are known dating to the late-Roman period. The large settlements dating to the preceding MRP all have yielded archaeological evidence of severe depopulation or complete abandonment.

Early-medieval period A: AD 450 - 525 (EMPA)

During the EMPA the rural population declined even further. After the Roman occupation definitively ended, the number of settlements in the study area decreased. Research by Dijkstra (2011) for the Rhine and Meuse estuaries has shown that settlement size during the EMPA increased slightly to 3-5 houses per settlement. For our reconstructions we have conservatively set the number of houses at an average of 3.

Military presence

There is no evidence of centralised military presence during the EMPA.

Large settlements

¹ An overview of LRP military sites and the corresponding numbers of soldiers were provided by dr. S. Heeren, to whom we are extremely grateful.

No large settlements are known dating to the EMPA.

Early-medieval period B: AD 525 - 725 (EMPB)

During the EMPB the first signs of revival and demographic rise occurred in the study area, which is mainly reflected by an increasing number of settlements dating to this period. According to Dijkstra (2011) settlement size during this period was similar to the preceding period, consisting of 3-5 houses. Therefore, in the demographic calculations we have set the settlement and household sizes to the same levels as were used for the EMPA period.

Military presence

There is no evidence of centralised military presence during the EMPB.

Large settlements

In the Netherlands large settlements dating to the EMPB are rare. In the study area only two sites, at Nijmegen and Lent, appear to have been significantly larger than the majority of rural settlements (see main text, Table 5). Both are located in the eastern part of the Rhine-Meuse delta near the current border with Germany. Based on research by Harmsen et al. (2012), Den Braven (2014), and Hendriks et al. (2014), we could determine that both settlements probably were inhabited by ca. 500 individuals.

Early-medieval period C: AD 725 – 950 (EMPC)

The EMPC was characterized by a continuation and intensification of the demographic rise that had started during the EMPB. The number of settlements in the study area significantly increased under Carolingian rule. Settlement size in the estuary of the Rhine and Meuse in this period appears to have been equal to settlement sizes during the preceding early-medieval periods (Dijkstra, 2011). Therefore we set the settlement and household sizes in the study area to the same levels as the preceding early-medieval periods, at 3 houses per settlement.

Military presence

There is no evidence of centralised military presence during the EMPC.

Large settlements

During the EMPC large settlements at Dorestad, Nijmegen and Utrecht developed into pre-urban towns (see main text, Table 5). The population centre at Nijmegen was located slightly to the southeast of the preceding EMPB settlement phase and has yielded archaeological evidence of continuous habitation (Kuys & Bots, 2009; Den Braven, 2014; Hendriks et al., 2014). During the EMPC the settlement appears to have doubled in size to 10 ha. At the same time in Utrecht a larger settlement developed consisting of several smaller inhabited zones clustered around the old Roman *castellum* (e.g. Renes, 2000; Van Rooijen, 2010). The largest settlement dating to this period, Dorestad, developed south-east of Utrecht and west of Nijmegen. This remarkable settlement clearly surpassed all other EMPC settlements both in terms of surface area and its number of inhabitants (see main text, Table 5). According to recent calculations based on building density by Van Es & Verwers (2015, p. 197-200) Dorestad in its heydays probably housed 10,000 people. Van Rooijen (oral communication) states that the building density in Utrecht will have been considerably lower at the start of the EMPC than in at the end of this period and during the following EMPD. An estimate of 500 inhabitants for the 9th-10th centuries is most likely. Since the site of Dorestad is well excavated, we have used the ratio of inhabitants per hectare of this settlement to extrapolate the population of Nijmegen during the EMPC. This is justified because the *Pfalz* constructed during this period (cf. Den Braven, 2014) must have drawn people towards this area, which must have resulted in a relatively high building density.

Early-medieval period D: AD 950 – 1050 (EMPD)

The EMPD was characterized by a slight drop in the number of settlements, which can be attributed to several non-exclusive causes: (1) The EMPD only covered a relatively short time span; (2) as was already suggested by Hamerow (2002) and Van Doesburg (in prep.), during the EMPD most likely the number of houses per settlement increased; (3) civil unrest caused by Viking raids (Henderikx 1986); and (4) difficulties to archaeologically date settlements to the EMPD, leading to an underrepresentation in the archaeological dataset (Bartels et al. 1997). In the demographic calculations we have compensated for the increased habitation clustering during this period by increasing the number of houses per settlement to 5.

Military presence

There is no evidence of centralised military presence during the EMPD.

Large settlements

In the study area three large settlements date to the EMPD. These were located at Nijmegen, Tiel, and Utrecht (see main text, Table 5). The settlements at Nijmegen and Utrecht represent continuations of the settlements located here during the EMPC. The population number at the settlement in Nijmegen (which included a *Pfalz*) appears to have remained comparable to population numbers during the preceding EMPC (Kuys & Bots, 2009; Den Braven, 2014). In Utrecht population numbers increased rapidly, and had almost doubled towards the beginning of the EMPD. This rapid increase is best explained by the arrival of the bishop to the former *castellum*, which led to the development of a major ecclesiastical centre in Utrecht (Van Rooijen, 2010). Striking is the decline and eventual abandonment of the largest EMPC settlement in the study area, Dorestad, and the subsequent rise of the settlement at Tiel to the south. Most likely due to majorly changing landscape conditions and river-transport routes, Tiel developed as a trade settlement of approximately 12 ha (Oudhof et al., 2013). In the demographic calculations, based on the ratio between inhabitants per hectare at Dorestad, we estimated the population at Tiel to have been around 600.

Quantification of Roman and early-medieval population

Based on the presented trends per ABR-subperiod we have quantified the rural population, potential military presence, and demographics per large settlement (Table A.2 and A.3; also see the main text, Tables 5-7).

Table A.2 | *Reconstructed rural population per ABR-subperiod. Calculations are based on the archaeological publications specified in Table 3 of the main text.*

Rural settlements						
Period	N settlements	Estimated discovery rate 50%	AvG houses	N houses	AvG individual per house	N people
ERP	1234	2468	1,5	3702	6,5	24063
MRP	1619	3238	3	9714	6,5	63141
LRP	664	1328	1,5	1992	6,5	12948
EMPA	306	612	3	1836	6,5	11934
EMPB	428	856	3	2568	6,5	16692
EMPC	818	1636	3	4908	6,5	31902
EMPD	711	1422	5	7110	6,5	46215

Table A.3 | *Reconstructed military presence in the study area during the ERP and MRP.*

Name <i>castellum</i> or <i>castra</i> (in study area)	N people <i>castellum</i> AD 70 - 104	N people <i>vicus</i> AD 70 - 104	Total population AD 70 - 104	N people <i>castellum</i> AD 104 - 270	N people <i>vicus</i> AD 104 - 270	Total population AD 104 - 270
Arnhem Meinerswijk	350	350	700	350	350	700
Nijmegen	4000	10000	14000	1000	1000	2000
Woerden	350	350	700	350	350	700
Utrecht De Meern	350	350	700	350	350	700
Utrecht Domplein	350	350	700	350	350	700
Vechten	350	350	700	350	350	700
Rijswijk Roodvoet	350	350	700	350	350	700
Maurik Eckse Waarden	350	350	700	350	350	700
Kesteren Lede en Oude Waard	350	350	700	350	350	700

Duiven Loowaard	350	350	700	350	350	700
Herwen De Bijland	350	350	700	350	350	700
Randwijk	350	350	700	350	350	700
Driel Baarskamp	350	350	700	350	350	700
Huissen Hazebergh	350	350	700	350	350	700
Rossum Kloosterwaard	350	350	700	350	350	700
Total	8900	14900	23800	5900	5900	11800