



Roman and early-medieval long-distance transport routes in north-western Europe: Modelling frequent-travel zones using a dendroarchaeological approach



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ABSTRACT

To what extent long-distance transport in north-western Europe changed after the Roman period is generally unknown. Few historical sources are available and existing archaeological records are unclear and sometimes conflicting. Traditionally, research on the long-distance exchange of goods mostly has focussed on the spatial analyses of luxury goods such as jewellery, weapons and religious artefacts. Relatively little attention has been paid to the spatial modelling of common exchange networks and transport routes.

In this study we used a dendroarchaeological approach to model long-distance transport of oak (a common good) to the Roman and early-medieval Netherlands. By combining established and newly-derived provenances of imported timbers with data on Roman and early-medieval route networks, we were able to reconstruct: (a) Roman and early-medieval exchange networks of imported timbers, (b) changing transport routes and (c) spatially shifting frequent-travel zones. The findings were compared with distribution patterns of other commodities for daily use: pottery and stone household goods.

Results show that in the early and middle-Roman periods (12 BCE – CE 270) timbers were imported from the German Rhineland, the Ardennes and the Scheldt region. We have no evidence for wood import to the current Netherlands during the late-Roman period and first phase of the Early Middle Ages (CE 270 – 525). In the following centuries, between CE 525–900, oak again was brought to the current Netherlands, this time exclusively originating from the German Rhineland. This pattern significantly changed during the last phase of the Early Middle Ages (CE 900–1050) when timbers were derived from the Ardennes only. We used these patterns to calculate changes in long-distance transport routes and frequent-travel zones in the research area. Through our analyses existing data on Roman and early-medieval route networks could be expanded and improved. The calculated wood-transport patterns agree well with the distribution of imported pottery and (other) household goods in these periods.

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1. Introduction

Our study area, the present-day Netherlands, is located in north-western Europe. A large part of the area consists of the low-lying estuary of three major European rivers: the Rhine, Meuse and Scheldt. Here landscape conditions for a long time were very dynamic. The central, western and northern Holocene parts have been

exposed to strong fluvial and/or marine influences and frequent flooding throughout the Holocene (Stouthamer and Berendsen, 2000; Erkens, 2009; Vos et al., 2011; Cohen et al., 2012; Toonen, 2013; Vos and De Vries, 2013; Vos, 2015). The eastern and southern Pleistocene parts of the area are somewhat more elevated and relatively stable (Steur and Heijink, 1991; De Vries et al., 2003; Koomen and Maas, 2004).

The history of the Dutch landscape is characterized by a complex interplay between fluvial and marine influences on the landscape. The rivers and sea had an obvious impact on the geomorphological development of the area and flooding occurrences. In addition they facilitated long-distance transport of people, goods and ideas and

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“opened-up” distant lands. During the Roman and early-medieval periods (respectively 12 BCE – CE 450 and CE 450–1050) rivers in the study area were arteries in long-distance exchange networks and frontier control and in this sense they can be regarded as “highways of the past” (e.g. Pirenne, 1939; Hodges and Whitehouse, 1983; Lebecq, 1983; Lebecq, 1999; Van Es and Verwers, 2010; Hodges, 2012).¹ However, these rivers equally will have benefitted (in case of water transport) and hampered (in case of land transport) long-distance transport (Van Lanen et al., 2015a/b).

In the study area Roman and early-medieval transport networks differ considerably (Van Lanen et al., in review). The Roman trade system in the western empire collapsed during the 5th century (Davis and McCormick, 2008) and in our research area this happened even one or two centuries earlier (e.g. Van Es and Verwers, 2010). However in these latter parts revival already set in during the 6th century, when the Rhine regained much of its transport-geographical importance (Van Es and Verwers, 2010). The extent and nature of changing trade networks and their influence on long-distance transport during this period remains largely unclear. So far research on long-distance exchange of Roman and early-medieval goods has generally focussed on either (1) the spatial analysis of luxury goods or very specific commodities such as pottery and rotary querns (e.g. Kars, 1983; Verhoeven, 1990, 1992) or (2) essentially theoretical models explaining trade and exchange networks (e.g. Theuws, 2004, 2012). In our opinion there is much to be gained by implementing quantitative approaches to the reconstruction of long-distance transport of common commodities. Additionally, the provenance and spatial distribution of such goods should be compared to (modelled) past route networks.

Using dendroarchaeological data the shifting provenance of imported Roman and early-medieval structural timbers excavated in the Netherlands will be determined. We use the term ‘dendroarchaeology’ as a container term for all tree-ring research aimed at reconstructing past human activity. The results are compared to recently developed models of Roman and early-medieval route networks in the Netherlands (Van Lanen et al., 2015b). The central aim is to (1) reconstruct long-distance transport routes connected to this region based on the provenance of imported timbers and (2) model frequent-travel zones within Roman and early-medieval route networks using evidence-based modelling and Geographical Information Systems (GIS). Frequent-travel zones in this context are best defined as selected route sections (land or water) within a network that were intensively used for the distribution of a specific commodity during a certain period. An additional ambition of this study is to show the importance of analysing large (material) archaeological and environmental datasets (*Big Data*) in combination with evidence-based modelling when researching (long-distance) route networks.

2. Theoretical background

Although reconstructing Roman and early-medieval trade networks is not a new field of research in our study area (e.g. Verhoeven, 1990, 1992; Van Es and Verwers, 2010; Theuws, 2012; Domínguez-Delmás et al., 2014; Jansma et al., 2014; Van Dinter et al., 2014; Jansma and Van Lanen, 2016; Orenge and Livarda, 2015), very little focus has been placed on reconstructing and explaining large-scale spatial changes between networks in different periods. Few historical sources deal with Roman and early-medieval exchange networks. Therefore most available

reconstructions are based on archaeological data, more specifically on ‘luxury’ finds such as jewellery, weapons and to some extent coins. Much less attention has been paid to more common commodities and bulk goods such as building materials. In our opinion especially construction wood is well suited for modelling long-distance transport routes, since provenance and spatial distribution usually can be reconstructed in some detail.

A variety of different exchange networks must have been active in both the Roman and early-medieval periods in the Netherlands. The exchange of people, goods and ideas must have been influenced by military activity, political and religious rules and economic conditions. Most smaller-scale exchange networks can be expected to have been linked to long-distance transport routes. We define transport routes as routes that connect production and distribution areas but in themselves do not reflect any specific kind or intensity of trade. They should simply be regarded as spatial zones facilitating the long-distance translocation of goods and ideas.

In this study we use transport routes of imported timbers to model frequent-travel (transport) zones within past-route networks. Although in the Netherlands during the Roman and early-medieval periods indigenous oak was used for many construction purposes (e.g. Jansma, 1995; Doeve, 2015), we modelled long-distance transport routes and frequent-travel zones using imported material only. Frequent-travel zones are calculated for routes located within the Netherlands, since no Roman and early-medieval route network data similar to those developed by Van Lanen et al. (2015b) are available outside the research area. We assume that the bulk of the timbers brought in over large distances was transported over water, often in combination with other goods. Based on this assumption the distribution of imported timbers can be used to model main transport routes. For short-distance transport in the Netherlands land and water routes are assumed to be equally likely.

Recent studies already have shown that dendroarchaeology is well suited for identifying the geographical provenance and most likely transport routes of imported oak excavated in the present-day Netherlands. Jansma et al. (2014) for example established that Roman military river barges and a punt constructed in ca. CE 100, CE 148 and after CE 158 and wrecked along the Dutch limes near the town of Utrecht originally were built in current Flanders, Belgium. And Domínguez-Delmás et al. (2014) showed that timbers used to construct the harbour of the Roman town *Forum Hadriani* in ca. CE 160 and CE 205 were brought here along the Rhine from respectively Southern Germany and the Ardennes. Between ca. CE 600 and 850 oak from the German Rhineland reached the Netherlands in the form of a dug-out and a river barge as well as through cargo (wine barrels, re-used along the Rhine and North-Sea coast as the lining of water wells; Doeve, 2015; Jansma and Van Lanen, 2016).

The dendroarchaeological approach is very useful when modelling long-distance route networks since it offers high-resolution dates and general provenance areas. ‘Luxury’ goods such as jewellery, weapons and gold coins frequently changed ownership and location through inheritance, gift exchange or trade. The opposite is true for timbers, which reflect a much more direct spatial link between provenance area and find spot. This link obviously is less straightforward for shipwrecks, re-used barrels and re-used timbers found in (repaired) revetments. However, with such finds we can at least assume that the areas of construction/provenance and location of re-use (or sinking) were connected by water routes.

Van Lanen et al. (2015a/b) used an evidence-based modelling approach to reconstruct Roman and early-medieval routes in the Netherlands based on network friction and settlement patterns.

¹ The publication of Pirenne's *Mohammed and Charlemagne* (1939) triggered a discussion among historians and archaeologists on trade and trade networks during the Early Middle Ages. See: e.g. Hodges and Whitehouse, 1983.

The resulting networks were validated against archaeologically-known infrastructural finds. The current study aims to chronologically and spatially expand these networks by researching long-distance transport routes. Data on imported timbers, pottery and stone household goods are used to determine long-distance transport routes and to calculate frequent-travel zones within these Roman and early-medieval route networks. This evidence-based approach excludes historical presumptions (e.g. regarding transport methods and known trade centres) as much as possible and aims to create a spatial framework for further research on Roman and early-medieval long-distance trade networks in north-western Europe.

In the last decades the amount of data on early-medieval Europe has grown substantially (McCormick, 2008). New methods and techniques from the sciences (e.g. geosciences) and humanities (e.g. archaeology) allow us for the first time to analyse and compare vast amounts of data. Davis and McCormick (2008) rightly stated that the way forward for 21st century research of the Early Middle Ages is to learn to collaborate better within and across disciplines such as archaeology, history, economics, biology and the computer sciences. Kristiansen (2014) recently advocated the important role of Big Data in the future of archaeological method and theory. This paper is set against these theoretical backgrounds and aims to provide a first step in analysing large-scale dendrochronological and archaeological data in order to increase our understanding of Roman and early-medieval long-distance transport (changes) in north-western Europe.

3. Material

3.1. Past route networks

Roman and early-medieval route networks for the Netherlands have been modelled by Van Lanen et al., in 2015 (Fig. 1). Land and water routes for CE 100 and 800 were calculated by combining network friction with archaeological data. Network friction calculates landscape prerequisites for probable route networks based on a number of large-scale environmental datasets: palaeogeography of CE 100 and 800, the geomorphological map of the Netherlands, the soil map of the Netherlands and the height model of the Netherlands (Van Lanen et al., 2015a).² Route networks were calculated using archaeological data on settlements, burial sites, shipwrecks, infrastructure and isolated finds, which were extracted from the Archaeological Information System of the Netherlands (ARCHIS; Roorda and Wiemer, 1992; Wiemer, 2002). The modelled route networks have been validated against actual finds of infrastructure (e.g. roads, revetments, jetties, dikes) and isolated finds (i.e. individual finds without clear archaeological context; Fig. 2). Given the fact that 89.2% and 85.4% of the infrastructural and 81.7% and 72.2% stray finds are located in the modelled route networks, this approach is very promising when applied to lowland areas such as our study region (Van Lanen et al., 2015b).

3.2. Dendrochronological reference data

For the current research we used the dendrochronological datasets of oak resulting from two previous studies regarding the provenance of timbers excavated in the Netherlands (Jansma et al., 2014; Jansma and Van Lanen, 2016). These were combined with all other dendrochronological time series of oak with end dates

between 100 BCE and CE 1100 available through the heritage-based Dendrochronological repository DCCD (Jansma et al., 2012; Jansma, 2013) (Supplementary Material A).³ The selected time series already had been dated absolutely by matching them to absolutely-dated reference chronologies. The statistical foundations of these dates, their further chronological interpretations and details about the reference chronologies that were used can be found in Supplementary Material B and the metadata sections of the project file stored in the DCCD repository (P:2016503).

3.3. Archaeology

Archaeological data were derived from the Archaeological Information System of the Netherlands (ARCHIS) and the Electronic Archiving System (EASY) (Fig. 2). ARCHIS contains a national overview of excavated archaeological finds (Roorda and Wiemer, 1992; Wiemer, 2002).⁴ Van Lanen et al. (2015a) expanded and improved this datasets by digitizing and including results of newly published research.⁵ EASY is an online archiving system for depositing and downloading research data from a variety of scientific disciplines (i.a. archaeology).⁶ Since 2007 archaeologists are obliged to upload their research data to EASY using the e-depot of Dutch Archaeology (EDNA). EASY can be used to search and download research reports as well as database and GIS files.

4. Method

4.1. Dendrochronology

Some Roman and early-medieval imported timber groups (TGs) already were identified prior to this study (Domínguez-Delmás et al., 2014; Jansma et al., 2014; Jansma and Van Lanen, 2016). The aim was to extend these and to identify new TGs. To this end dendrochronological comparisons were made between the measurement series and already identified TGs, and between the ungrouped series themselves, using standard dendrochronological cross-dating statistics. The variables we used are Student's t -values (t_H) based on Pearson's cross-correlation coefficients (r) between measurement series detrended using a logarithmic transformation (Hollstein, 1980), and the percentage of Parallel Variation (%PV) with its significance level p (Eckstein and Bauch, 1969). Tree-ring series representing elements derived from the same tree were averaged into single-tree series (TS). Following the approach outlined in Jansma et al. (2014) the TS, if possible, were assigned to TGs.

It should be noted that the results of this approach are minimum estimations based on stringent criteria. Due to the high threshold values defined for t_H and %PV in some cases timbers belonging to a particular TG will not be selected for inclusion into this TG (Jansma et al., 2014). This means that the number of TSs assigned to a TG may be an underrepresentation of the actual number of timbers

³ The international DCCD repository amongst other contains thousands of datasets derived from dendrochronological research in the Netherlands. It can be accessed through: <http://dendro.dans.knaw.nl>.

⁴ ARCHIS is maintained by the Cultural Heritage Agency of the Netherlands (RCE) and was created in 1992. Website: <https://archis.cultureelerfgoed.nl/#/login>.

⁵ Van Lanen et al. (2015a) digitized data from the following publications: Miedema, 1983; Knol, 1993; Bechert and Willems, 1995; Verwers, 1998; Van Beek, 2009; Gerrets, 2010; LGL World Heritage Database, 2010; Verlinde and Hulst, 2010; Dijkstra, 2011 and Van der Velde, 2011b.

⁶ EASY is maintained by Digital Archiving and Networked Services (DANS) which is part of the Royal Netherlands Academy of Arts and Sciences. Website: <https://easy.dans.knaw.nl/ui/home>.

² For a detailed description of the network-friction method and references to these individual datasets please see the original publication: Van Lanen et al., 2015a.

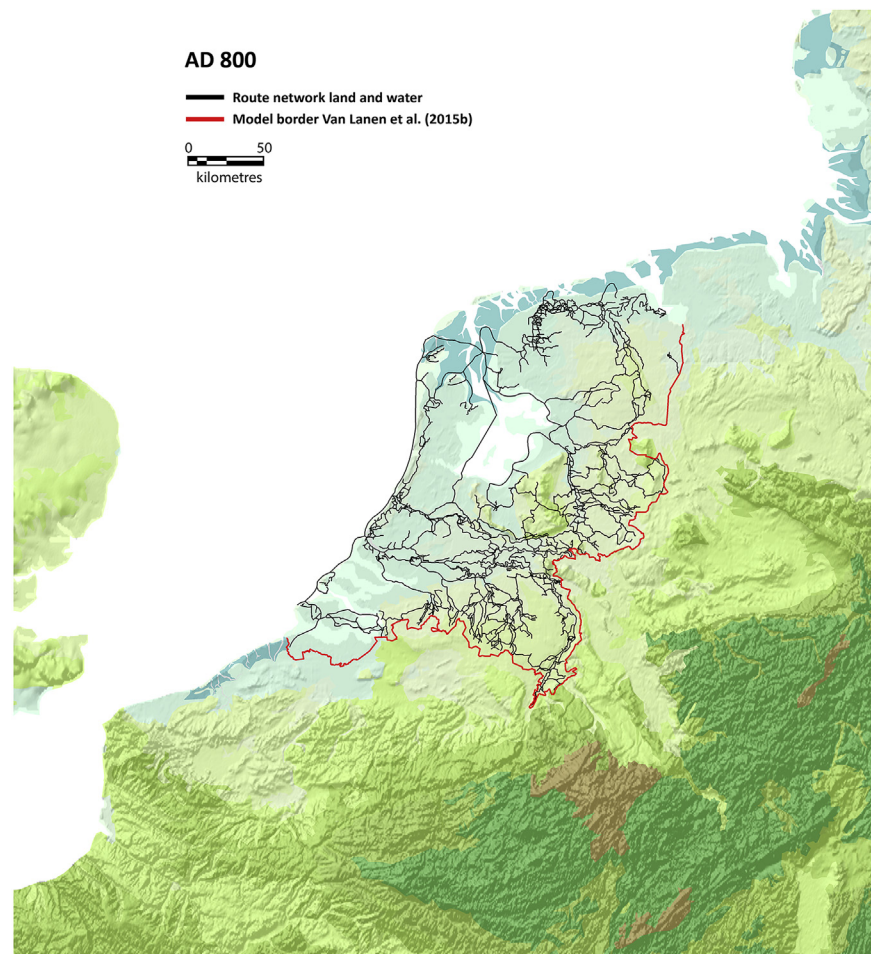
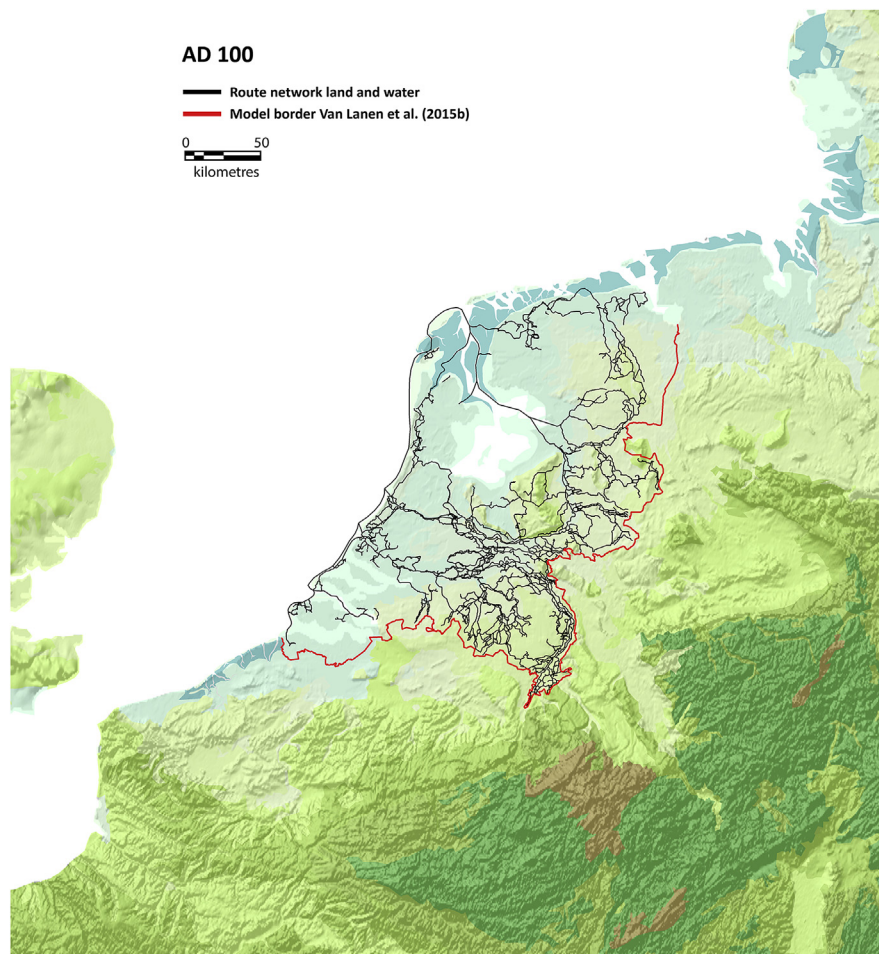


Fig. 1. Modelled Roman (CE 100) and early-medieval (CE 800) route networks (land and water routes) in the present-day Netherlands. Adapted from [Van Lanen et al., 2015b](#).

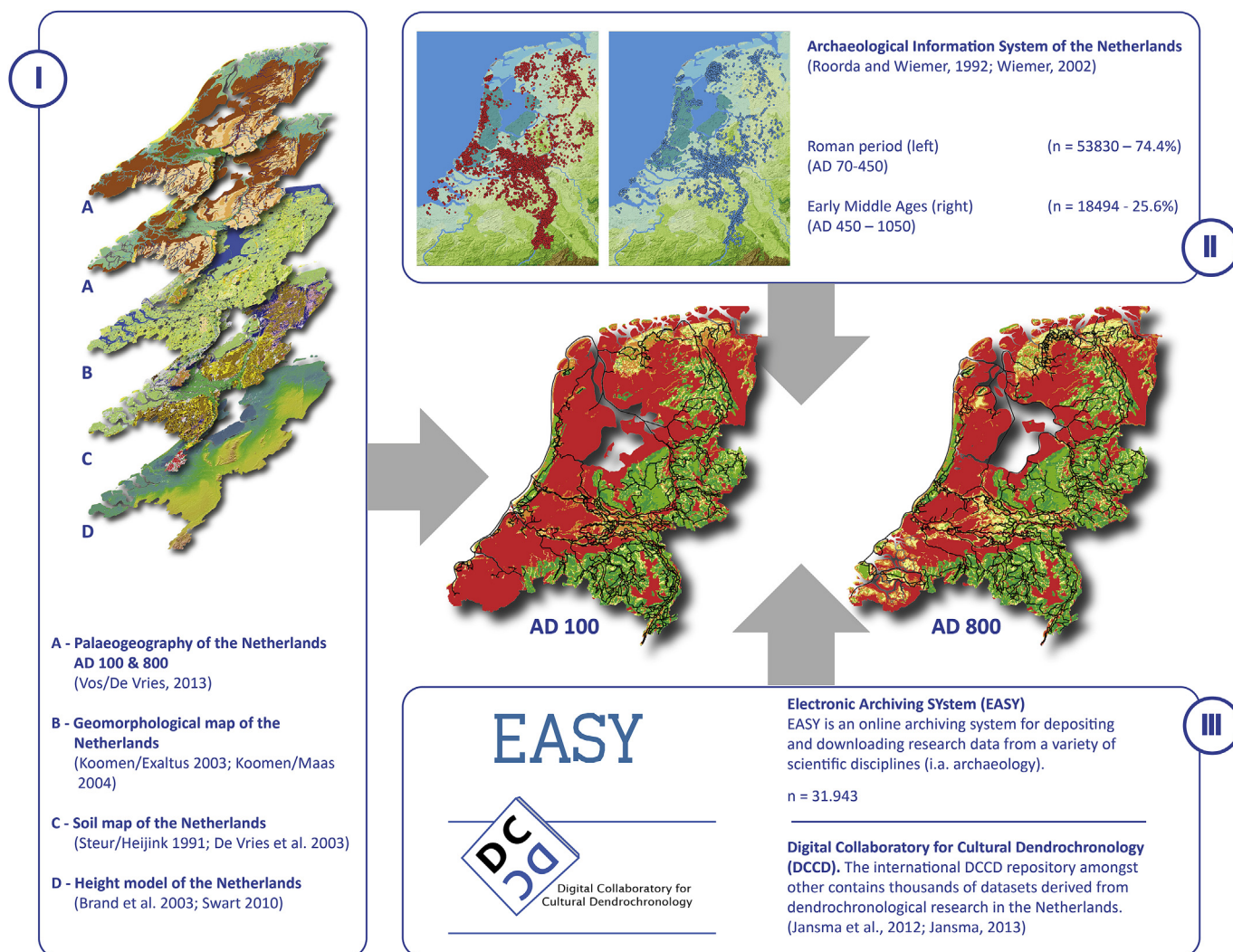


Fig. 2. Underlying large-scale datasets used to calculate frequent-travel zones in the current paper: I) environmental data were used to calculate network-friction values for the Roman and early-medieval periods, CE 100 and 800 respectively (central maps), II) route networks were calculated by using archaeological data on settlements, burial sites, shipwrecks, infrastructure and isolated finds (central maps) and III) frequent-travel zones were calculated using data derived from DCCD and EASY.

belonging to this group. Our reconstruction of imported timbers therefore represents the core of long-distance transport networks of imported timbers.

4.2. Calculating frequent-travel zones

Frequent-travel zones were calculated based on the spatial and chronological distribution of the imported timbers. These zones were derived from route-network data depicting two time slices that are centuries apart: CE 100 and 800 respectively (Fig. 2). Since our aim was not to identify annual to decadal changes of wood provenance, but to reconstruct general long-distance wood transport during the Roman Period and Early Middle Ages, in the analyses next to absolutely dated dendrochronological series we also included series for which only a *terminus-post quem* (TPQ) date had been established. For each individual wooden element (e.g. plank, stave) we recorded the year in which the oldest and youngest measured tree ring was formed, the (estimated) felling date, the provenance, and the find-location coordinates (Supplementary material B). Find locations were compared to settlement data developed by Van Lanen et al. (2015a). Provenance areas of the timber groups were derived from existing publications and/or

deduced from the geographical distribution of the TGs within the Netherlands. In the few cases where dendrochronology had resulted in ambiguous results (e.g. series BAT00041: felling date in 803 ± 8 or after 815 ± 8 ; Supplementary material B) the youngest date was selected for further analyses.

Using the dendroarchaeological results we increased the chronological resolution of the route-network data by calculating frequent-travel zones for all Roman and early-medieval subperiods as defined by the Archaeological Basic Register (ABR).⁷ Although ABR periodization suggests very specific time intervals, these are not defined by one specific (cultural) event and therefore do not have the same dating resolution as dendroarchaeology. To compensate for this we focussed our research on an extended time interval of 100 BCE–CE 1100 (see section 3.2). Based on the chronological and spatial data frequent-travel zones were calculated using the shortest distance between provenance area and find

⁷ The Archaeological Basic Register is maintained by the Cultural Heritage Agency of the Netherlands and aims at the standardization of archaeological terms used in the Netherlands. Website: http://cultureelerfgoed.nl/sites/default/files/downloads/dossiers/abr_website2.pdf.

location within the Roman and early-medieval route networks. Frequent-travel zones for the Roman periods were calculated based on the Roman route network (ca. CE 100), for the early-medieval periods the route network around CE 800 was used. It should be noted that these calculations only were done for the Netherlands, since no similar detailed route-network data are available for adjacent regions in Belgium, France or Germany. For the latter we assume that the rivers constituted the main lines of transport (see section 2).

4.3. Non-wood imported goods

Besides imported timbers, pottery and stone household goods were used as proxies to determine the spatial development of route networks through time. These proxies qualitatively were compared to the established import patterns of timbers to deduce the variability of the patterns. In this case quantitative analyses were impossible since no repositories with detailed data on objects of daily use are available and therefore no additional frequent-travel zones or spatial overviews could be calculated. We selected commodities typically found in almost every Roman and early-medieval settlement, such as pottery, and stone tools and household items (e.g. quern stones, mortars, grindstones, wetstones). More luxury goods such as jewellery, weapons and dress accessories were excluded from the analyses since their exchange mechanisms were probably much more complex. Household objects such as glassware and metal objects were also omitted from the analyses, since their quantities are usually limited and determining their provenance in most cases requires archaeometrical analyses (e.g. Dijkstra, 2012; Roxburgh, 2013).

We selected sites located in the western, central and eastern river areas since these correspond to the modelled frequent-travel zones. Moreover these areas have been intensively investigated and the archaeologically-known settlements in these areas date from all Roman and early-medieval subperiods defined in this study. In addition these areas contain a variety of settlement types, ranging from agrarian to military and from farmsteads to elite sites, and also were inhabited during the 4th–5th century, which is rare in the Netherlands.⁸ We also included sites from the IJssel area in the comparison since the river IJssel, as a new branch of the Rhine, became a vital part of the long-distance transport system during the Early Middle Ages (e.g. Groothedde, 2013). Based on finds of pottery and stone household goods in all areas import patterns were reconstructed and compared to the dendroarchaeological results.

5. Results

5.1. Dendroarchaeology

5.1.1. Imported timbers

A total of 465 individual wooden elements were classified as imported during the Roman and early-medieval periods (202 and 263 elements respectively; Table 1; Fig. 3; Supplementary material B). A mere 16 elements have a *terminus post quem* (TPQ) date for the youngest measured ring in the early-Roman period (ERP; 12 BCE – CE 70). The vast majority of the Roman imported timbers have absolute or TPQ dates in the middle-Roman period (MRP; CE 70–270; $n = 190$). No material could be ascribed to the late-Roman

period (LRP; CE 270–450) and to the early-medieval A period (EMPA; CE 450–525). For the following early-medieval periods B (EMPB; CE 525–725) and C (EMPC; CE 725–900) respectively 98 and 132 elements can be classified as imports. The early-medieval period D (EMPD; CE 900–1050) is represented by 34 imported oak elements. During the Roman period we inferred that oak was imported from the German Rhineland, the Ardennes and Scheldt region, whereas the early-medieval oak timbers were likely derived from the German Rhineland and the Ardennes (Fig. 4).

5.1.2. Transport routes

Based on these imported timbers we could infer that three long-distance transport routes were used during the Roman and early-medieval periods: the Rhine (oak from the German-Rhineland, the Meuse (oak from the Ardennes) and the Scheldt (oak from Flanders) (Table 2). In the ERP and MRP the majority of the imported timbers was transported along the Meuse (Fig. 5). In the ERP all timbers were dated TPQ, with exception of the Meuse material found in the south-eastern part of the research area (Fig. 5). Therefore the estimation of oak imports during this period most likely is an overestimation, since these timbers also could have belonged to trees cut down during the later MRP. The MRP is characterized by a strong increase of both Rhine and Scheldt transport (Table 2; Fig. 5). During the EMPB and EMPC imports were brought here using the Rhine exclusively. This pattern drastically changed during the EMPD, when all imports followed the Meuse (Table 2; Fig. 5).

5.1.3. Spatial distribution

A single ERP-dated piece of imported timber from the German Rhineland was found in the western part of the Netherlands (Fig. 6). The majority of the timbers from the ERP originate from the Ardennes and have been found in the vicinity of the Meuse. Material from the Scheldt was used only locally along the coast in Belgium during this period (Fig. 6). It should be noted that with the exception of the timbers excavated in the south of the research area, all wood from this period is TPQ dated. MRP timbers from the German Rhineland and Ardennes regions have been found all along the Rhine and Meuse respectively. Material from the Scheldt was used near the Flemish and adjacent Dutch coasts and more inland in the central Netherlands near the city of Utrecht (Fig. 6).

In the EMPB only timbers from the German Rhineland were imported and distributed along the Rhine and the Dutch coast, and even found their way into Denmark (Fig. 7). The EMPC is characterized by similar patterns, with the addition of a connection to southeast England. Imported timbers from the following EMPD exclusively originate from the Ardennes region and were used along the Meuse, the coastline, the central parts of the Netherlands and the river IJssel, which by then probably had developed sufficiently to be navigable (e.g. Cohen et al., 2009; Groothedde, 2013, Fig. 7).

5.2. Frequent-travel zones

Based on the spatial distribution of timber finds two possible frequent-travel zones could be calculated for the ERP: one running from south to northwest and following the rivers Meuse and Rhine, and one running from east to west following the river Rhine. Since no route-network data is available for Belgium and wood from the Scheldt region probably only was applied locally, no frequent-travel zones could be calculated for Scheldt material (Fig. 8). For the MRP three frequent-travel zones could be calculated. The first runs from the south in a north-western direction along the river Meuse and the estuary of the Rhine. This frequent-travel zone also suggests the use of the small river Dommel in the south (Fig. 8), however a land-

⁸ Although 4th–5th century occupation is very limited outside the river area, examples of such sites can be found in other parts of the Netherlands as well (Deeben et al., 2006; Zoetbrood et al., 2006; for more specific references see: Supplementary material D).

Table 1
Overview of number of elements per ABR period divided by provenance area. Abbreviations are used for the following ABR periods: Early, middle, and late-Roman period (ERP, MRP and LRP, respectively), and early-medieval periods A, B, C and D (EMPA, EMPB, EMPC and EMPD, respectively).

Provenance area	ERP (12 BCE – CE 70)	MRP (CE 70–270)	LRP (CE 270–450)	EMPA (CE 450–525)	EMPB (CE 525–725)	EMPC (CE 725–900)	EMPD (CE 900–1050)
Ardennes	13	90	0	0	0	0	34
German Rhineland	1	54	0	0	98	132	0
Scheldt region	2	46	0	0	0	0	0
Total	16	190	0	0	98	132	34
Absolutely dated series	1	156	0	0	9	24	19

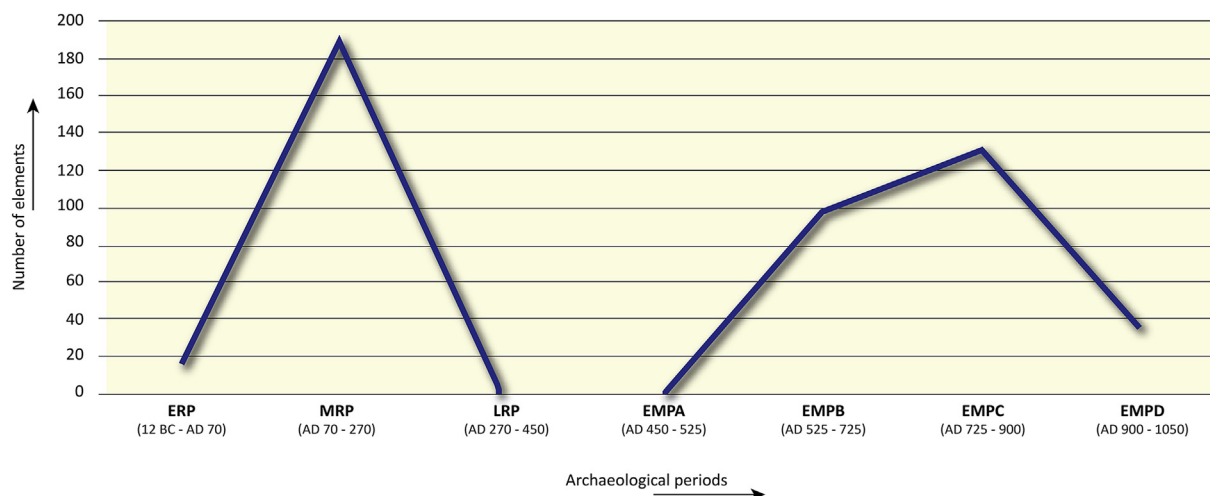


Fig. 3. Number of imported and dendrochronologically dated (individual) wooden elements (e.g. plank, stave, pile) per Roman and early-medieval subperiod excavated in the present-day Netherlands ($n = 465$). The reference collection contains measurement series from a total of 4260 wooden elements.

route connection south of the Peel was calculated to be equally probable. The second frequent-travel zone runs from east to west following the Rhine. The third zone follows the coastline in the Netherlands. Based on the route-network data this frequent-travel zone is placed offshore, however the river vessels excavated near Utrecht from which this route was deduced (two river barges and a punt) were not seaworthy, which suggests a (not yet reconstructed) inland connection (Jansma et al., 2014, Fig. 8).

The EMPB was characterized by a frequent-travel zone that runs from the southeast to the west following the Meuse estuary and the western part of the Rhine. In the western part of the study area this zone branches to the north and south (Fig. 9). Based on the dendroarchaeological results and available palaeogeographical reconstructions (Vos et al., 2011, 2015; Vos and De Vries, 2013) two probable sections were added to the route network developed by Van Lanen et al. (2015b): one in the southwest and one in the west just north of the current city of Amsterdam (Fig. 9, dashed lines). Both routes would provide a navigable inland connection. This frequent-travel zone may have had an international connection with Ribe (Denmark). For the EMPC a similar pattern is visible: a single frequent-travel zone runs from east to west. Again, this frequent-travel zone branched out to the north and south (Fig. 9). Similar to the preceding period two inland connections (a southern and western trajectory) were added to the route-network data from Van Lanen et al. (2015b; Fig. 9, dashed lines). For the EMPD a single frequent-travel zone was identified that runs from the southeast to the north of the Netherlands, following the rivers Meuse, Rhine, Vecht and IJssel. Based on timbers excavated in the United Kingdom a likely additional frequent-travel zone was reconstructed, running to the west and southwest, following the Hollandse IJssel and the Meuse estuary, and continuing to the North Sea (Fig. 9, dashed lines).

5.3. Imported pottery and stone household goods⁹

During the ERP imported pottery was almost absent in rural settlements (<1%; Willems, 1986; Bosman, 1997) (Table 3). Both in the river area (the region in the Netherlands between Rhine and Meuse) and near the river IJssel nearly all pottery was locally produced and handmade (e.g. Sier and Koot, 2001; Hermesen, 2007; Van Renswoude and Van Kerckhove, 2009) (Table 3; Figs. 10 and 11). Roman military sites are an exception and here an abundance of imported pottery originating from different parts of the Roman Empire is present (90–95%; e.g. Zandstra and Polak, 2012). During the MRP the percentage of imported pottery rose dramatically, in rural sites reaching values of ca. 85% and in the Roman city *Forum Hadriani* even reaching 97% (Driessen and Besselsen, 2014, p. 324, fig.II-1.1) (Table 3). In the IJssel area imports were still rare (<1%) (Table 3). During the LRP the import percentage in the River area dropped to 50%. These imports mainly originated from kilns in the Eifel region in current Germany. In the IJssel area during this period the percentage of imported material rose to ca. 5% (Hermesen, 2007, Table 3).

Data on imported pottery dating to the EMPA are scarce. Based on the few known sites (e.g. Katwijk-Zanderij and Wijk bij Duurstede-De Geer) a fair amount of imported pottery is expected in the river area (ca. 50%; Van der Velde, 2008; Aarts et al., in prep.) and almost none in the IJssel area (<1%; Vermeulen et al., 2009, Table 3). During the EMPB import percentages in the river area rose again to 85–95% (Van Grinsven and Dijkstra, 2005; Hemminga and

⁹ For a detailed description of import patterns and provenance areas regarding Roman and early-medieval pottery and stone household goods per ABR period, including more references see: [Supplementary Material C, D](#) and the reference list.

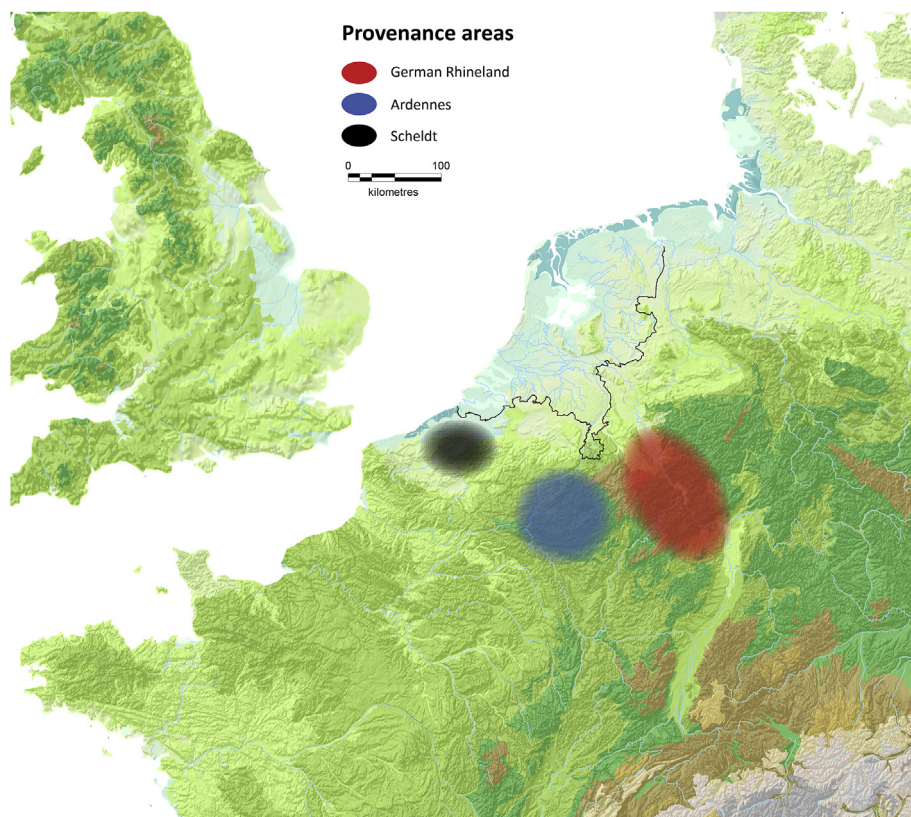


Fig. 4. Inferred provenance areas of imported Roman and early-medieval timbers excavated in the present-day Netherlands. Areas projected on a map showing reconstructed Roman period landscape conditions, including river courses.

Table 2

Percentage of individual timbers per long-distance transport route in each ABR period. Abbreviations are used for the following ABR periods: Early, middle, and late-Roman period (ERP, MRP and LRP, respectively), and early-medieval periods A, B, C and D (EMPA, EMPB, EMPC and EMPD, respectively).

Transport route	ERP (12 BCE – CE 70)	MRP (CE 70–270)	LRP (CE 270–450)	EMPA (CE 450–525)	EMPB (CE 525–725)	EMPC (CE 725–900)	EMPD (CE 900–1050)
Rhine	6.25%	28.42%	0%	0%	0%	0%	100.00%
Meuse	81.25%	47.37%	0%	0%	100.00%	100.00%	0%
Scheldt	12.50%	24.21%	0%	0%	0%	0%	0%

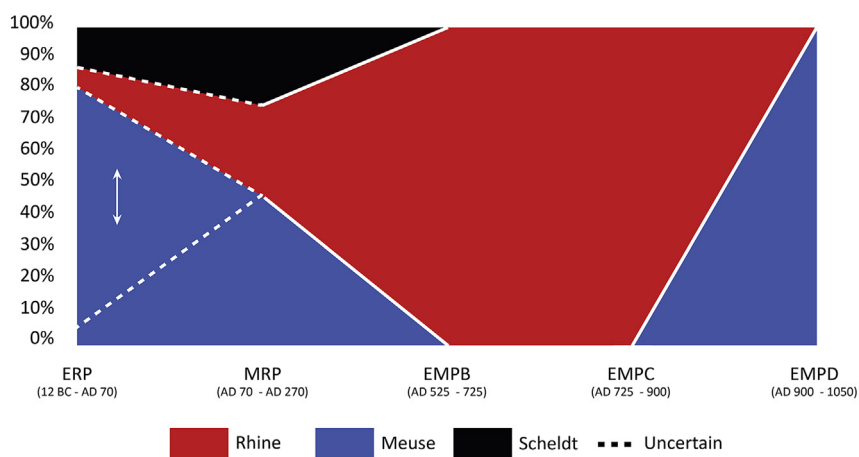


Fig. 5. Relative contribution of each long-distance transport route (Rhine, Meuse or Scheldt) in the distributed timbers per archaeological period. Only periods with imports are projected. Subperiods without absolutely dated material are marked by a dashed line. Contribution of the Meuse as a long-distance trade route in the ERP period is uncertain and could vary between 0 and 80%.

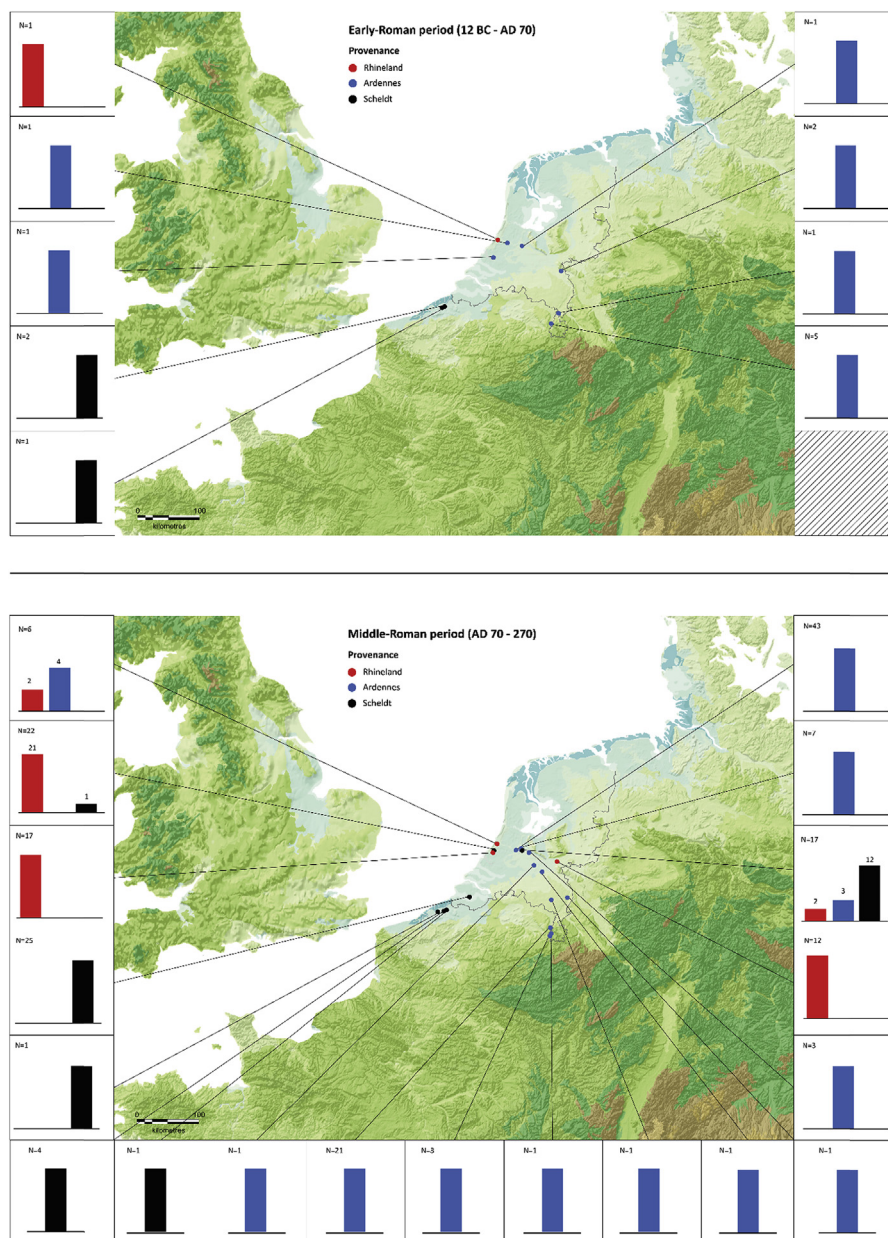


Fig. 6. Find spots of imported timber during the early- and middle-Roman periods (Table 1). For each site the number of individual wooden elements is given, as well as their provenance (red = German Rhineland, blue = Ardennes, black = Scheldt region). For the ERP period the elements are based on TPQ dates only, with the exception of sites in the south-eastern part of the research area. Timbers from the other sites might therefore also (probably) date to the MRP period (see: [Supplementary material B](#)). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Hamburg, 2005; Hemminga, 2009; Nokkert et al., 2009; Van der Velde, 2011a).¹⁰ In the IJssel area imports also increased slightly, to 15% in Zutphen (Groothedde, 1996) and a little further up north to 7.6% in Deventer-Colmschate (Groenewoudt, 1987). During the EMPC import percentages dropped to 50% in most river-area sites (Jezeer and Jongma, 2002; Nokkert et al., 2009, Table 3). The main exception is Dorestad where the amount of imported wares only decreased slightly to 85% (Van Es and Verwers, 1980, Table 3; Van Doesburg and Verwers, 2004; Dijkstra, 2012, fig. 4.102). During

the EMPD the overall import percentages remained unaltered (Table 3). However this phase in the Rhine-Meuse and IJssel areas is characterized by the influx of pottery from the Ardennes, initially in relatively small numbers but from the 11th century onwards in larger quantities (up to 20%; e.g. Verhoeven, 1990; Van der Velde, 2001; Dijkstra and Van Benthem, 2004; Van der Kamp, 2011; Van Renswoude, 2011; Dijkstra, 2012; Van Renswoude and Schurmans, 2015).

Imported stone household goods have been found in both rural and military sites dating to the Roman period, EMPA and EMPB. Quernstones were imported from the German Rhineland (Eifel region) and wetstones were either of local or imported (Eifel and Ardennes) origin (Vos, 2000; Sier and Koot, 2001; Van Renswoude and Van Kerckhove, 2009; Driessen and Besselsen, 2014). During

¹⁰ Just north of the Frankish frontier (± 40 km) this ratio drops to ca. 50%. The sites of Kootwijk (70–80%) and Hoog-Buurl (ca. 90%) are exceptions on this rule (Groenewoudt, 1987), which could point to the presence of an important land route (Heidinga, 1987).

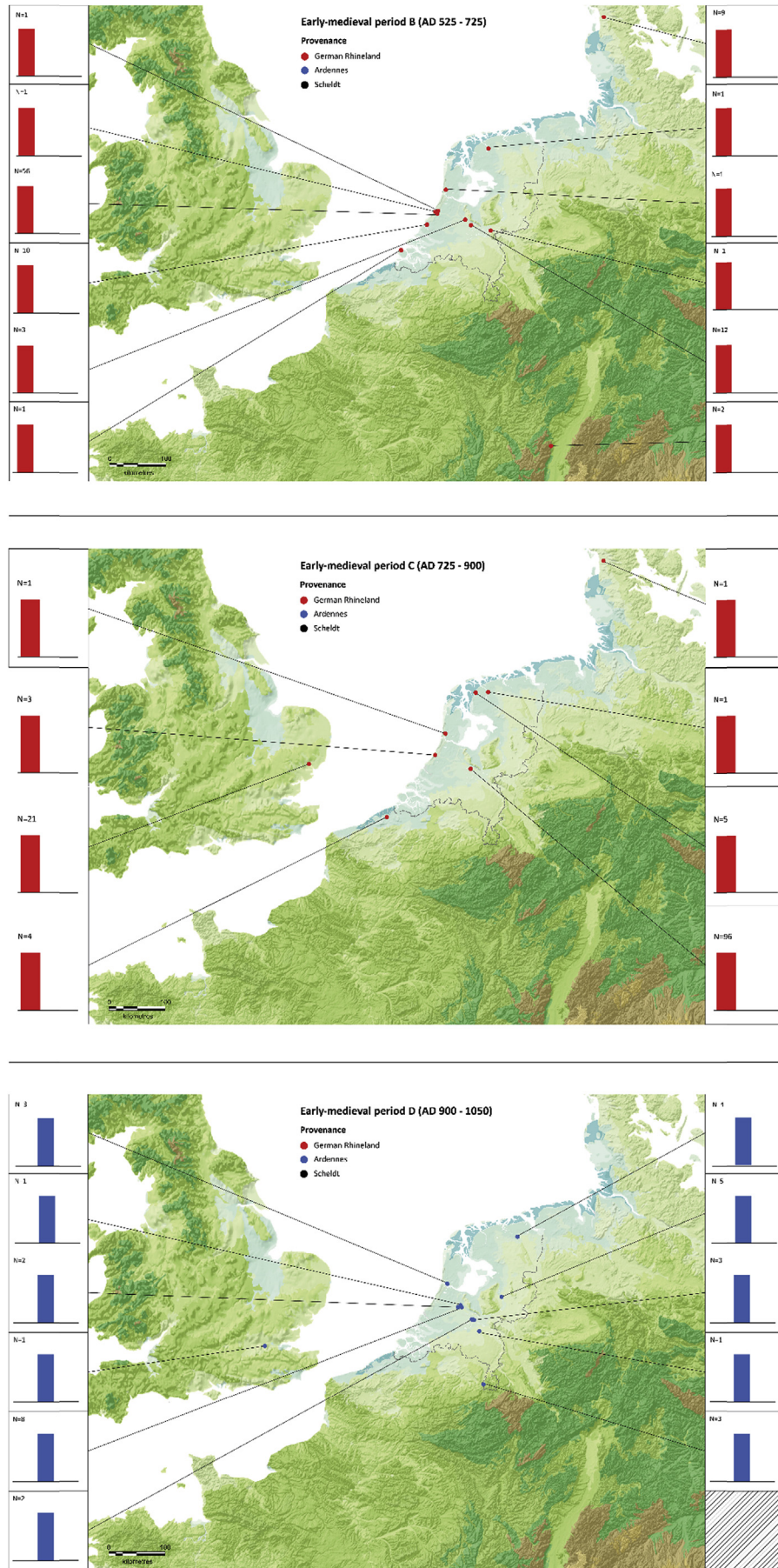


Fig. 7. Find spots of imported timbers dating to the early-medieval B, C and D periods (Table 1). For each site the number of individual wooden elements is given, as well as their provenance (red = German Rhineland, blue = Ardennes, black = Scheldt region). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

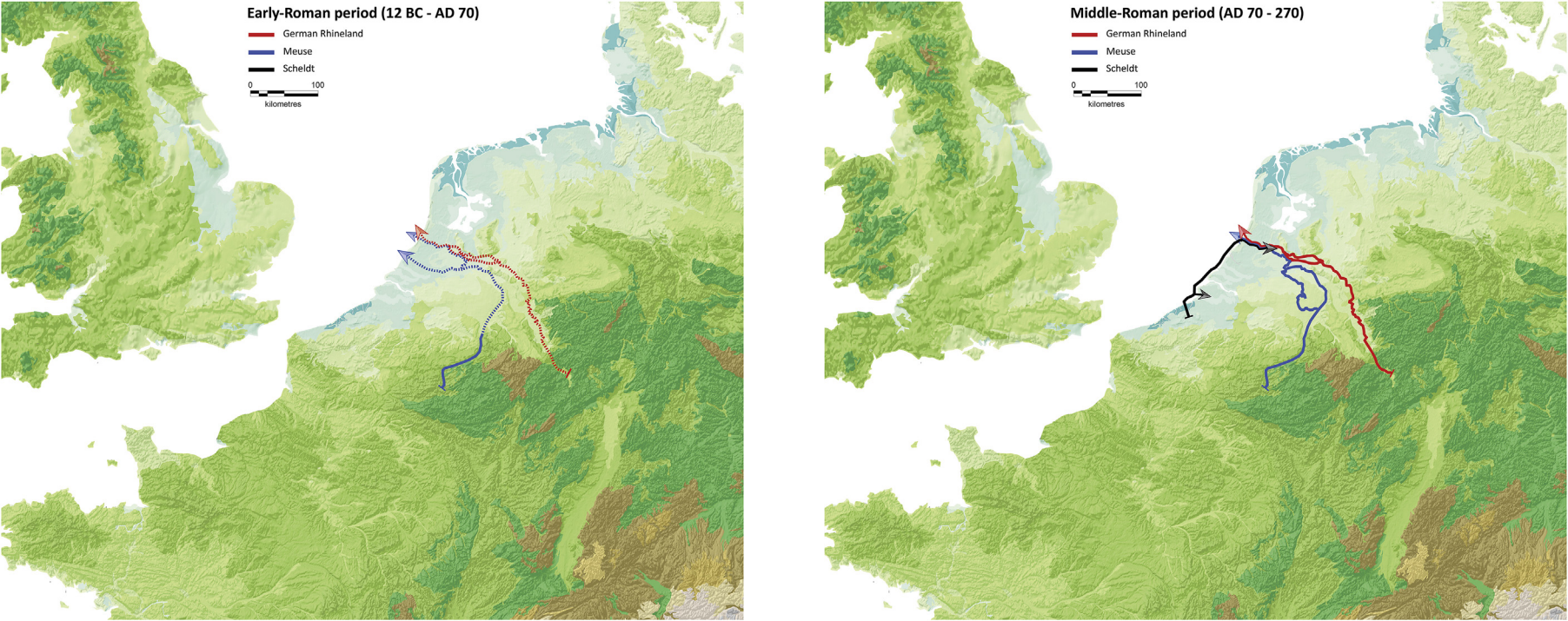


Fig. 8. Reconstructed Roman-period frequent-travel zones in the present-day Netherlands. For the ERP period the elements found are based TPQ dates only. Timbers from this region might therefore actual reflect later MRP frequent-travel zones (dashed lines) (see: [Supplementary material B](#)).

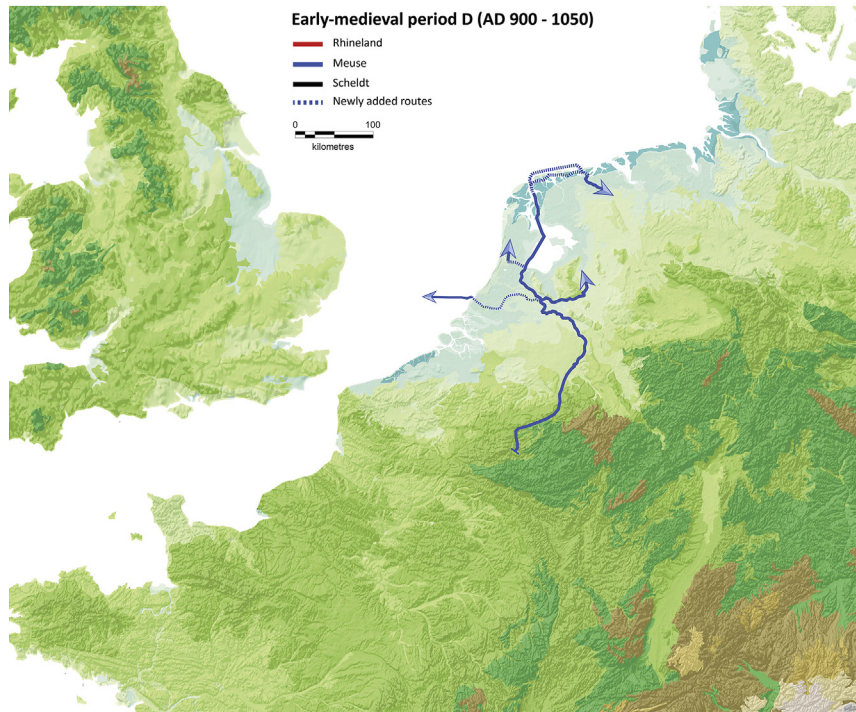
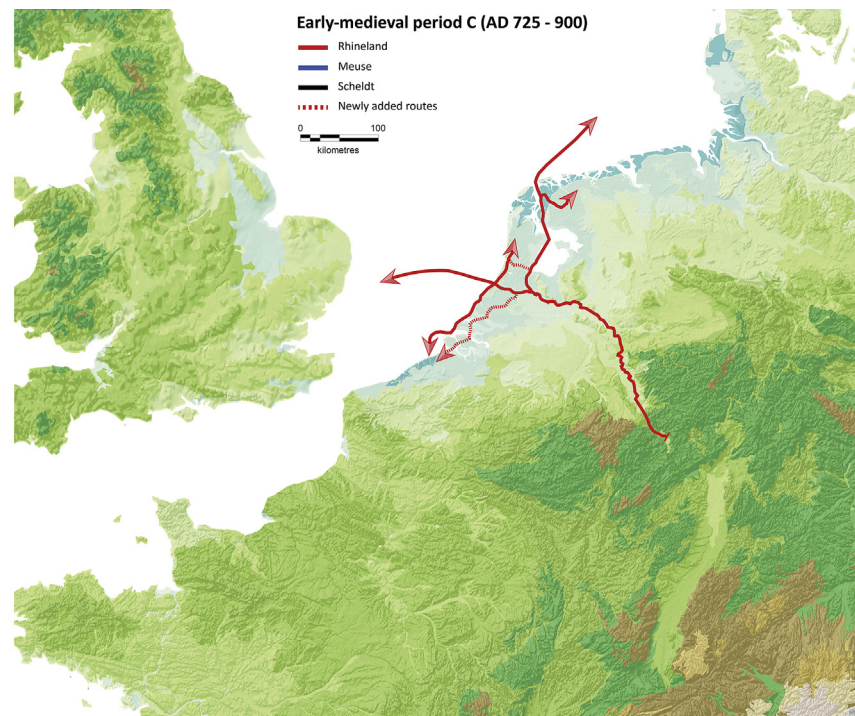
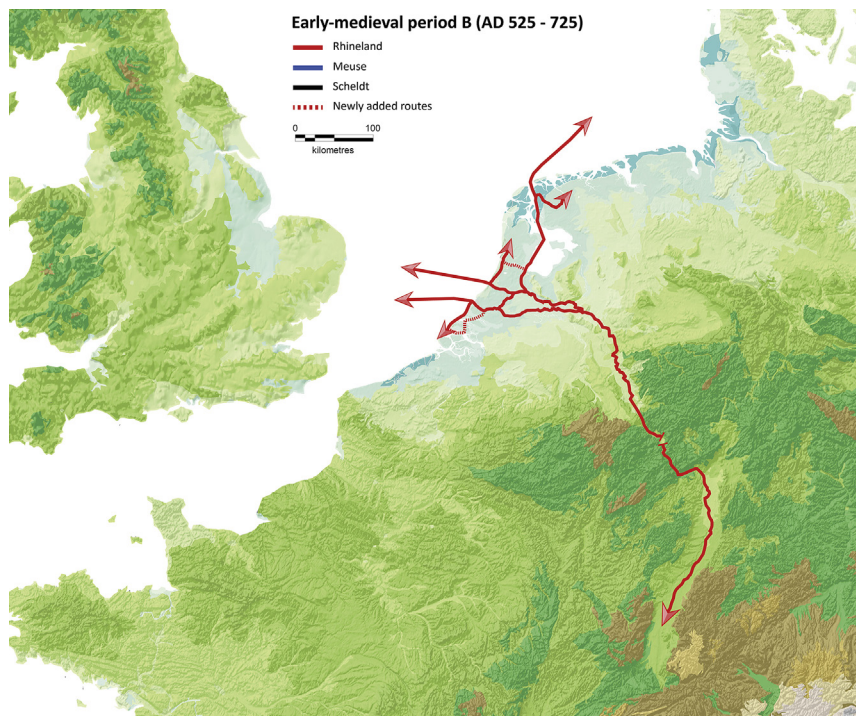


Fig. 9. Reconstructed early-medieval frequent-travel zones in the present-day Netherlands.

Table 3
Percentage of imported versus local pottery for each ABR period (averages based on [supplementary material C](#)). Abbreviations are used for the following ABR periods: Early, middle, and late-Roman period (ERP, MRP and LRP, respectively), and early-medieval periods A, B, C and D (EMPA, EMPB, EMPC and EMPD, respectively).

Period	River area		Ijssel area		Dominant provenance
	Local	Imported	Local	Imported	
ERP (12 BCE – CE 70)	99%	1%	99.5%	0.5%	Insufficient data
MRP (CE 70–270)	15.0%	85.0%	99.0%	1.0%	Gaul, Meuse, Mosel and Scheldt valleys and German Rhineland
LRP (CE 270–450)	50.0%	50.0%	95.0%	5.0%	German Rhineland (especially Eifel region)
EMPA (CE 450–525)	50.0%	50.0%	99.5%	0.5%	German Rhineland (especially Eifel region)
EMPB (CE 525–725)	10.0%	90.0%	90.0%	10.0%	German Rhineland and area around Bonn
EMPC (CE 725–900)	50.0%	50.0%	55.0%	45.0%	German Rhineland and area around Bonn
EMPD (CE 900–1050)	50.0%	50.0%	55.0%	45.0%	Meuse valley (Ardennes) and German Rhineland

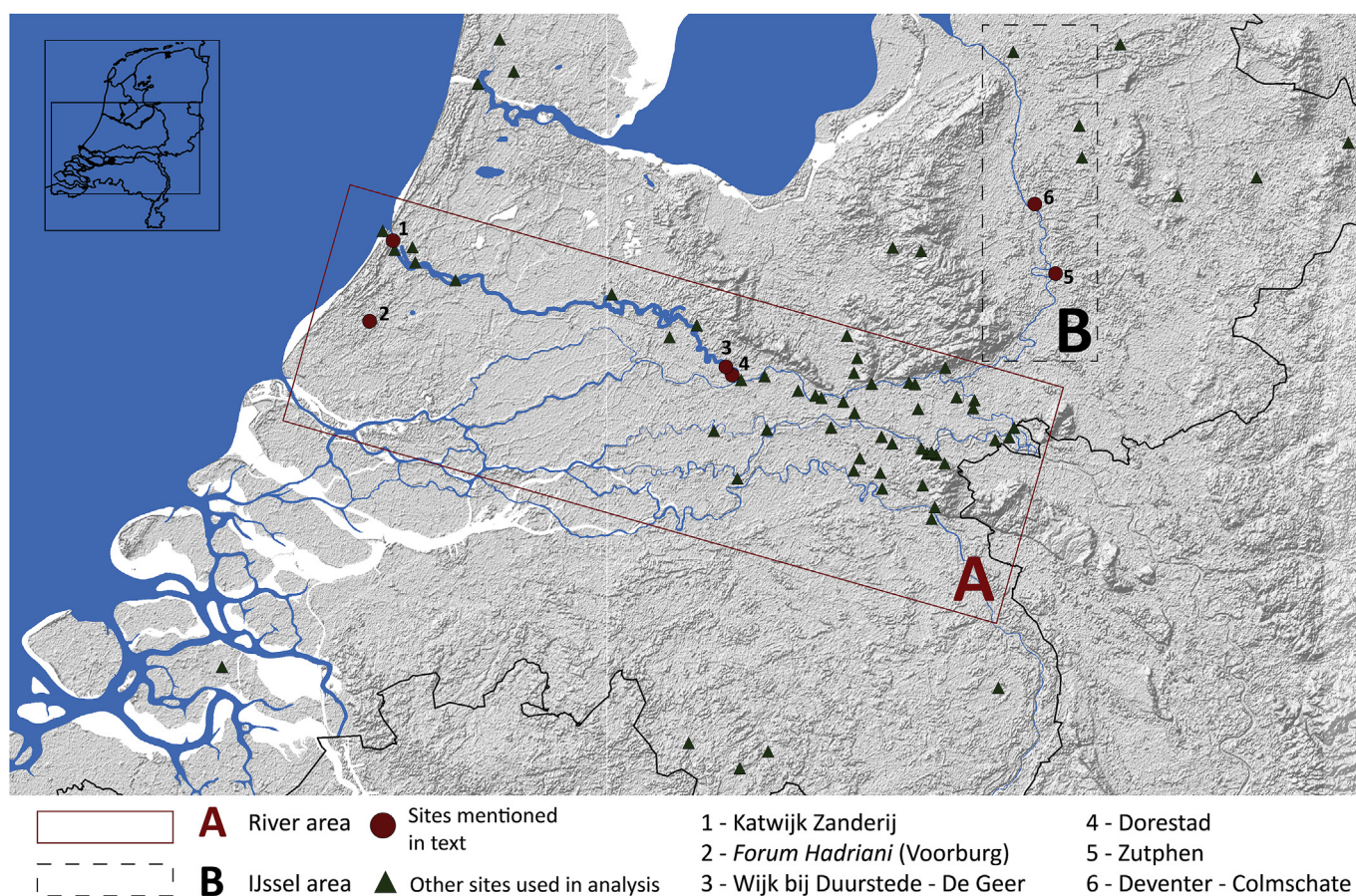


Fig. 10. Overview of sites and areas used to analyse pottery import (section 5.3).

the Roman period *tufa* (volcanic rock) was imported from the Eifel region as a building material, to be applied mainly on military sites and in some cases in *villae*. During the Early Middle Ages stone was mostly extracted from Roman ruins and used for different purposes such as net weights. From the 8th century onwards the types of imported stone objects increased and included quernstones from the Eifel region, limestone mortars from the Meuse valley, grindstones from Northern Germany (Solling area) and wetstones from Southern Norway (e.g. [Kars, 1981, 1983a](#)).

6. Discussion

The results of the qualitative analyses of imported pottery and stone household goods shows some correspondence to the patterns

we established for imported timber ([Figs. 3 and 11](#)). The MRP was most diverse in terms of timber and pottery imports. After the Roman period the provenance of oak timber and pottery shifted towards the German Rhineland and afterwards, during the EMPD, in part towards the Ardennes. The corresponding patterns between imported timbers and pottery suggest that our reconstruction of long-distance transport routes and frequent-travel zones is reliable. However these patterns are difficult to compare since in the qualitative analyses we only focussed on the 'local' (handmade) versus import (wheel thrown) pottery ratio, and not on quantities. Therefore if local pottery production increased and the quantity of imported material remained unaltered, the calculated import percentage would decrease despite transport routes remaining unchanged. However this does not affect qualitative results such as

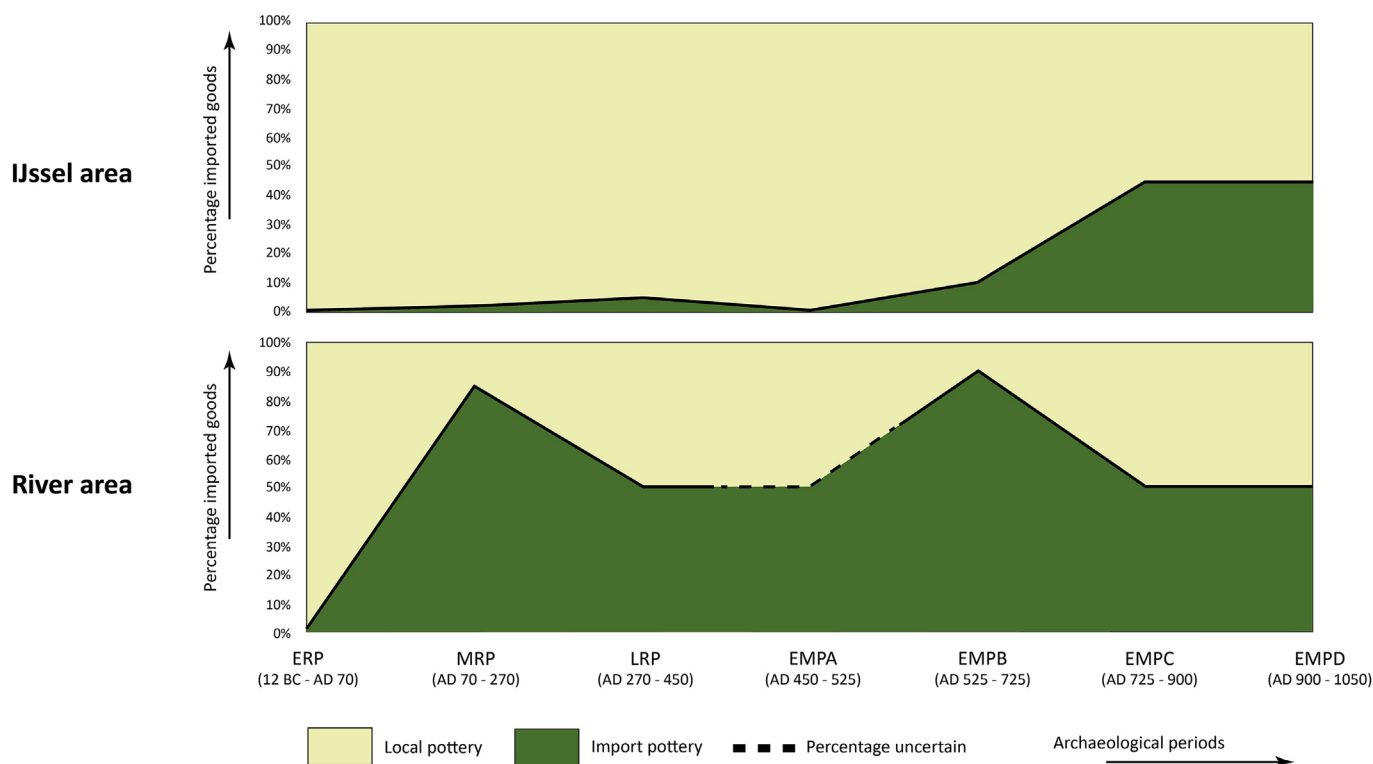


Fig. 11. Percentages of imported pottery in the Dutch river area and along the IJssel. The dashed line reflects a high degree of uncertainty (i.e. percentage based on < 3 well-documented sites).

shifting provenance areas and import diversity.

It has been established already that during the Roman period part of the imported timbers excavated in the present-day Netherlands originate from the German Rhineland and the Scheldt basin in Flanders (Belgium; Domínguez-Delmás et al., 2014; Jansma et al., 2014). Visser (2015) recently deduced that timbers used in ca. CE 125 in a military road constructed along the Dutch *limes* were derived from the area between Venlo (the Netherlands) near the river Meuse and Xanten (Germany) near the river Rhine. The results of the current study, based on a larger and updated dataset (Supplementary Materials A and B), indicate that these timbers originated further south in the Ardennes and were transported northwards along the Meuse (Table 1; Fig. 8). Imported oaks used in Roman river barge *Woerden 7*, previously thought to have been brought here along the Rhine from Central Germany (Vorst, 2005, 32), also must have originated from the Ardennes.

With the exception of the south-eastern Netherlands the datasets contain no absolutely dated imported timbers from the ERP. Since we included TPQ-dated timbers in our analyses to calculate frequent-travel zones, the spatial distribution of imported timbers for this period probably is an overrepresentation (Figs. 6 and 8). We cannot rule out the possibility that these timbers could also date to the MRP and that the patterns shown in Figs. 6 and 8 actually depict the MRP situation. If we exclude the non-absolutely dated timber from our results, long-distance transport during the ERP seems to have been restricted to the river Meuse in the very south of our research area (Fig. 8). This would imply that elsewhere during the ERP only locally-derived oak was used for construction purposes.

Our results indicate that during the Roman period the main long-distance timber transport route in the Netherlands was the Meuse. It started to function during the ERP and remained dominant during the MRP, although during this period the Rhine and Scheldt connections also served as transport corridors. During the

Early Middle Ages this pattern drastically changed, the sole long-distance transport route for imported oak being the Rhine. This pattern continued until the EMPD when the Meuse connection again became dominant (Table 2; Fig. 5). The exact reasons of this transition are not yet clear and beyond the scope of this paper. However, they may well reflect changing organizational structures occurring through alterations of (a) the political situation (e.g. disintegration of the Frankish empire), (b) production methods (e.g. scarcity of raw material in the German Rhineland) (c) landscape setting (e.g. main discharge channel of the Rhine shifting to the south to the current Waal; Cohen et al., 2016) and/or (d) distribution networks (Cologne developing as a new open market place around 957; Aten, 2001). Additionally, the spatial distribution of timber shows that the imports are clearly linked to water-related transport. This pattern is underlined by the results of our import pottery analysis, which shows clear differences between the River and IJssel areas until the latter becomes navigable.

The spatial distribution of imported timber indicates a strong influence of long-distance transport routes on Roman and early-medieval route networks. For most studied periods we have not been able to identify sites containing oak from multiple long-distance sources (Figs. 6 and 7). The exception is the MRP, with sites located on the western part of the *limes* and *Forum Hadriani* near the North-Sea coast yielding timbers from multiple long-distance provenances. However it should be noted that this pattern might not be fully representative, because dendrochronological sampling usually is restricted to a few samples per archaeological structure and is not always done systematically. Additionally the current modelling approach included oak timbers only. Results would benefit from a more extended analysis including all available imported timbers, especially silver fir.

The majority of the modelled Roman frequent-travel zones ran along the rivers Rhine and Meuse, providing southeast to west and

east to west long-distance connections. For the MRP our dataset contains no imported timbers that allow reconstructing a frequent-travel zone connection following the Meuse estuary, which was calculated for all other investigated periods (Figs. 8 and 9). Results also point to the probable existence of routes not included in the route-network data developed by Van Lanen et al. (2015b) (Fig. 9). Frequent-travel zones could not be modelled for the LRP and EMPA due to a lack of imported timbers. This may well reflect the abandonment of Roman *limes* in ca. CE 270 and a simultaneous population decline (e.g. Cheyette, 2008; Jansma et al., 2014). It also implies that at this time only indigenous timber was used.¹¹

Given the similarities between the calculated provenances of timber and pottery, in our research area tree-ring analysis turns out to be very useful for determining long-distance transport routes. However this approach does have its limitations. First of all, the statistical method applied during the grouping of timbers only is successful because it uses high statistical threshold values, which automatically results in underrepresentation. Secondly, in the Netherlands only a fraction of the excavated timbers has been analysed dendrochronologically, which doubtlessly introduces bias in the dendrochronological datasets. Thirdly, preservation circumstances differ strongly between Holocene and Pleistocene areas. In Pleistocene sandy soils, wood preservation is poor and consequently frequent-travel zones cannot be modelled using imported timbers. However the qualitative analysis of imported pottery and stone household goods is not affected by these preservation differences. The analysis of these finds results in similar long-distance transport patterns which shows that the limitations of tree-ring analysis due to preservation circumstances do not prevent it from being a successful method for reconstructing long-distance transport routes.

Long-distance transport routes were reconstructed following the Rhine, Meuse and Scheldt rivers. However, the spatial distribution of timber from the Scheldt region in both the ERP and MRP is limited to coastal zones in present-day Belgium and the southwest Netherlands and, further up north, to shipwreck finds only. Although these latter finds do not directly reflect timber trade, they represent the direct spatial link between the find location and provenance area and are therefore included in the analyses of long-distance transport routes.

Results show that using timber and pottery datasets, long-distance Roman and early-medieval transport routes can be modelled successfully. Through our evidence-based approach we were able to reconstruct the main routes within exchange networks, and to significantly increase our understanding of the spatial dimensions and dynamics of long-distance trade networks. However we have not modelled these trade networks in great detail. To do so would require a much more detailed approach, among others taking into account political and economic settings and settlement hierarchies. In addition, through lack of data, the current model is only able to calculate frequent-travel zones within the present-day Netherlands. Because of contemporary cost effectiveness we have assumed that long-distance transport routes generally correspond with the course of major rivers. Our results support this hypothesis since the imported material and provenance areas we identified in this study are all located in close proximity of these rivers. Results would benefit from a more detailed analysis including route-network data from Belgium and Germany and dendrochronological data on a larger geographical scale.

Our multidisciplinary, integrated approach has shown that

route-network data can be enhanced by combining them with the spatial distribution of imported commodities and palaeogeographical data. This study therefore illustrates the knowledge gain resulting from integration of archaeological and geoscientific data. The comparison of different archaeological material groups greatly increases our understanding of the dynamics of common trade networks and frequent-travel zones within route networks. This research therefore illustrates the knowledge gain that can result from integrated, multidisciplinary *Big Data* approaches of archaeologically excavated materials.

7. Conclusion

Oak timber was brought to the present-day Netherlands from adjacent areas during both the Roman and early-medieval periods. Dendroarchaeological analyses have demonstrated that it was derived from the German Rhineland, the Ardennes and Scheldt region. The provenance regions all were located near major rivers. Based on the distribution of exogenous oak, three long-distance transport routes can be discerned: the Rhine, Meuse and Scheldt rivers. The calculation of frequent-travel zones shows that during the Roman period the Meuse was the most dominant transport line the Netherlands, although during the MRP the role of both the Rhine and Scheldt increased. During the Early Middle Ages these patterns altered and the Rhine clearly was the most import transport route. At the end of the Early Middle Ages (EPMD) a major change occurred and oak was imported solely from the Ardennes region, with the Meuse regaining its transport-geographical importance.

The import patterns of timber show a clear similarity to those of pottery and stone household goods. During the MRP imports and their origin were very diverse, and the Rhine, Meuse and Scheldt were important transport arteries. During the Early Middle Ages this pattern changed and timbers and pottery were imported from the German Rhineland only. The same is true for the majority of stone household goods; only a small number originated from the Ardennes. During the EPMD timbers were no longer imported from the German Rhineland, but were derived from the Ardennes region. This change is also partly visible in the imported pottery from this period, which increasingly originated from the Ardennes, although the import from the Rhineland remained dominant. During this period stone household goods were imported from both areas.

This study shows that systematic studies of archaeologically excavated material combined with evidence-based modelling can be very helpful in reconstructing past long-distance transport routes. Identifying these routes is particularly crucial for our understanding of the spatial dimension of, and within, exchange networks and as a starting point for studying these phenomena. In addition, past transport networks are usually transnational and their reconstruction would significantly benefit from close international collaboration.

Acknowledgements

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¹¹ No indigenous wood was analysed in context of this research, (local) material is however available for the LRP and EMPA through the DCCD.

Dendrochronology/RING Foundation, which contributed the majority of the tree-ring data used in this study. We are also grateful to Flemish Heritage (B), BAAC BV (NL), BIAAX Consult (NL), Dendronet (D) and Dendro.dk (DK), who contributed single datasets. Special thanks go to dendrochronologists and students who developed tree-ring data, which we list here with the affiliations they worked at when the data were developed: Ajolt Brongers (State Service for Archaeological Heritage; ROB), Aoife Daly (Dendro.dk), Petra Doeve (student, RING Foundation), Marta Domínguez-Delmás (RING Foundation), Kristof Haneca (Flemish Heritage), Elsemieke Hanraets (RING Foundation), Josue Pinto Andrade (student, RING Foundation), Tamara Vernimmen (RING Foundation), Yardeni Vorst (student, RING Foundation), Willy Tegel (Dendronet), Sjoerd van Dalen (BAAC BV), Marjolein van der Linden (BIAAX Consult, trainee RING Foundation), Niels van Helmond (student, RING Foundation), Ronald Visser (PhD student, Free University Amsterdam) and Bert Zandbergen (student, RING Foundation). We would like to thank Cathy and Ian Tyers (University of Sheffield and English Heritage/Historic England respectively) for their help in understanding and improving the early-medieval dendrochronological (meta)data from the United Kingdom used in this paper. Tree-ring chronologies and supplementary materials developed within the framework of this paper will be stored in, and will be available for download through, the DCCD repository (<http://dendro.dans.knaw.nl>; project identifier P:2016503).

Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.jas.2016.07.010>.

References

- Aarts, J., Bekkema, M., Botman, A., Van Doesburg, J., Van Driel-Murray, C., Van Es, W.A., Goubitz, O., Groot, M., Van Haasteren, M., Heeren, S., Hensing, W.A.M., Jansma, E., Jezeer, W., Van Lanen, R.J., Lauwerier, R.C.G.M., Van Lith, S.M.E., Scharringhausen, K., Smits, E., Thach, S., Van der Velde, H.M., Verwers, W.J.H., 2016. Wijk bij Duurstede-De Geer in de Romeinse tijd en vroege middeleeuwen. Graven naar de wortels van Dorestad? in prep (working title).
- Aten, N., 2001. Römische bis neuzeitliche Befunde der Ausgrabung auf dem Heumarkt in Köln. *Kölner Jahrb.* 34, 623–700.
- Beichert, T., Willems, W.J.H., 1995. De Romeinse rijksgrens tussen Moezel en Noordzeekust (Utrecht).
- Bosman, A.V.A.J., 1997. Het culturele vondstmateriaal van de vroeg-Romeinse versterking Velsen 1. PhD thesis. University of Amsterdam, Amsterdam.
- Cheyette, F.L., 2008. The disappearance of the ancient landscape and the climatic anomaly of the early Middle Ages: a question to be pursued. *Early Mediev. Eur.* 16 (2), 127–165.
- Cohen, K.M., Stouthamer, E., Hoek, W.Z., Berendsen, H.J.A., Kempen, H.F.J., 2009. Zand in Banen – Zanddiepte kaarten van het Rivierengebied en het IJsseldal in de provincies Gelderland en Overijssel. Provincie Gelderland, Arnhem.
- Cohen, K.M., Stouthamer, E., Pierik, H.J., Geurts, A.H., 2012. Digitaal Basisbestand Paleogeografie van de Rijn-Maas Delta/Rhine-Meuse Delta Studies' Digital Basemap for Delta Evolution and Palaeogeography. Dept. Physical Geography. Utrecht University (digital dataset). <http://persistent-identifier.nl/?identifier=urn:nbn:nl:ui:13-nqjn-zl>.
- Cohen, K.M., Toonen, W.H.J., Weerts, H.J.T., 2016. Overstromingen van de Rijn gedurende het Holoceen. Relevantie van de grootste overstromingen voor archeologie van het Nederlandse rivierengebied. Deltareport 2016 B, project 1209091–000.
- Davis, J.R., McCormick, M. (Eds.), 2008. *The Long Morning of Medieval Europe. New Directions in Early Medieval Studies*. Ashgate, Hampshire.
- Deeben, J.H.C., Groenewoudt, B.J., Hallewas, D.P., van Rooijen, C.A.M., Zoetbrood, P.A.M., 2006. In search of the archaeological resource. *Ber. Rijksd. het Oudheidkd. Bodemonderz.* 46, 113–126.
- De Vries, F., de Groot, W.J.M., Hoogerland, T., Denneboom, J., 2003. De bodemkaart van Nederland digitaal. Toelichting bij inhoud, actualiteit en methodiek en korte beschrijving van additionele informatie. Alterra-rapport 811. Alterra Research Instituut voor de Groene Ruimte, Wageningen.
- Dijkstra, J., Van Benthem, A., 2004. Definitief Archeologisch Onderzoek op terrein 9 in Houten. Amersfoort (ADC-rapport 264).
- Dijkstra, M., 2011. Rondom de mondingen van Rijn & Maas. Landschap en bewoning tussen de 3e en 9e eeuw in Zuid-Holland, in het bijzonder de Oude Rijnstreek. PhD thesis. University of Amsterdam, Amsterdam.
- Dijkstra, J. (Ed.), 2012. Het domein van de boer en de ambachtsman. *Archeologisch onderzoek op het voormalige veilingterrein aan de Zandweg te Wijk bij Duurstede*. ADC-monografie 12, Amersfoort.
- Doeve, P., 2015. *The Long Journey of Early Medieval Wood; Establishing Absolute Dates and Determining the Provenance of Timbers from the Oegstgeest-Rijnfront Site*. Leiden University, Leiden unpublished M.A. thesis.
- Domínguez-Delmás, M., Driessen, M., García-González, I., Van Helmond, N., Visser, R.M., Jansma, E., 2014. Long-distance oak supply in mid-2nd century AD revealed: the case of a Roman harbour (Voorburg-Arentsburg) in the Netherlands. *J. Archaeol. Sci.* 41, 642–654. <http://dx.doi.org/10.1016/j.jas.2013.09.009>.
- Driessen, M., Besselsen, E. (Eds.), 2014. Voorburg-Arentsburg. Een Romeinse havenstad tussen Rijn en Maas. *Themata* 7, Amsterdam.
- Eckstein, D., Bauch, J., 1969. Beitrag zur Rationalisierung eines dendrochronologischen Verfahrens und zur Analyse seiner Aussagesicherheit, pp. 230–250. *Forstwissenschaftliches Centralblatt* 88 issue 1.
- Erkens, G., 2009. Sediment Dynamics in the Rhine Catchment – Quantification of Fluvial Response to Climate Change and Human Impact. PhD thesis. Utrecht University, Utrecht.
- Gerrets, D.A., 2010. Op de grens van land en water. Dynamiek van landschap en samenleving in Frisia gedurende de Romeinse tijd en de volksverhuizingstijd. PhD thesis. Groningen University, Groningen.
- Groenewoudt, B.J., 1987. Deventer-Kloosterlanden: pottery and settlement traces from the Merovingian period. *Ber. Rijksd. het Oudheidkd. Bodemonderz. (BROB)* 37, 225–243.
- Groothedde, M., 1996. Leesten en Eme : archeologisch en historisch onderzoek naar verdwenen buurtschappen bij Zutphen (Kampen).
- Groothedde, M., 2013. Een vorstelijke palts te Zutphen? Macht en prestige op en rond het plein 's-Gravenhof van de Karolingische tijd tot aan de stadsrecht-verlening. PhD thesis. Leiden University, Leiden.
- Heidinga, H.A., 1987. Medieval Settlement and Economy North of the Lower Rhine. *Archaeology and History of Kootwijk and the Veluwe (The Netherlands)*. Cingula 9, Assen/Maastricht.
- Hemminga, M., Hamburg, T., 2005. Een merovingische nederzetting op de oever van de Oude Rijn : opgraving (DO) en inventariserend veldonderzoek (IVO) Oegstgeest – Rijnfront zuid 2004. *Archol-rapport* 69, Leiden.
- Hemminga, M. (Ed.), 2009. Vroeg Middeleeuwse nederzettingssporen te Oegstgeest. Een Inventariserend Veldonderzoek en Opgraving langs de Oude Rijn. *Archol-rapport* 102, Leiden.
- Hermesen, I., 2007. Een afdaling in het verleden. Archeologisch onderzoek van bewoningsresten uit de prehistorie en de Romeinse tijd op het terrein Colmschate (gemeente Deventer). *Archeologische Rapporten Deventer* 19, Deventer.
- Hodges, R., 2012. *Dark Age Economics: a New Audit* (London).
- Hodges, R., Whitehouse, D., 1983. Mohammed, Charlemagne & the Origins of Europe (archaeology and the Pirenne thesis, London).
- Hollstein, E., 1980. *Mitteuropäische Eichenchronologie: Trierer dendrochronologische Forschungen zur Archäologie und Kunstgeschichte (Trierer Grabungen und Forschungen)*. Verlag Philipp von Zabern, Mainz am Rhein.
- Jansma, E., 1995. *RemembeRINGS : the Development and Application of Local and Regional Tree-ring Chronologies of Oak for the Purposes of Archaeological and Historical Research in the Netherlands*. University of Amsterdam, Amersfoort. Nederlandse Archeologische Rapporten (NAR) 19, PhD thesis.
- Jansma, E., Van Lanen, R.J., Brewer, P., Kramer, R., 2012. The DCCD: a digital data infrastructure for tree-ring research. *Dendrochronologia* 30 (4), 249–251.
- Jansma, E., 2013. Towards sustainability in dendroarchaeology: the preservation, linkage and reuse of tree-ring data from the cultural and natural heritage in Europe. In: Bleicher, N., Koninger, J., Schlichtherle, H., Woltersdorf, M. (Eds.), *DENDRO – Chronologie, –Typologie, –Ökologie*. Janus-Verlag, Freiburg im Breisgau, pp. 169–176.
- Jansma, E., Haneca, K., Kosian, M.C., 2014. A dendrochronological reassessment of three Roman boats from Utrecht (the Netherlands). *J. Archaeol. Sci.* 50, 484–496.
- Jansma, E., Van Lanen, R.J., 2016. The dendrochronology of Dorestad: placing early-medieval structural timbers in a wider geographical context. In: Willemsen, A., Kik, H. (Eds.), *Golden Middle Ages in Europe*. Brepols Publishers, Turnhout, pp. 105–144.
- Jezeer, W., Jongma, S., 2002. Valkenburg-De Woerd. Werkput 510 – De Geul. Een studie naar vroegmiddeleeuws aardewerk uit Valkenburg (Z-H) (unpublished study). University of Amsterdam, Amsterdam.
- Kars, H., 1981. Dorestad, an archaeo-petrological study. Part IV: the mortars, Sarcophagi and other limestone objects. *Ber. Rijksd. het Oudheidkd. Bodemonderz. (BROB)* 1, 415–452.
- Kars, H., 1983a. Dorestad, an archaeo-petrological study. Part V: the wetstones and touchstones. *Ber. Rijksd. het Oudheidkd. Bodemonderz. (BROB)* 33, 1–38.
- Kars, H., 1983b. Dorestad, an archaeo-petrological study. Part VIII: summary of the petrological results. *BROB* 33, 83–94.
- Koomen, A.J.M., Maas, G.J., 2004. Geomorfologische Kaart Nederland (GKN); Achtergronddocument bij het landsdekkende digitale bestand. Alterra research institute, Wageningen. Alterra-rapport 1039.
- Knol, E., 1993. *De Noordnederlandse Kustlanden in de Vroege Middeleeuwen*. PhD thesis. Free University Amsterdam, Amsterdam.
- Kristiansen, K., 2014. Towards a new paradigm? The third science revolution and its possible consequences in archaeology. *Curr. Swed. Archaeol.* 22, 11–34.
- Lebecqz, S., 1983. Marchands et navigateurs frisons du Haut Moyen Age (Lille).
- Lebecqz, S., 1999. Long distant merchants and the forms of their ventures at the time of Dorestad's heyday. In: Sarfaty, H., Verwers, W.J.H., Woltering, P.J. (Eds.), In

- Discussion with the Past: Archaeological Studies presented to W.A. van Es, Zwolle, pp. 233–242.
- Lower Germanic Limes World Heritage Database, 2010. Der Deutschen Limeskommission and the cultural heritage agency of the Netherlands (RCE). Bödecker, S., Van Marrewijk, D. (2010) Auf dem Weg zum Welterbe? Internationale Tagung zum Niedergermanischen Limes. Nachrichtenblatt Dtsch. Limeskommission 4 (1) (München).
- McCormick, M., 2008. Discovering the early medieval Economy. In: Davis, J.R., McCormick, M. (Eds.), *The Long Morning of Medieval Europe. New Directions in Early Medieval Studies*. Ashgate, Hampshire, pp. 13–18.
- Miedema, M., 1983. Vijfentwintig eeuwen bewoning in het terpengebied ten noordoosten van Groningen. PhD thesis. Free University Amsterdam, Amsterdam.
- Nokkert, M., Aarts, A.C., Wynia, H.L., 2009. Voegmiddeleeuwse bewoning langs de A2. Een nederzetting uit de zevende en achtste eeuw in Leidsche Rijn. Basisrapportage Archeologie 26, Utrecht.
- Orengo, H.A., Livarda, A., 2015. The seeds of commerce: a network analysis-based approach to the Romano– British transport system. *J. Archaeol. Sci.* 66, 21–35. <http://dx.doi.org/10.1016/j.jas.2015.12.003>.
- Pirenne, H., 1939. Mohammed and Charlemagne (London).
- Roorda, I.M., Wiemer, R., 1992. The ARCHIS project: towards a new national archaeological record in the Netherlands. In: Larsen, C. (Ed.), *Sites and Monuments: National Archaeological Records*. The National Museum of Denmark, Copenhagen, pp. 117–122.
- Roxburgh, M.A., 2013. Castaways. New Insights from the Metal Detected Brooches of Early Medieval Frisia. unpublished MA thesis. Leiden University, Leiden.
- Sier, M.M., Koot, C.W., 2001. Kesteren-De Woerd: bewoningssporen uit de IJzertijd en de Romeinse Tijd. RAM-rapport 82, Amersfoort.
- Steur, G.G.G., Heijink, W. (Eds.), 1991. Bodemkaart van Nederland. Schaal 1:50000. Algemene begrippen en indelingen, 4de uitgave, Wageningen.
- Stouthamer, E., Berendsen, H.J.A., 2000. Factors controlling the Holocene avulsion history of the Rhine-Meuse delta (The Netherlands). *J. Sediment. Res.* 70 (5), 1051–1064.
- Theuvs, F.C.W.J., 2004. Exchange, religion, identity and central places in the Early middle ages. *Archaeol. Dialogues* 10, 121–138. <http://dx.doi.org/10.1017/S1380203804001217>.
- Theuvs, F.C.W.J., 2012. River-based trade centres in early medieval northwestern Europe. Some 'reactionary' thoughts. In: Gelichi, S., Hodges, R. (Eds.), *From one Sea to Another. Trading Places in the European and Mediterranean Early Middle Ages*. Proceedings of the International Conference Comacchio, 27th–29th March 2009, Brepols, Turnhout, pp. 25–45.
- Toonen, W.H.J., 2013. A Holocene Flood Record of the Lower Rhine, *Utrecht Studies in Earth Sciences* 41. PhD thesis. Utrecht University, Utrecht.
- Van Beek, R., 2009. Reliëf in tijd en ruimte, Interdisciplinair onderzoek naar bewoning en landschap van Oost-Nederland tussen vroege prehistorie en middeleeuwen. PhD thesis. Wageningen University, Wageningen.
- Van Grinsven, P.F.A., Dijkstra, M.F.P., 2005. De vroeg-middeleeuwse nederzetting te Koudekerk aan den Rijn: een bijna vergeten opgraving in de Lagewaardse Polder (Leiden).
- Van der Velde, H.M., 2001. Houten, Hoogdijk terrein 89; Onderzoek in het kader van de Vinexlokatie Loerik, Hofstad II. ADC-rapport 80, Bunschoten.
- Van der Velde, H.M. (Ed.), 2008. Cananefaten en Friezen aan de monding van de Rijn: tien jaar archeologisch onderzoek op de Zanderij-Westerbaan te Katwijk (1996–2006). ADC Monografie 5, Amersfoort.
- Van der Velde, H.M., 2011a. Centrale erven langs de monding van de Oude Rijn gedurende de Vroege Middeleeuwen: Archeologisch onderzoek op en rond de Zanderij-Westerbaan in Katwijk: De projecten Duinvallei fase 8 en 9 en Coligny. ADC-rapport 2846, Amersfoort.
- Van der Velde, H.M., 2011b. Wonen in een grensgebied. Een langetermijngeschiedenis van het Oost-Nederlandse cultuurlandschap (500 v. Chr. – 1300 na Chr.). PhD thesis. Free University Amsterdam, Amersfoort. Nederlandse Archeologische Rapporten (NAR) 40.
- Van Dinter, M., Kooistra, L.L., Dütting, M.K., Van Rijn, P., Cavallo, C., 2014. Could the local population of the Lower Rhine delta supply the Roman army? Part 2: modelling the carrying capacity using archaeological, palaeo-ecological and geomorphological data. *J. Archaeol. Low Ctries.* 5 (1), 5–50.
- Van Doesburg, J., Verwers, W.J.H., 2004. Aardewerk. In: Dijkstra, M.F.P. (Ed.), *Gulle gaven, greppels en waterputten. De opgraving Wijk bij Duurstede – David van Bourgondiëweg*, Amsterdam, pp. 28–45.
- Van der Kamp, J.S., 2011. Boeren langs de Hogeweide, Een (post)middeleeuws boerderijlint op kapittelgrond in Leidse Rijn. Rapportage Archeologie 20, Utrecht.
- Van Es, W.A., Verwers, W.J.H., 1980. Excavations at Dorestad 1, the harbour: Hoogstraat 1. Nederlandse Oudheden 9, Amersfoort.
- Van Es, W.A., Verwers, W.J.H., 2010. Early medieval settlements along the rhine: precursors and contemporaries of Dorestad. *J. Archaeol. Low Ctries.* 2 (1), 5–39.
- Van Lanen, R.J., Kosian, M.C., Groenewoudt, B.J., Jansma, E., 2015a. Finding a way: modeling landscape prerequisites for Roman and early-medieval routes in the Netherlands. *Geoarchaeol. An Int. J.* 30, 200–222.
- Van Lanen, R.J., Kosian, M.C., Groenewoudt, B.J., Spek, T., Jansma, E., 2015b. Best travel options: modelling Roman and early-medieval routes in the Netherlands using a multi-proxy approach. *J. Archaeol. Sci. Rep.* 3, 144–159 (JASR).
- Van Lanen, R.J., Kosian, M.C., Groenewoudt, B.J., Spek, T., Jansma, E., 2016. Route persistence. Modelling and quantifying historical route-network stability during the last two millennia: a case study from the Netherlands. *Archaeol. Anthropol. Sci.* (in review).
- Van Renswoude, J., 2011. Archeologisch onderzoek in de dorpskern van Kapel-Avezaath, gemeente Tiel. Een uitzonderlijk rijk 13de-eeuws erf en een 14de-eeuwse gracht in het plangebied Muggenborch. ZAR 43, Amsterdam.
- Van Renswoude, J., Van Kerckhove, J., 2009. Opgravingen in Geldermalsen-Hondsgemet. Een inheemse nederzetting uit de Late IJzertijd en Romeinse tijd. ZAR 35, Amsterdam.
- Van Renswoude, J., Schurmans, M.D.R., 2015. Handel, ambachtelijke activiteiten en bewoning langs de rivier de Linge in de Vroege en Volle Middeleeuwen. ZAR 349, Amsterdam.
- Verhoeven, A.A.A., 1990. Ceramics and economics in the low countries AD 1000–1300. In: Besteman, J.C., Bos, J.M., Heidinga, H.A. (Eds.), *Medieval Archaeology in the Netherlands. Studies presented to H.H. van Regteren Altena, Assen/Maastricht*, pp. 265–281.
- Verhoeven, A.A.A., 1992. Verspreidingsgebieden van aardewerk in de vroege en volle middeleeuwen. In: Carmiggelt, A. (Ed.), *Rotterdam Papers VII. A Contribution to Medieval Archaeology. Teksten van lezingen gehouden tijdens het symposium 'Handel, handelsplaatsen en handelswaar vanaf de Vroege Middeleeuwen in de Lage Landen' te Rotterdam*, van 2 t/m 3 november 1990, Rotterdam, pp. 75–84.
- Verlinde, A.D., Hulst, R.S., 2010. De grafvelden en grafvondsten op en rond de Veluwe van de Late Bronstijd tot in de Midden-IJzertijd. Nederlandse Archeologische Rapporten (NAR) 39, Amersfoort.
- Vermeulen, B., Hermesen, I., Mittendorff, E., 2009. Achterblijvers in de volksverhuizingstijd. Archeologisch onderzoek in het kader van de aanleg van de Tweedse Tunnel, Colmschate (gemeente Deventer). Rapportage Archeologie Deventer 27, Deventer.
- Verwers, W.J.H., 1998. North Brabant in Roman and Early Medieval Times. Habitation History. PhD thesis. Free University Amsterdam, Amersfoort.
- Visser, R.M., 2015. Imperial timber? Dendrochronological evidence for large-scale roadbuilding along the Roman limes in the Netherlands. *J. Archaeol. Sci.* 53, 243–254.
- Vorst, Y., 2005. De constructie en herkomst van de Romeinse platbodem 'Woerden 7'. Een studie van jaarringpatronen en bewerkingssporen. unpublished M.A. thesis. University of Amsterdam, Amsterdam.
- Vos, W.K., 2000. Archeologisch onderzoek Houten-Zuid op terrein 8A. ADC-rapport 30, Bunschoten.
- Vos, P.C., Bazelmans, J., Weerts, H.J.T., Van der Meulen, H.J.T. (Eds.), 2011. Atlas van Nederland in het Holoceen (Amsterdam).
- Vos, P.C., De Vries, S., 2013. 2e generatie palaeogeografische kaarten van Nederland (versie 2.0) (Deltares, Utrecht).
- Vos, P.C., 2015. Origin of the Dutch Coastal Landscape; Long Term Landscape Evolution to the Netherlands during the Holocene, Described and Visualized in National Regional and Local Palaeogeographical Map Series. PhD thesis. Utrecht University, Utrecht.
- Wiemer, R., 2002. Standardisation: the key to archaeological data quality. In: García Sanjuan, L., Wheatley, D.W. (Eds.), *Mapping the Future of the Past, Managing the Spatial Dimension of the European Archaeological Resource*, Sevilla, pp. 103–108.
- Willems, W.J.H., 1986. Romans and Batavians. A Regional Study in the Dutch Eastern River Area. PhD thesis. University of Amsterdam, Amsterdam.
- Zandstra, M.J.M., Polak, M., 2012. De Romeinse versterkingen in Vechten-Fectio. Het onderzoek in 1946–1947. *Auxiliaria* 11, Nijmegen.
- Zoetbrood, P.A.M., van Rooijen, C.A.M., Lauwerier, R.C.G.M., Van Haaff, G., van As, E., 2006. Uit Balans. Wordingsgeschiedenis en analyse van het bestand van wet- telijk beschermde archeologische monumenten (Amersfoort).

Websites

- Archaeological Basic Register (ABR). http://cultureelerfgoed.nl/sites/default/files/downloads/dossiers/abr_website2.pdf. (visited on: 7-1-2016).
- Archaeological Information System of the Netherlands (ARCHIS). <https://archis.cultureelerfgoed.nl/#/login> (visited on: 6-1-2016).
- Dendrochronological repository DCCD. <http://dendro.dans.knaw.nl> (visited on: 6-1-2016).
- Electronic Archiving System of the Netherlands (EASY). <https://easy.dans.knaw.nl/ui/home>. (visited on: 6-1-2016).

Further reading

- Bakker, A., 1997. Laat-Romeins en Merovingisch ruwwandig aardewerk van De Geer in Wijk bij Duurstede. unpublished M.A. thesis. Free University Amsterdam, Amsterdam.
- Bosman, W., de Koning, J., 2005. Groot Olmen, Nationaal Park Zuid-Kennemerland. Inventariserend veldonderzoek in een gereanimeerd duinlandschap. Zaandam (Hollandia-reeks).
- Bouwmeester, H.M.P., 2000. Eme in de Romeinse en Frankische tijd. Archeologisch onderzoek naar de nederzetting en het grafveld op de terreinen van het Laaksche veld en de Laaksche tuin in de Ooyerhoek, gemeente Zutphen. BAAC-rapport 98.045.
- Den Hartog, C.M.W., 2009. Appellaantje LR55: Een vroegmiddeleeuwse nederzetting aan de Wilhelminaalaan bij Vleuten. Utrecht (Basisrapportage Archeologie 30).

- Hagens, J.-K., Sier, M., 1999. Castricum-Oosterbuurt, bewoningssporen uit de Romeinse tijd en Middeleeuwen. Amersfoort (RAM-rapport 53).
- Heidinga, H.A., Offenberg, G., 1992. Op zoek naar de vijfde eeuw. De Franken tussen Rijn en Maas (Zutphen).
- Heeren, S., 2009. Romanisering van rurale gemeenschappen in de civitas Batavorum: de casus Tiel-Passewaaij. PhD thesis. Free University Amsterdam, Amersfoort. Nederlandse Archeologische Rapporten (NAR) 36.
- Kars, E.A.E., 2000. Natuursteen. In: Oudhof, J.W.M., Dijkstra, J., Verhoeven, A.A.A. (Eds.), (2001) 'Huis Malburg' van spoor tot spoor. Een middeleeuwse nederzetting in Kerk-Avezaath, pp. 341–362. RAM-rapport 81, Amersfoort.
- Kars, E.A.E., 2001. Natuursteen. In: Verhoeven, A.A.A., Brinkkemper, O. (Eds.), (2001) Archeologie in de Betuweroute: Twaalf eeuwen bewoning langs de Linge bij de Stenen Kamer in Kerk-Avezaath, pp. 149–159. RAM-rapport 85, Amersfoort.
- Kars, H., 1980. Dorestad, an archaeo-petrological study. Part I: general introduction. Tephrite Querns Ber. Rijksd. het Oudheid. Bodemonderz. (BROB) 30, 393–422.
- Nicolay, J.A.W. (Ed.), 2008. Opgravingen bij Midlaren: 5000 jaar wonen tussen Hondsrug en Hunzedal (Eelde/Groningen).
- Schotten, J., Groenewoudt, B.J., 1997. Halverwege Wijster en Gennep, vierde- en vijfde-eeuwse nederzettingstvondsten uit Elsen, gemeente Markelo. Interne Rapporten ROB 34, Amersfoort.
- Schurmans, M.D.R., Verhelst, E., 2007. Oudheden uit Odijk: bewoningssporen uit de Late IJzertijd, Romeinse tijd en Merovingische tijd aan de Singel West/Schoudermantel. ZAR 30, Amsterdam.
- Spek, T., Van der Velde, H.M., Hannink, H., Terlouw, B., 2010. Mens en land in het hart van Salland: bewonings- en landschapsgeschiedenis van het kerspel Raalte (Utrecht).
- Van der Velde, H.M. (Ed.), 2007. Germanen, Franken en Saksen in Salland: archeologisch en landschappelijk onderzoek naar de geschiedenis van het landschap en nederzettingen uit de Romeinse tijd en Vroege Middeleeuwen in centraal Salland. ADC-monografie 1, Amersfoort.
- Van Es, W.A., 1990. Dorestad centred. In: Besteman, J.C., Bos, J.M., Heidinga, H.A. (Eds.), *Medieval Archaeology in the Netherlands*, Assen, pp. 151–182.
- Van Es, W.A., Verwers, W.J.H., 2009. Excavations at Dorestad 3. Hoogstraat 0, II–IV, with contributions by J. van Doesburg, H. Enno van Gelder (†) and C. Isings, Nederlandse Oudheden 16, Amersfoort.
- Van Es, W.A., Verwers, W.J.H., 2015. Excavations at Dorestad 4. The Settlement Area at the Harbour. Nederlandse Oudheden 18, Amersfoort.