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Approaches towards analysing and mapping greater quantities of provenanced material – background, method, potential and challenges from a southern Scandinavian research project

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Handling, mapping, and analysing large quantities of fuzzy data is a challenge. Scientifically determined provenances of raw materials in archaeologically retrieved finds are generally not very specific but point to smaller or larger regions of origin. When a dataset comprises several hundred probable and approximate geographical records representing a vast number of partly overlapping regions of provenance, it is difficult to comprehend the dataset and even harder to analyse and illustrate the results. This article presents data models and methods to solve this challenge using a dataset of approximately 1,800 scientifically determined provenances of raw materials from archaeological finds retrieved within southern Scandinavia, primarily from 200–1200 CE. The materials are often everyday durables, such as iron, wood, and ceramics. The aim is to find new methods to gain insight into resource flows from, into and within geographical areas through quantitative GIS analysis of the scientifically determined provenances.

Keywords: raw material, provenance, Southern Scandinavia, GIS, mapping of fuzzy data

Introduction

In a globalised society, intercontinental transport of the earth's resources and raw materials takes place on a huge scale, and there is often no correlation between the site of manufacture and the site of consumption. This has – to a certain degree – been the case throughout history. In Denmark, some of the oldest examples of a non-domestic raw material are the so-called *shoe-last* axes dating to the transition from the Mesolithic to the Neolithic era. The axes were made from amphibole rock found in Central and south-eastern Europe (Jensen 2013:123–125). Similar examples of exotic and presumably highly esteemed objects can be found throughout human history, but in all probability, more common raw materials made up the bulk of the flow of resources. Metals, wood, skins, rocks, foods, plant fibres, glass, animals etc., were essential elements of the foundation of society in prehistoric as well as later eras.

The extent and characteristics of the geographical movement of raw materials offer essential information in understanding a society and the often complex relation between raw materials and society – both then and now. The flow of resources can reveal the extent of networks as well as the background for contacts and exchange in a region or inter-regionally. Shifting flows of resources can reflect changes in the political situation, elite alliances, trade or fiscal relations, or landmarks in the course of history. In consequence, studying flows of resources has the potential to illuminate various aspects of society and societal development. Studies of resources and the geographical mobility of raw materials must take their starting point from the raw materials themselves, not necessarily the origin of the actual artefacts. This is also the point of interest in this article, which is part of the outcome of the research project "Årtusinders råvarer – Ressourcernes geografi" *[Raw materials throughout millennia – the geography of resources]* (Hansen 2018; Hansen et al. 2018; Dam et al. 2021b; Dam et al. 2022).

The aim of the research project is to implement the unredeemed analytic potential of determining to what extent continuity and changes can be determined in the flow of resources in the period 200–1200 CE. An effort to collect and systemise supra-regional data of this volume has not previously been made.

The present article clarifies and debates the methodological challenges and possible models for solutions attached to complex raw material and scientifically determined provenance issues. How does one handle large datasets that consist of possible and approximate provenances in a single database, and how are analyses of this data best visualised and mapped? These questions will be answered partly by discussing the complexity of the data, and partly by explaining the basic structure of the database. Finally, three minor analyses will exemplify the dataset's possible inherent answers to various research questions. However, the aim of these three examples is not primarily to provide definitive answers for concrete archaeological questions, but rather, and in continuation of the first part of the article, to present and discuss the advantages and disadvantages of concrete methods of handling and mapping the data.

Determination of provenances – an archaeological and historical perspective

In prehistoric contexts, it is often difficult to specify the origins of the flows of resources that one can detect at different times in history (Sindbæk 2005:268–273; Roesdahl 2018:943–944). The flow of resources between southern Scandinavia and other regions is especially hard to study because of the scarcity of written sources with even superficial information about such movements (Hybel & Poulsen 2007; Tillisch 2011:42; Roesdahl 2018:943, 948). The oldest known document from the Danish area is from 1085 CE (Cnut the Holy's Donation Letter), and it is not until the 13th century that the written sources become more frequent (Hansen 2019). Therefore, archaeological investigations constitute the primary source of information on the flow of resources in the past – to and from southern Scandinavia as well as within the region.

The archaeological data is a constantly growing source of material since practically every archaeological excavation provides new artefacts, such as pottery sherds, metals, animal bones and other organic material. However, the bulk of provenance studies have so far been concerned primarily with conspicuous and regular recognisable artefacts or types that originate outside the area of finding (e.g. Näsman 1984; Lund Hansen 1987; Sindbæk 2005; Henriksen 2009:215ff; Horsnæs 2010, 2013; Baastrup 2014; Michaelsen 2015:91ff; Bollingberg & Lund Hansen 2016). The vast majority of the materials, e.g. metals that were transformed into local jewellery or weapons, are included in the studies only to a minimal extent.

Despite the vast body of material at hand and the fact that work on scientific determination of provenances has been carried out for decades, it is only in recent years that the provenance methods have become commonly accessible for archaeological studies. In the last few decades, significant technological advances have been made in the field of scientifically determined provenancing, and various scientific analyses are increasingly applied to archaeological studies (Kristiansen 2014).

A wide and very heterogeneous range of analyses is used to scientifically determine the provenance of raw materials: strontium isotope analyses, XRF analyses, DNA analyses, and dendrochronology, to mention a few. Many such analyses have been carried out and, crucially, have often led to revised views on the past. For example, DNA research and genome sequencing have given rise to the revision of theories about human distribution on the planet (Rasmussen et al. 2011; Kristiansen 2014:13). On a smaller domestic scale, scientific analyses can help confirm or adjust theories about geographical flows and cultural networks in the past. For instance, ICP analyses of ceramics have helped to confirm that ceramics that appear to be imported can be manufactured of local clay, and vice versa, that ceramics which appear to have a local design can originate in a region remote to that of the findspot (Christensen et al. 1994; Brorsson 2013; Dam et al. 2021b). The example emphasises that scientific determinations of provenances contribute to improvement of an inadequately researched field of interest within archaeology. In archaeological research based on typological provenances, objects made from

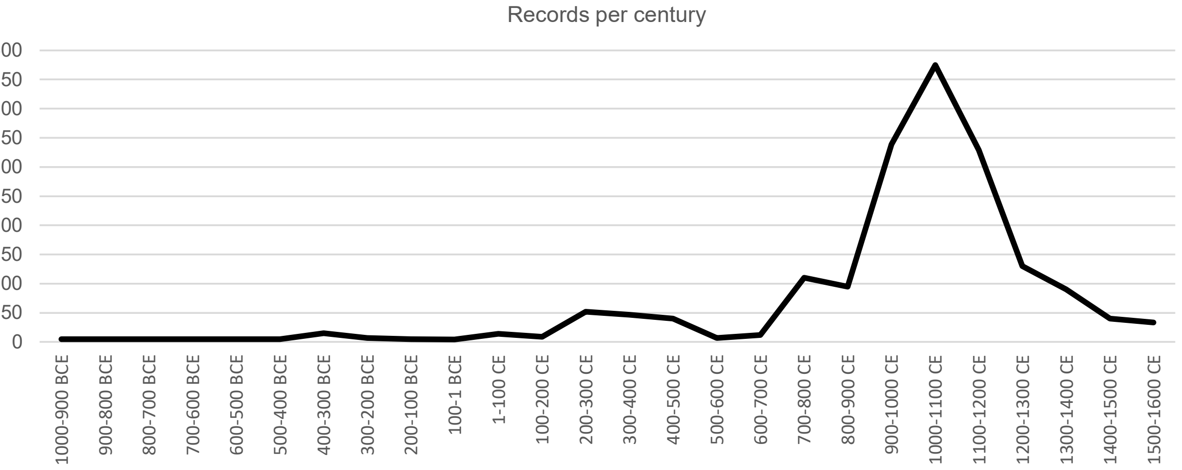


Figure 1. Generalised account of number of records per century.

local raw materials but inspired by foreign design can result in false conclusions about the origin of the raw materials. Likewise, imported raw materials that are transformed into jewellery and weapons of local design will lose any distinct typological relation to the area of provenance. Add to this the groups of artefacts for which visual and typological determination of provenance has never been readily present: domestic and wild animals, foods, textiles, skins etc. The focal point in older studies of the flow of resources has primarily been a limited group of artefacts, namely imported objects, or semi-finished products such as jewellery or weapons, rather than the flow of raw materials such as bronze, iron, or wood etc.

Undoubtedly, if the local institutions that carry out archaeological excavations implemented long-term collection strategies with a focus on scientific provenancing to a larger degree, it would efficiently develop and supplement our knowledge of resource flows and, in addition, would lend a voice to the otherwise taciturn materials and artefacts (Hansen 2018).

Scientific methods of analysis are constantly refined and increasingly accessible, which will result in an increase of data and an improvement of data in the future. But even now, the number of scientifically determined provenances is so large that there is a great potential in working not just with provenances for individual objects but in collecting, mapping and analysing the accumulated number of determined provenances in a collective database.

Method and material

Methodologically, the present study is a quantitative macro-study with a diachronic perspective focusing on the general flows of resources between geographical regions. In this way, the dataset presented here can support studies that implement theories of networks, growth centres and central places, which have dominated archaeological research in recent years (cf., e.g. Sindbæk 2005; Christensen 2018). The collected data can also, in turn, form the basis for conducting qualitative micro studies focusing on specific types of objects, materials or places. While the components and provenances of the raw materials are measurable factors, the inherent intent of material culture is constantly transformed through human interaction. The quantitative study forms a solid empirical foundation for analysing the active role of material culture as a constitutive dimension of the social practices and the concept of identities in past societies (Bourdieu 1977; Naum 2008; Aannestad 2016).

The circumstances under which the objects were transported from one region to another – be it trade, indirect trade, gift-giving, or piracy – are irrelevant in the present analysis since the focus is methodological and on the resources and raw materials themselves. In the following, the word *import* covers all kinds of transportation into a region (cf. Baastrup 2014:353).

All determinations of provenances in the dataset are based on scientific analyses. As is evident from this article, the provenance data is heterogeneous, and the underlying determinations of provenances are complex. The records that constitute the dataset are not evenly distributed in terms of time, types of material or findspot (Figs. 1–2; all maps in this paper are produced by the first author). As described below, materials such as wood have been provenanced in relative high numbers, but mostly wood found in relatively few locations and mainly from the Viking Age (750–1050 CE). This makes analysis of changes over time and seeing differences between regions difficult. Another

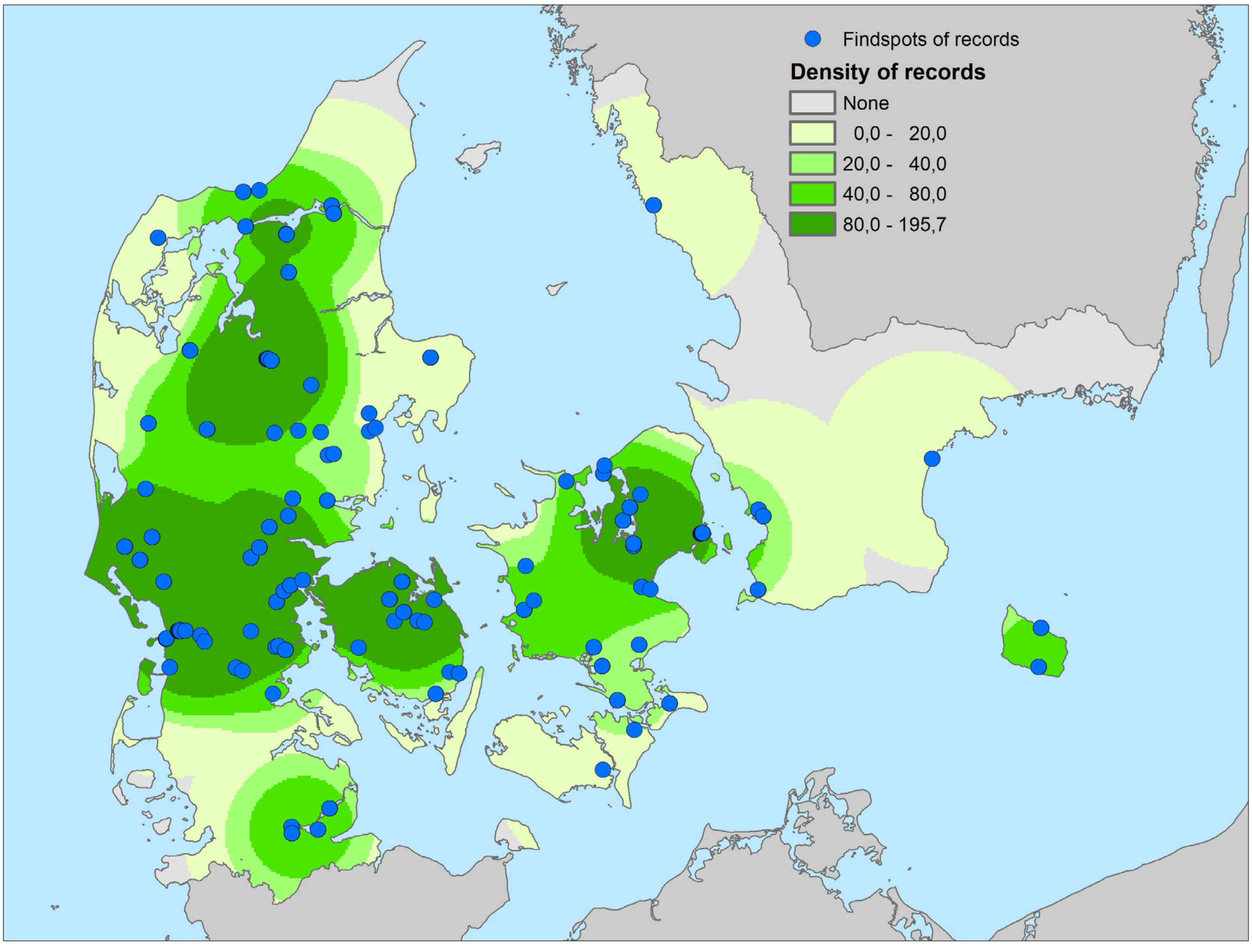


Figure 2. Findspots of records in the database and the concentration of records shown as a heatmap (Kernel Density Estimation) with a 50 km search radius. Since some findspots have multiple records; not all individual records are visible as findspots since they overlap. However, the underlying heatmap illustrates the concentrations: the darker the green background colour, the higher the number of records within 50 km. The area shown is present-day Denmark, northern Germany and southern Sweden. Total number of records: 1773. All data can be accessed freely as a spreadsheet and GIS-data in the database (Dam et al. 2021a).

distortion in the data is that scientifically determined provenances of materials are overrepresented at sites of greater cultural-historical importance. For example, most of the provenanced objects from the Middle Ages (1050–1536 CE) have been found in urban areas, and there are not many from rural sites from this period. In the years to come this will probably smoothen out as provenances become more numerous, but at least at the time of writing it is important to be aware that some types of analysis can be better founded than others, depending on the materials, periods, and regions they relate to. It is far from within the scope of this project to resolve inconsistencies in the data since our primary goal has been to collect, map, and analyse existing determined provenances.

Furthermore, the methods for determining provenances are constantly developing, and the regions of provenance that they produce are highly varied and partly overlapping. One method to handle this is to select and evaluate all parts of the data, for example, by combining materials, dates, and locations in the specific analyses. Another method, however, is to gather large amounts of data with the assumption that many of the challenges and uncertainties will be evened out and become insignificant in the accumulated dataset. This is pertinent if the research questions concerning the dataset are addressed with a sufficient understanding of its possibilities and limitations, as discussed later. Consequently, we have chosen to focus on a few but central facts from a large number of provenance records instead of on in-depth analyses of single objects. In other words, the method is a simplistic approach to complexity – which allows us to analyse a large and diverse dataset chronologically and geographically.

The database is primarily compiled from existing databases, reports and archaeological publications, but approximately 40 determinations of provenances have been carried out within the framework of the project mentioned above. The database can be downloaded as a spreadsheet with the primary data, including citations for information on the individual provenances, a GIS file with provenance regions, and a meta-document. The data is open source and can be freely used for other studies (Dam et al. 2021a).

Our database constitutes approximately 1,800 determinations of provenances based on material. Regardless of material, these provenances represent 120 individual geographical regions. Wood is by far the largest group (47% of the records in the database), followed by ceramics (13%), iron (14%) and other metals such as steel, lead, bronze, silver, and brass (9%). Determined provenances of human remains (primarily teeth and bones) constitute 8%, and animal remains around 1%. In addition to those, rocks, glass, seeds, and other groups of materials make up less than 1% each. The framework of the present project means that most of the determinations of provenance have been carried out on material found in southern Scandinavian (91%) and dated between 200 and 1200 CE (84%) (Dam et al. 2021a). However, a small number of determinations of provenance that fall outside this geographical or temporal frame have been included when rational in connection with the collection of data.

Determinations of provenance

All determinations of provenance in the dataset are based on scientific analyses, but it should be noted that the scientific methods vary fundamentally according to raw material and to some extent also according to when and by whom the analyses are made. The methods of determining provenance are under constant development, especially in terms of the *reference network*, i.e. the concrete geographical data that each sample is compared to and based on which the provenance is determined.

For metals, the combinations of a number of main components and trace elements in each artefact are analysed, e.g. aluminium oxide (Al_2O_3), potassium oxide (K_2O), titanium dioxide (TiO_2), and calcium oxide (CaO) for iron, and using multivariate statistics the results are compared with known values for the main components and trace elements in iron production slag from various European regions. For other metals such as copper alloys and silver, one compares trace-element composition and the relation between various isotopes of a number of metals in ores and artefacts. The basis for provenancing iron and other metals is that ores from each European region had – and have – different chemical compositions of both main- and trace elements depending on the geology of the area. These differences are reflected in the composition of slag inclusions in iron or in the trace elements found in other metals. By building a reference network of these regional compositions, it can be argued with some probability that the raw materials used in archaeological objects stem from specific regions (Jouttijärvi 2020a). Arne Jouttijärvi (2019) has conducted the vast majority of determinations of metal provenances in the database, and his previous and non-public determinations of provenance were, just prior to this study, statistically re-evaluated in relation to a larger dataset of references. The groupings in the reference dataset have also been reviewed and statistically verified. The re-evaluation was made possible by the improvement of reference networks as data from – and knowledge of the provenance regions – increases. Where it was previously often only possible to determine a provenance for iron to a larger area such as the Scandinavian peninsula, it is today usually possible to determine a provenance at least to Norway/northern Sweden or central/southern Sweden and in some cases to smaller regions. In the coming decades, there will probably be even better opportunities to determine the provenances to even smaller regions as the reference network develops further.

Some of the iron provenances and a few of the steel provenances were determined by Vagn Fabricius Buchwald (2005), but since he, at that time, lacked data on chemical compositions of iron and steel in certain regions, especially outside Scandinavia, some of his provenances cannot be localised more precisely than *south of Scandinavia*. The borders of Jouttijärvi's and Buchwald's regions of provenance are not entirely identical, and Buchwald's 2005 distinction between iron from Norway and the rest of Scandinavia has been debated (Grandin 2009). The exact regions of provenances are not indisputable or final but are rather in a process in which borders and divisions into regions are continuously adjusted and refined. Recently, Jouttijärvi (2020b:47) has worked with subdivisions of the Norwegian regions of provenance.

The determination of provenances of ceramics in the database are carried out by Kaare Lund Rasmussen (e.g. Rasmussen & Hjermind 2006; Rasmussen & Sørensen 2011) and Torbjörn Brorsson (2013, 2018). Rasmussen utilises a combination of measuring magnetic susceptibility and thermoluminescence, i.e. measuring the nature and amount of ferrous components as well as the amount of electronically excited states trapped in the ceramics. Brorsson utilises the ICP-

MA/ES method in which the chemical composition – the trace elements – of the ceramics is examined. As with the metals, the results are then compared to a reference database containing information on various chemical compositions of clay in different regions.

When determining the provenance of wood samples, one does not consider the composition of the material but the dendrochronological information in the sample. Just as the patterns of growth rings can date the year a tree was cut down they can also indicate the provenance. The patterns of the growth rings will vary according to the circumstances of the regional climate year by year. The patterns in samples of wood to be provenanced are compared to regional master patterns, calculated from a large amount of wood with known geographical origin, and the so-called t-values are calculated to see if the patterns in the wood to be provenanced correspond to a regional master pattern. As described with reference networks for iron, the regional master patterns for wood develop over time as data becomes larger and is improved. The method has primarily been utilised and developed by Aiofe Daly (2007:17–39), and her records and determined provenances constitute a large part of the current database. A large number of provenances for wood have also been carried out by Orla Hylleberg Eriksen (e.g. 2018), Niels Bonde (e.g. 2013), Claudia Baittinger (e.g. 2012), and others.

Human or animal remains can be provenanced via the strontium isotope method or to some extent by DNA studies. In a strontium isotopic analysis, the distribution of various strontium isotopes in, for example, bones or tooth enamel is compared to the naturally occurring strontium level in landscapes. The database includes determined provenances of bones and teeth via the strontium isotopic analyses conducted by T. Douglas Price and Karin Frei (e.g. Price et al. 2014). DNA studies are represented by an analysis carried out on cod bones by Bastiaan Star (Star et al. 2017). The data from the large DNA study of emigrated Viking Age Scandinavians (Margaryan et al. 2020) and an extensive study of the provenance of agricultural products in the first millennium CE based on strontium isotopic analyses (Larsson et al. 2020) are unfortunately not yet included in the database.

Not all scientific provenance analyses end up by determining a provenance for the objects. The reasons for this can be many, e.g. that the region of origin at the time was not in the reference network or that the material is of mixed origin, making the result unclear. Such objects with unclear provenance have not been included in the database.

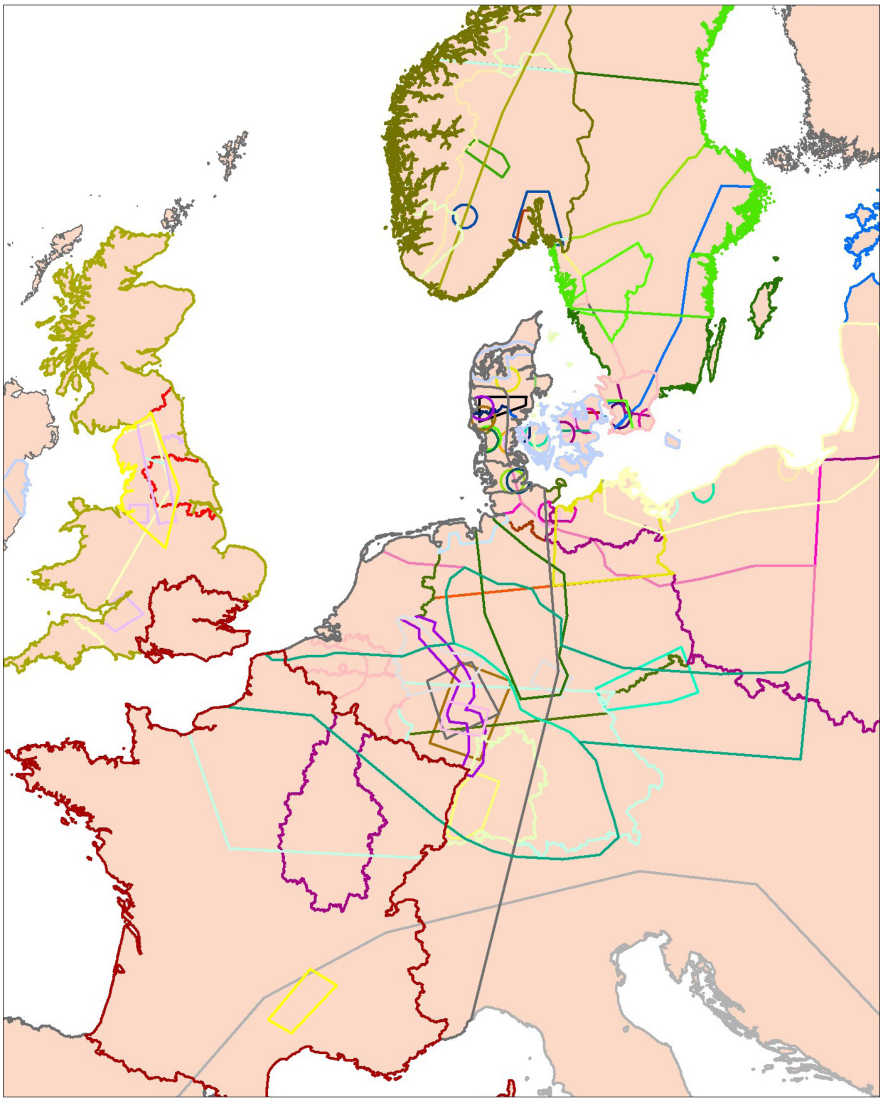
In general, the methodological uncertainties in connection with the sampling and analysis of the artefacts are small, but the reference network to which the results are compared to determine the provenance is still being expanded and developed, as cited above. In the database (Dam et al. 2021a), citations can be found for all recorded provenances and the researchers who conducted and/or published them. It is not possible to credit them all in this article, but the information can be found in the database. All provenances recorded in the database have been published in peer-reviewed journals or are based on generally accepted methods and have therefore not been subjected to further investigation by the authors.

Data structure and analytic parameters

Each record of a determined provenance is recorded in the database with two geographical locations – that of the findspot and that of the provenance. All findspots are precisely located with x- and y-coordinates (Fig. 2). The provenances, on the other hand, can only be located approximately to regions of a certain size (Fig. 3). The provenances are presented as a) local area to that of the findspot, b) a place near a specific locality, or c) other geographically defined areas. Both a, b, and part of c are relatively small areas, but some regions of provenance can be very large. At present, the largest region is “the Mediterranean coast”, but even very broad provenances like this are included in the database. Depending on the research questions with which one approaches the database, such records can always be excluded later if appropriate for specific analyses. Thus, all determined provenances are included in the database, as long as they meet the criteria stated below. The vast majority of regions of provenance are significantly smaller than “the Mediterranean coast” mentioned above. This means that 43% of the records of provenances are determined to regions smaller than 10,000 km^2 and only 5% to areas larger than 250,000 km^2.

It is much more challenging to handle a large amount of fuzzy geographical data like the regions of provenance than precise data like the findspots – in terms of registration, analysis and visualisation. Much literature deals with the subject *Fuzzy Logic within GIS* (de Runz et al. 2009; Santos et al. 2014). In the present case, the challenges have been the complexity and diversity of the data, the need for continuous editing and adding of new data when new or more refined information becomes available, and a demand for various types of analyses and mappings.

Figure 3. Map section of regions of provenance shown with random coloured borders. In some instances, there are more than ten overlapping regions of provenance.



The solution to these challenges is to initially record the data in its raw and unprocessed form and then process it through several steps for analysis and mapping. Initially, the provenances are recorded as text taken directly from excavation reports, articles or databases, e.g. "The area around Haderslev, Denmark", "The Oslofjord area, Norway" or "southern Germany". These regions are then digitised as polygons in GIS. For unambiguous definitions like "around Haderslev", a 25 km buffer is introduced. It is debatable whether a 10 or 100 km buffer would be more suitable, but it has no significance for small scale mapping and analysis of resource flows within Europe or north-western Europe.

The complexity of the finds is addressed with a simplistic data approach in the database. As long as the determined provenances of raw materials are considered valid and reliable, all finds and provenances are included in the dataset regardless of the circumstances and contexts surrounding the finds if the following parameters are known:

1. Raw material (e.g. iron, wood, human bones)
2. Date (specific year or a period)
3. Findspot (point)
4. Provenance (area of a certain size)

To this can be added a long list of metadata about the scientific method, object type, unique sample IDs, and references and reservations, which can be helpful in extending, refining or choosing from the database. But the four parameters constitute the core of the database and the derived analyses. It is a central assumption that the challenges caused by the fuzzy nature of the determined provenances and the different contexts of the finds will diminish analytically as the dataset grows and as more general research questions are addressed through the dataset. In this perspective, it is not an issue that a piece of timber has been reused or that a metal artefact is retrieved as a stray find – factors that could otherwise be disqualifying for other analyses. The essential in this case is that a specific artefact

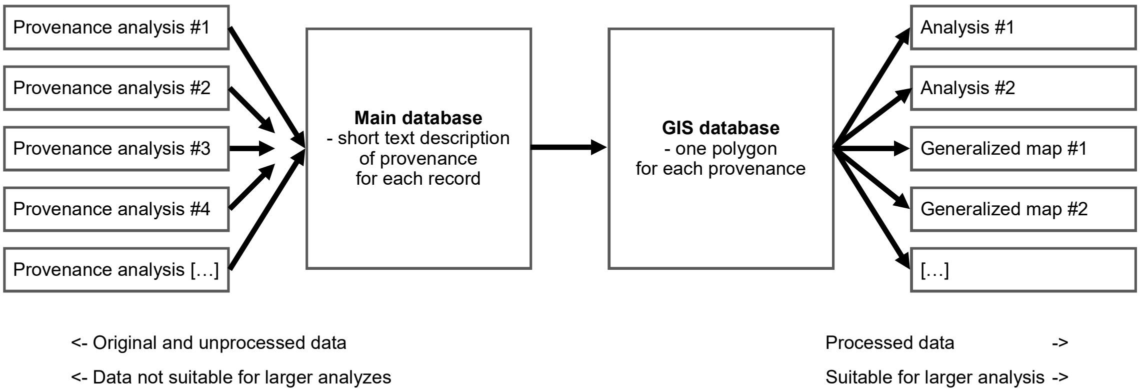


Figure 4. Principle sketch of the data's process from the initial analysis of provenance to generalised maps and statistics.

from a specific period has moved from A to B. Thus, we activate data from a potentially massive number of artefacts that has so far not contributed actively to traditional analyses of provenance.

The GIS database is difficult to grasp in its entirety and even more difficult to communicate because of its many overlapping regions, e.g. "Germany", "southern Germany", or "The Rhine Region", each having a number of attached records. Some European areas are covered by more than ten overlapping polygons (Fig. 3). However, both the main and the GIS databases are relatively easily adjusted and expanded with additional records and regions of provenance. Based on the GIS database, various generalised maps and statistics can be created that are easier to interpret and communicate. In Fig. 4, the left side represents the raw and unprocessed data that is also unmanageable when working with hundreds or thousands of provenances. More data is processed and systematised the further one looks to the right, making it possible to grasp the complexity of the data. All levels of this process are preserved since every step from left to right has advantages and disadvantages.

Analysis example I: All determined provenances

There are several ways to present data as maps, and each of them has advantages and disadvantages. The challenge is that the provenances are not precisely localised to one place, but only localised to somewhere within larger regions, and that these regions are often overlapping, as seen in Fig. 3. Below we present three methods of mapping using all the provenances in the database per April 2020 (Dam et al. 2021a). The maps in Figs. 5–7 show the provenances, not the finding spots. Since this data covers records, all eras, and all types of materials, maps will not provide immediately meaningful representations, but they can help to highlight different ways of presenting and studying the data. The maps shown below could be further optimised, but the layouts are thought to reveal strengths and weaknesses in each method.

The simplest way to map the provenances is to show every record as a point within the region of provenance (Fig. 5). The points are placed randomly inside the polygons and thus create a layer that visualises the concentration of all determined provenances in the database, even though there are sometimes ten or more overlapping regions. The point map gives an intuitive sense of the concentrations, but it can easily be misinterpreted. The individual points do not represent *an exact provenance* – they merely represent *the rela-*

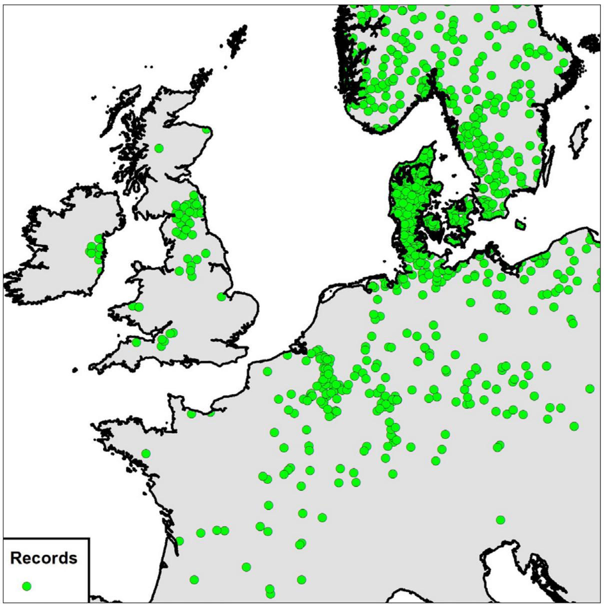


Figure 5. All scientifically determined provenances (200–1200 CE) shown as points placed randomly inside the regions of provenance as shown in figure 3. Total number of provenances: 1,773.

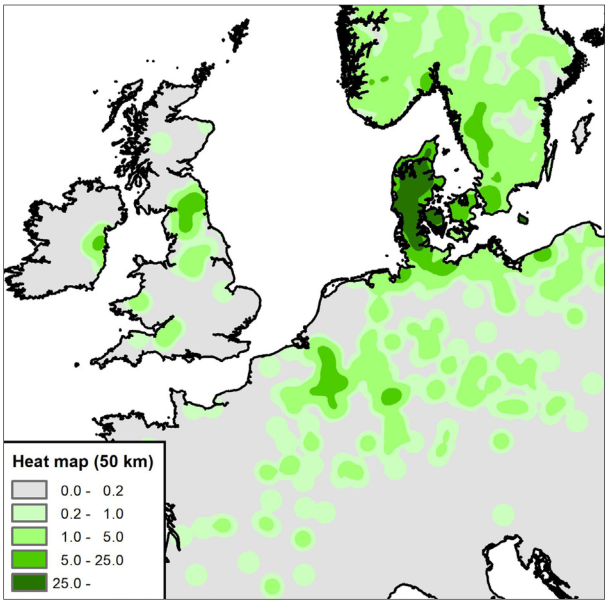


Figure 6. Heatmap (Kernel Density Estimation) based on the point map of all determined provenances in Fig. 5 using a search radius of 50 km.

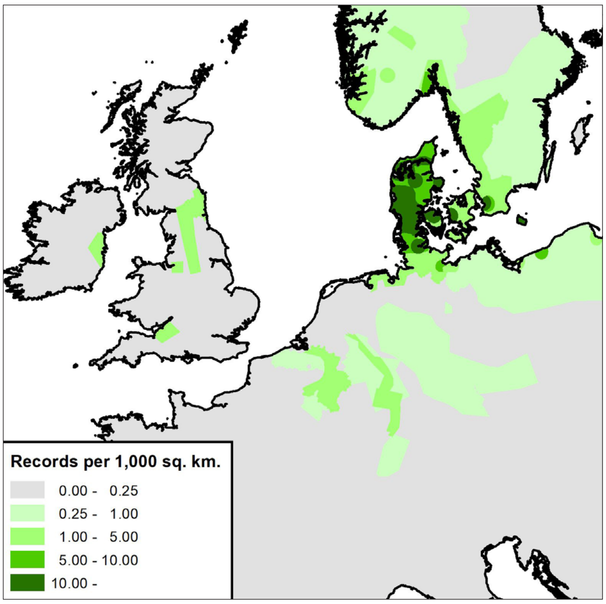


Figure 7. Sub-polygons showing the number of all determined provenances per 1000 km² in all regions of provenance.

tive dominance of the provenances within the areas. The map is a good illustration of the fact that many of the records have a provenance from southern Scandinavia, whereas there are only a few from other regions, e.g. the northern part of the Netherlands. But the individual points do not necessarily tell much. Furthermore, a challenge of this mapping method is that the density of points in most of southern Scandinavia makes it impossible to detect internal geographical variations.

One way to comprehend dense concentrations of points is to create a heatmap, e.g. a graphical visualisation of the number of records within a specific radius. For Fig. 6, this has been done based on the randomly placed points from Fig. 5 using a 50 km radius. This method is applicable for areas with a high density of points – e.g. western Denmark – but less so for areas with a low density of observations, such as Central Europe or South-east England. North of London, one sees an isolated light green circle surrounded by grey, giving the reader of the map the impression that this is a local *hotspot*. In reality, this is merely a product of the provenance determination of a single piece of substitutional timber from the Viking ship *Skuldelev 2*, which cannot be provenanced more exactly than the British area (Bonde 1999; Bonde & Stylegar 2011). Thus, a single random point is placed here (Fig. 5), which causes this circle. Such local circles caused by one random point are obviously unfortunate. One solution to this could be to increase the limit value for when records appear light green on the heatmap, but this will also obscure the visualisation in those cases where the points are more precisely placed. An alternative solution could be to increase the search radius to more than 50 km when creating the heatmaps. This would even out the sharp borders of the circles along with the gradually increased radius, but it would also impair the level of detail for areas with many points. The challenge with *heatmaps* is that this dataset has areas with a high density of points and other areas with a low density. Furthermore, some provenances are relatively geographically exact, while others are only approximate. As the database is expanded and refined, this challenge will lessen, but it will always linger to some extent with the heatmaps.

At present, *polygon-based sub-areas* are the preferred means to communicate the content of the database. The regions of provenance are subdivided so that any area covered by a unique combination of regions of provenance, e.g. one, five, or ten regions, is converted into a single sub-polygon. The values from all the relevant regions of provenance are then aggregated based on relative numbers of records per area. The sub-polygon around the town of Varde in western Jutland (Denmark) is thus attributed with all the records ascribed to that area. In addition, it is also attributed with a minor share of the records that have been provenance to western Jutland (i.e. approximately 16% of all provenances determined to that region) and an even smaller share of the records from the Denmark region of provenance (i.e. approximately 4%). The advantage of this approach is the resulting map on which every area is covered by one – and only one – polygon with aggregated values from all relevant regions of provenance.

The results are shown as number of records per area, since some sub-polygons are very small, and some are very large. The map might not appear pretty or smooth, but this result is closest to the input and, therefore, often the optimal choice for interpretations. The substitutional timber from the Skuldelev 2 ship is distributed all over the British area, but the high density around Varde is still evident. For comparison, Fig. 7 is shown with only green shades and a limited number of intervals, but for interpretation purposes, one could, of course, choose to use more colours and more intervals.

All three maps help to visualise an exhaustive amount of geographical data, but of course, they cannot stand alone. For detailed interpretations, the original data must be scrutinised – evident from the example of the timber from the Skuldelev 2 ship – and it is necessary to investigate the figures from the main- and GIS databases to gain statistical insight into the data. This will be presented in the examples of analyses below.

Analysis example II: Iron provenances from three periods

Provenanced iron is particularly interesting to map from the database at the time of writing, as the data here is more evenly distributed by place of finding and more evenly distributed chronologically than the other materials. Wood in the database is admittedly more numerically represented than iron, but most of the wood has been found in relatively few localities and is predominantly dated to the Viking Age. The better and more evenly distribution of iron makes this data easier to use, and changes in provenance are shown over time (Figs. 8–10).

In southern Scandinavia, iron could be extracted locally from bog iron, but iron was also imported from areas where the raw materials for iron extraction were accessible and of a higher quality (Jouttijärvi et al. 2005:288). The best iron bog resources are found in the western parts of the Jutland peninsula (Denmark), western Schleswig, and western Holstein (Germany). The landscapes here were created by the Saale glaciation, which ended approximately 128,000 years ago as well as by the melting of the Weichsel glaciation, which ended approximately 11,500 years ago and did not cover this area (Houmark-Nielsen 2020).

Iron from the West Jutland region and more remote regions was of great significance from the Iron Age onwards in southern Scandinavia. Below, the flow of resources will be mapped and evaluated for the individual periods.

Figs. 8–10 map the iron provenances in three Danish archaeological eras: Late Iron Age, i.e. 200–750 CE (50 records), Viking Age 750–1050 CE (87 records), and the Middle Ages 1050–1536 CE (53 records, primarily from before 1200 CE). Only finds retrieved from within the southern Scandinavian area, i.e. Denmark, Schleswig and Scania, are included. The provenances are shown with sub-polygons, as explained in connection with Fig. 7.

Fig. 8 shows that iron from western Jutland is highly dominant in the Late Iron Age. Almost half of the iron records (22 of 50) from the late Iron Age are provenanced to that relatively small region. Eighteen of the 22 records can only be provenanced to the overall region, but the final four are provenanced more closely to the area around the villages Snorup and Tarm. This results in a local hotspot centrally placed in the West Jutland region. A few records of iron – only five – were provenanced to other areas of southern Scandinavia with some certainty, and yet three others were broadly provenanced to southern Scandinavia, northern Germany or northern Poland. Fifteen records of iron were provenanced to the Scandinavian peninsula, primarily Norway, while only five were provenanced to regions south of Scandinavia.

For the Viking Age records, 14% of the samples were provenanced to the West Jutland region (12 of 87 records). The rest of the Danish areas were only represented with nine provenances, and some of these could even stem from northern Germany or northern Poland. Most of the iron in this era seems to have been imported from the Scandinavian peninsula, primarily Norway (59 out of 87 records), although this is not immediately obvious on the map since it shows relative numbers (records per area) and Norway is much larger than western Jutland.

In the Middle Ages, iron was still extracted within the present-day Danish area, but only two records are provenanced to western Jutland. Six records are provenanced to eastern Denmark, while eight are provenanced to either Denmark outside western Jutland, northern Germany, or northern Poland. Two records are provenanced to the Danish area overall. Only a single record is provenanced to Central Europe. It must be pointed out that Scania (the southernmost part of the Scandinavian peninsula) was part of the Danish realm in the Middle Ages. It is quite likely that a large but undefined share of the records provenanced to the Scandinavian peninsula is from Scania.

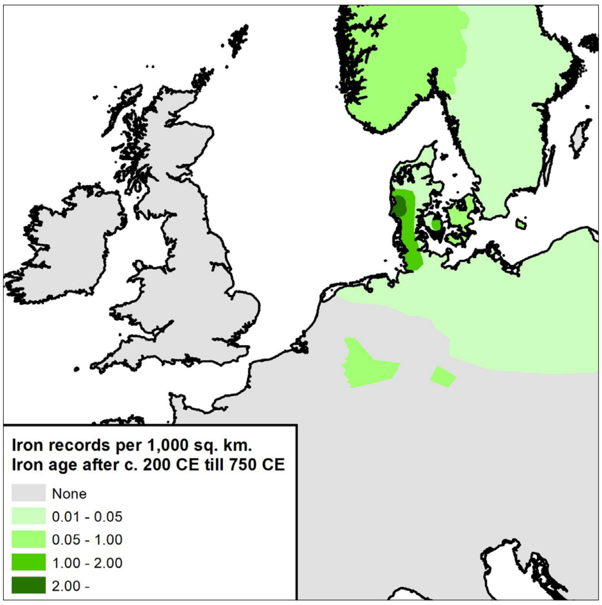


Figure 8. Sub-polygons showing the number of provenances for 200–750 CE iron found in southern Scandinavia and from all regions of provenance per 1000 km². Total number of records: 50.

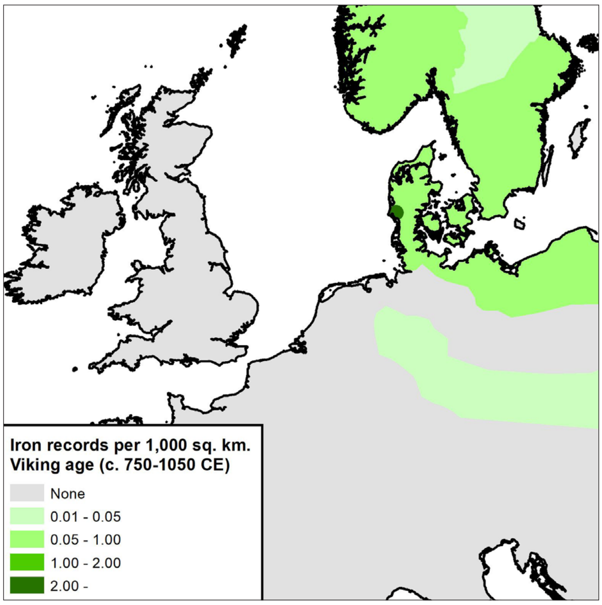


Figure 9. Sub-polygons showing the number of provenances for Viking Age (750–1050 CE) iron found in southern Scandinavia and from all regions of provenance per 1000 km². Total number of records: 87.

An increasing number of provenance analyses in the years to come will definitely add to the observations presented here, but some trends are already evident. The western Jutland iron was significant during the late Iron Age, but in the Viking Age, iron would frequently come from the Scandinavian peninsula. Norwegian iron in particular dominated in the Viking Age. This was, in part, also the case in the Middle Ages, but presumably, Scanian iron also played a large part in this period. Iron was also imported from regions south of Scandinavia in all three periods, especially the Iron Age, but this only made up a small portion compared to local iron and iron from the Scandinavian peninsula.

The three maps do not provide a complete insight into changing provenance of iron used in southern Scandinavia over time. That would require far more data. However, the signs of a shift from mainly iron from western Jutland to Norwegian iron are relatively clear. Moreover, the three examples illustrate several factors that should be taken into account in such analyses and surveys. The differences between relative values (records per area), which it is necessary to use on the maps, and absolute values must be emphasised to see the important role Norwegian iron had from the Viking Age an onwards. Since Norway is much larger than western Jutland, the overrepresentation during the Viking Age is not that clear at first sight of the map. That is clearer when using the absolute values. In addition, the data and the maps illustrate the challenge that the provenance often can only be determined to larger regions, like central and southern Sweden, although one might suspect that most of the iron with a provenance of this larger region is from a smaller region within, Scania. At the time of writing, the more precise provenance is just not possible to establish scientifically.

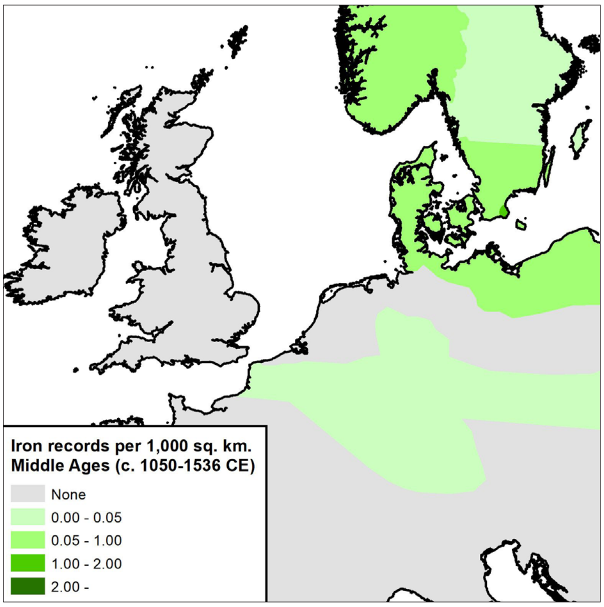


Figure 10. Sub-polygons showing the number of provenances for medieval (1050–1536 CE) iron found in southern Scandinavia and from all regions of provenance per 1000 km². Total number of records: 53.

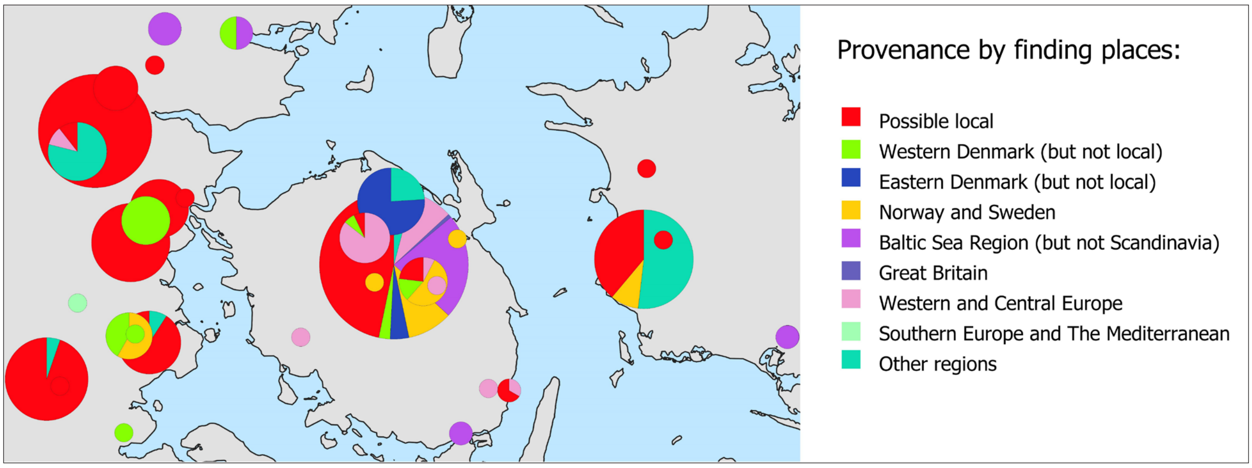


Figure 11. All determined provenances in central Denmark grouped by findspots. Funen in the centre, parts of eastern Jutland to the left, and western Zealand to the right. The smallest circles represent a single provenanced sample, while the largest circle at Odense in the centre of the map represents 122 provenanced samples.

Analysis example III: Provenances in a findspot perspective

Above, the provenances have been mapped as one data group regardless of findspots. In this analysis, the starting point will be the place of finding, which then will be visualised according to provenances. Again, the primary goal is not to draw unambiguous cultural-historical conclusions or investigate specific cultural-historical questions, but rather to discuss the challenges and limitations with the current data, as well as to outline the possibilities of visualising and analysing the data despite the limitations.

One challenge in mapping provenances with regard to findspots is that many locations of great cultural-historical importance have delivered a large number of provenanced findings. Consequently, it is impossible to visualise the provenances for each unique find as points on a map as they would overlap. Instead, they can be visualised, for instance, by displaying the number of finds for each location as points of graduated size, as shown in Fig. 11.

The large number of regions of provenance is another challenge. It is difficult to display more than 120 regions of provenance adequately using colours and figures. For Fig. 11, this challenge is met by merging all *possible local* provenances into a single group. *Potentially local* in this context is used to cover determined provenance areas equal to that of the findspots. For the town of Odense, which is seen centrally in Fig. 11, *possible local* covers regions of provenance such as “the Odense area”, “Funen”, “eastern Denmark” and “Denmark”. The remaining regions of provenance are merged into eight larger groups for the sake of clarity. Furthermore, only a part of central Denmark is shown, as a map of the whole of southern Scandinavia would be too complex visually to be discussed in this context.

However, Fig. 11 is like comparing apples and oranges. The objects are partly from the late Iron Age, partly from the Viking Age and partly from the Middle Ages, and wood, iron and all the other material groups are shown. Each of these subgroups is to a greater or lesser extent over- or under-represented at each location. The map can of course potentially be a window to see and understand some regional and cultural differences, but when data is not divided by periods and material groups, the map will to a large degree be a visualisation of the decisions made to get the scientific provenance of specific types of materials from certain periods. When data as in Fig. 11 is reviewed, it is clear that there are major variations in what types of materials and from which periods objects have been chosen for scientific provenance analysis.

For eastern Jutland, there are 258 determined provenances, mainly wood (161 records) and ceramics (60 records). Most of these have local or at least potentially local provenance – i.e. 84% and 93%, respectively. In total, there are 12 iron provenances, three of which are local, six of which are from western Jutland, while only three are imported from the Scandinavian peninsula. Other imports are represented by steel (four records), bronze (one record) and wood from barrels (nine records). Overall, the dataset from this region shows raw materials that are local or from the near periphery to a greater extent than other regions. However, the example illustrates that the pattern may be a reflection of the material selected for provenancing since wood is more likely to be local than other materials, e.g., bronze. Of the combined finds, 31% date to the Viking Age, while 27% are from the preceding era and 42% are from the subsequent era, showing an acceptable chronological distribution of the data. This means that asking questions regarding the change of provenance of a specific kind of raw material over time could be meaningful.

For Odense and the surrounding area, which is in the centre of Fig. 11, a more significant proportion of the provenances prove to be non-local. Since the second part of the 10th century, Odense has been considered an urban settlement and it became one of the most important cities in Denmark (Runge & Henriksen 2018). From central Odense, the database holds 121 determined provenances from the Middle Ages, primarily pre-1200, which is temporarily in contrast to the finds from eastern Jutland. Approximately half of these represent imported material. Among other things, there are a lead bar from Wales, 16 steel or iron objects primarily from the Scandinavian peninsula, 19 ceramic sherds primarily from eastern Denmark, northern Poland, and northern Germany and also 29 pieces from wooden barrels primarily from Flanders, northern Poland, and northern Germany. The presumably local objects are iron (9 records), ceramics (5 records) and wood (43 records, all of which are construction timber) (Dam et al. 2021a).

In a 15 km radius around Odense, a number of locations have provenanced material primarily from the Iron Age and the Viking Age. Again, the material is dominated by imported goods. Among these are a group of swords from the Viemose bog northeast of Odense, a well-known Danish Iron Age weapon deposit holding around 4,000 objects from the first centuries CE (Jensen 2003:371–373). Nine iron and steel swords from the bog have been provenanced primarily to Central Europe, a fact which bears witness to contacts between Scandinavia and the Roman Empire. North of Odense, at Galgedil, human femurs from a Viking cemetery have been provenanced via strontium isotopes. Out of 36 individuals, 19 have been determined as local, while six with relative certainty are non-local, although the precise provenance cannot be determined. Three of these six individuals are possibly from Norway or western Sweden, but all six are classified as “non-local” but with unknown origin because of uncertainty. The remaining 11 individuals cannot be identified as either local or non-local, and they are accordingly not included in the database (Price et al. 2014). From Kildehuse southeast of Odense, six knives from a Viking cemetery have been provenanced. All of them are two-component objects, consisting of iron and steel. A remarkable finding of this study, is that the iron from all six knives is either local or from western Jutland, while the steel is imported from more remote regions such as Central Europe or the Scandinavian peninsula (Jouttijärvi 2010; Jouttijärvi 2019). This implies the knives were manufactured locally using imported steel. A further three objects from three different locations around the Odense area were imported – two from Norway and one from the Maas Valley in Belgium (Dam et al. 2021a). Even though the non-local element is clear in this dataset, it is also worth noticing that in this area objects such as wood and ceramics, which have the potential to be local, have not been provenanced.

For western Zealand, it is even more evident that one must consider the types of raw materials and datings. All data from this area derive from the Trelleborg location, except for a few widespread locations that have produced one or two provenances each. Trelleborg was one of the royal military ring fortresses established around 980 CE, of which Nonnebakken near Odense was another example. However, there was no urban settlement near Trelleborg, and the ring fortress only functioned for a short time. The ring fortresses were closely connected to the establishment of royal power in Denmark and thus have always attracted research interest. Trelleborg is unique among the ring fortresses because of its bailey, in which 100 graves have been unearthed. Teeth from 52 human individuals from these graves have been provenanced. Twenty-one of these are locals from the area around Trelleborg, but the result is more ambiguous for the remaining samples. Some of these probably originate from Norway or the northern or central parts of Sweden, although a provenance to the northern part of the island of Ireland cannot be ruled out. Other individuals can only be provenanced as non-local (Price et al. 2011; Gotfredsen et al. 2014). Additionally, iron from a horseshoe has been provenanced to Scania, and iron from an arrowhead has been provenanced to an unknown region south of Denmark (Buchwald 2005). Consequently, the data for an entire region almost exclusively comprises a single raw material (human remains) from a single and historically exceptional location narrowly dated to a short period in the late 10th century.

The above illustrates that the observed differences on a findspot level to a large degree are due to different types of materials from different periods being chosen for provenancing. Artefacts have been selected for provenancing by the responsible archaeological in-

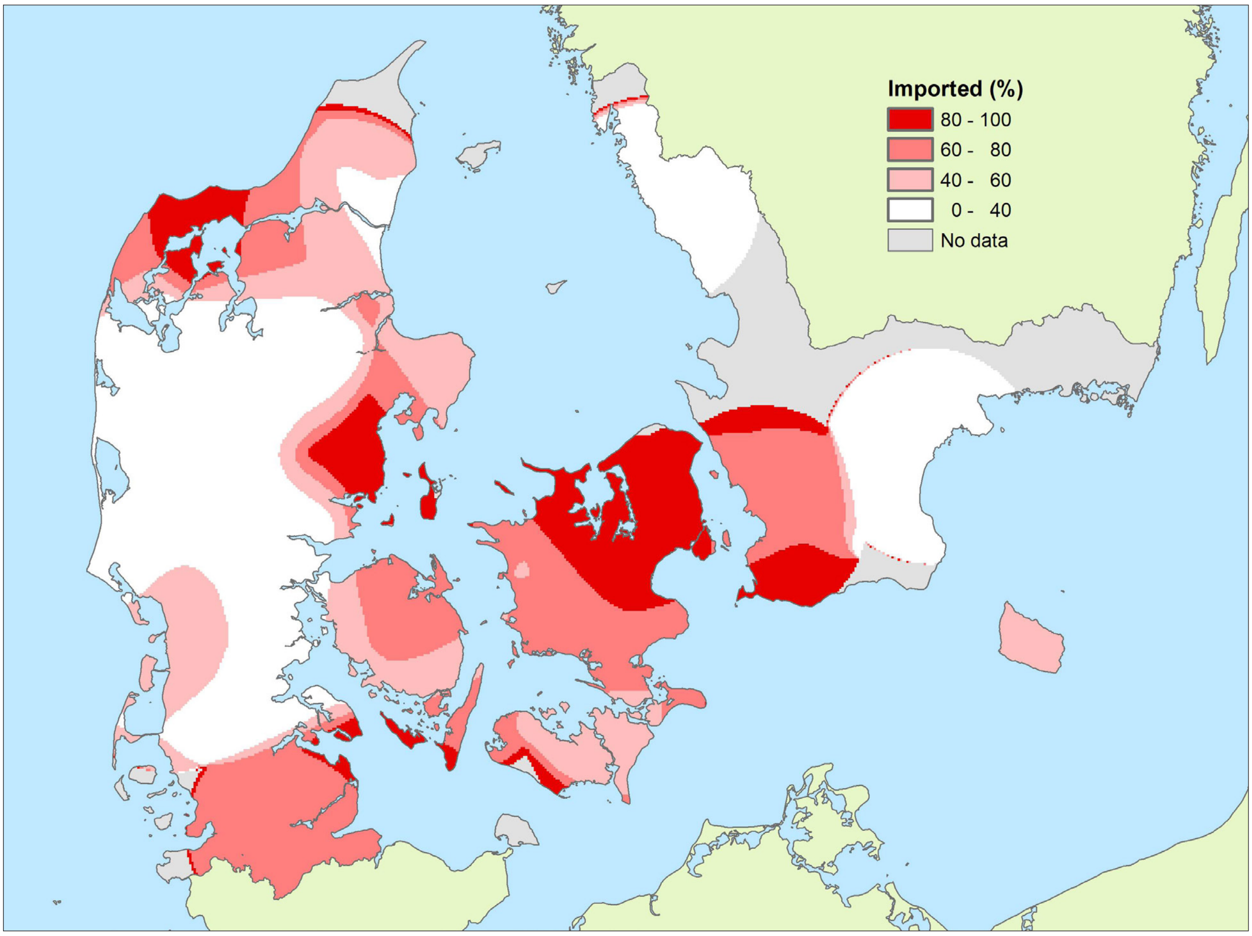


Figure 12. The proportion of imported materials defined as records with non-local provenance. The proportions are based on heatmaps (Kernel Density Estimation) measured within a 50 km radius. Findspots can be seen in Fig. 2.

stitutions for various research purposes, generally with a focus on specific types of raw materials, periods, or types of locations. The expansion of the database will over time lessen the skew as data increase, but it will, to some extent, always be a factor to consider. The typical solution for solving this analytical challenge would be to separate the data in Fig. 11 for each period and each material group making many new maps. Unfortunately, the data is not numerous enough for that at this point. The ideal solution would be to determine the provenance of a much larger number of objects, preferably evenly distributed in time and by findspots. Unfortunately, this is not within the frame of this project. With the current dataset, one solution is to group data in larger sets, either by geography or by a coarser grouping of the regions of provenance. This is done in Fig. 12, where the provenance only is differentiated into possible local and non-local (imported), and where an average is calculated within a 50 km radius. This type of coarser mapping does not solve all problems, or all challenges found in the skewed data, but it makes it possible to perform analysis on a more general level.

It must be emphasised that the most relevant element when interpreting the map in Fig. 12 is the relative differences. The proportion of imported material in large parts of Jutland will be low because many raw materials (wood, clay, and iron, for instance) were easily accessible there. Therefore, the most interesting aspect is the local or regional hotspots in which the proportion of imported materials is significantly higher than in the adjacent areas. The central urban settlements from the Viking Age and early Middle Ages stand out: Ribe in western Jutland, Haithabu/Schleswig in southern Jutland, Aarhus in eastern Jutland, Odense on Funen and Roskilde on Zealand. It is no surprise to find more imported materials in the early urban settlements and their close vicinity, as they are characterised as commercial and administrative centres, but the fact that these trends are already evident illustrates the perspective in the dataset and the methods presented here.

Nevertheless, the challenges of the dataset can still be seen. Currently, there are significantly fewer provenances for finds retrieved from Scania. Parts of the region are shown in grey shading because there are no finds at all within a 50 km radius, and the remaining part of the region is dominated by the circles caused by the 50 km query made for this mapping. The hotspot in northern Jutland is primarily caused by a large number of determined provenances from Aggersborg, another of the ring fortresses built around 980 CE. The provenances for the Aggersborg finds make up the majority of the provenanced finds from the region. From this location, 22 whetstones are provenanced primarily to Norway, ten iron artefacts have Norwegian origin, while a further two iron artefacts can only be provenanced to a region south of Denmark (Resi & Askvik 2014; Buchwald 2005).

Conclusion

There are several challenges in applying determined provenances for the purposes presented here. However, the prospects are many, and their potential will increase along with the addition of more provenance data.

The actual determination of provenance is often uncertain to some degree but is rarely due to uncertainties in the scientific analyses and theories. Moreover, it is often due to deficient or ambiguous referential datasets concerning the natural compositions of raw materials in individual regions.

However, the mapping of such referential data is permanently expanding and being refined, and the improvements and corrections of previous analyses that have taken place in recent years have generally produced smaller and more distinct sub-regions of provenance from the hitherto vast regions of provenance. On the other hand, relatively few completely new regions of provenance within Europe have been established.

The methods of collecting and mapping the provenance data presented here render it possible to handle the complex data both in its raw form and in more generalised versions. By preserving the data in its original form, it is easy to revisit and study the original information in cases of doubt, and the database can easily be adjusted and expanded when established provenances are refined or when new determinations of provenance are carried out. The generalised mappings or extractions from the database make the data more accessible for studies and easier to communicate to externals who do not have in-depth knowledge of the data or the methods.

Overall, there are promising perspectives in this dataset and the associated methods, but hopefully especially the more targeted approaches and requests to the dataset will benefit from a significant rise in the number of determined provenances that is to be expected in the coming years. Finally, it is evident that the potential for future analyses will increase exponentially with the expansion of the geographical area from which data is collected and the variation in the raw materials selected for provenancing. There needs to be a pan-European research approach and effort if we are to better comprehend the geography of resources in a European context, focusing not only on resource flows within certain regions but also out of them.

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