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The seeds of commerce: A network analysis-based approach to the Romano-British transport system

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abstract

Communication routes are an important subject in the study of the human past. They allowed in-teractions between communities and the dispersal of goods and ideas. Their study, therefore, can shed light on the way in which communities inhabited the landscape, related to each other and were affected by macro-regional trends. Many methods, such as archaeomorphological analysis and Least Cost Route modelling (LCR), have been devised and are routinely employed for the reconstruction of ancient routes. Their analysis in terms of communication, trade or historical significance, however, has usually been left unexplored. This is probably due to the connected nature of routes, which form communication networks: these are shaped by interconnected nodes and extend over territories surpassing the regional scale in such a way that even a change in a single node or link can affect the whole network. Consequently, the partial reconstruction of communication networks provided by the aforementioned methods does not usually allow a holistic analysis. In this paper the relatively well understood British Roman road network is employed to explore the analytical possibilities offered by a combination of Social Network Analysis, Spatial Network Analysis and spatial interpolation-based distribution analysis. The British road network has been reconstructed using published data but also a variation of LCR in which cost surfaces are derived from cultural data obtained from large-scale cultural inventories. The distribution of introduced food plants during the Roman period serve as an excellent proxy for the study of trade along the network and its historical consequences. This multi-period archaeobotanical dataset has some evident advantages to other types of material remains: archaeobotanical remains are not reused as, for example, amphorae and, accordingly, they reflect a distribution pattern based on consumption or commerce. Some of them are imported (as they cannot be produced locally) and, consequently, their distribution would be applied through usage of the main routes.

The results suggest a continuous inflow of exotics but highlight their changing transport routes, their differential access and the particular weight of certain nodal sites in the development of this commerce with direct impact on urbanisation and the overall economy of Britannia. The Roman road network acted as a major factor in the distribution of sites, their political and economic importance and their permanence or disappearance as global economic trends changed over time.

1. Introduction

Communication routes are an important subject in the study of the human past. They allowed interactions between communities and the dispersal of goods and ideas. Their study, therefore, can shed light on the way in which societies inhabited the landscape,

related to each other, and were influenced by macro-regional connections.

The road network of Roman Britain is particularly well understood in comparison to that of other Roman provinces. This is due to the long tradition of antiquarian interest in Roman roads and the work of several people and institutions. These include the seminal works of T. Codrington (1918) and I. Margary (1973), the mapping conducted by the Ordnance Survey, the efforts of institutions such as English Heritage (now Historic England, HE), and the continuing work of British archaeologists aided by the physical particularities

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of the British landscape, which allows for the detection of roads in aerial photographs in the form of crop, soil or shadow marks. These efforts have resulted in a wealth of evidence that has permitted an, although still partial, significant reconstruction of the Roman road network. Despite depiction of the Roman road system in multiple studies, the transport network itself has rarely been actively employed to address historical or archaeological questions.

This paper aims to remedy this by proposing first an integrated methodology for a more complete reconstruction of the Romano-British transport system. This is then examined using network analyses in conjunction with data on the distribution of exotic food plants to trace their commerce. Exotic food plants are defined here as those that were either only imported or their cultivation could have become established during the Roman period and these two categories are treated and analysed independently in this study. Systematic collection of plant remains in excavations all over Britain has led to a significant body of such data for the Roman period (Van der Veen et al. 2007), which can now provide primary evidence for the investigation of the exotics' distribution that contributed to the emergence of new foodways (e.g. Van der Veen et al. 2008; Livarda and Van der Veen, 2008; Livarda, 2011).

A combination of density interpolation surfaces and social and spatial network analyses to investigate the trade and distribution of exotics has been already employed for Roman London (Livarda and Orenco, 2015), which was then contextualised within the broader commerce of exotics in Britannia. This study demonstrated the need to treat London as a node of the greater British transport network and, as a consequence, a preliminary small-scale version of the network analysis was devised. The pattern identified within London appeared to largely reflect the changes in the overall commerce network of exotics in Britannia. With the present paper we aim to provide a general analysis of this network, which will allow the research community to use it in broader studies of Roman trade and in the investigation of the degree of connectivity and integration into the commerce network of particular nodes (i.e. sites). Such analysis can then contribute to explanations of changes in regards to site function and/or activity through time.

2. Methodology: networking Roman Britain

Methods, such as archaeomorphology (Palet and Orenco, 2011) and Least Cost Route modelling (LCR) (Fiz and Orenco, 2008), have been devised and are routinely employed for the accurate reconstruction of Roman routes. Their analysis in terms of communication, trade or historical significance, however, has generally been left unexplored. This is probably due to the connected nature of routes, which form communication networks. These are shaped by interconnected nodes that usually correspond to habitation nuclei, and extend over territories surpassing the regional scale in such a way that even a change in a single node or link can affect the whole network. Knappett et al. (2011) have demonstrated how the disappearance of Akrotiri in the Minoan communication network had important consequences for the whole of the Minoan culture. In the same way, Mol (2014: 193-4) showed how a small island community can be affected and in turn affect itself wider islands' networks in the 14th century North-eastern Caribbean. Such studies serve to illustrate the importance of a holistic approach in network studies. Consequently, the partial reconstruction of communication networks provided by the aforementioned methods does not usually allow holistic analyses. In regards to this study, since a site's relative importance in terms of access to exotics depends on its position within the exotics' distribution network, only considering the whole network, its access to exotics can be understood. In this section a new set of methodologies for the reconstruction and analysis of the Romano-British transport

network as a whole are described and their significance outlined. Britannia is a particularly adequate study area for this type of studies not just for the completeness of its transport system, but also because as an island it has a relatively closed network.

2.1. Filling up the gaps

The first methodological need was the reconstruction of the Romano-British road network in a suitable form for network analysis (Fig. 1). Extensive data on Roman roads are currently available and were provided by HE, the Royal Commission on the Ancient and Historical Monuments of Wales (RCAHMW) and the Royal Commission on the Ancient and Historical Monuments of Scotland (RCAHMS) (the data are available upon contacting the corresponding authorities). A number of published data were also taken into account (e.g. Bishop, 2014; Codrington, 1918; Maggs, 1987; Margary, 1973; Sherman and Evans, 2004; Viatores, 1964). All this wealth of evidence, however, still did not provide a suitable network since data on many roads are interrupted and discontinuous. The completeness of the network is an influential factor in network analysis and, therefore, a methodology had to be developed to fill in the gaps (Fig. 1). LCR was employed to reconstruct the best possible route between two points by generating cost surfaces: maps representing the cost of movement. These usually employ topographic and other environmental variables like movement constrains. Because of the particularities of the British overall soft topography and the data on British Roman road stretches, which often displayed a remarkable straight course for miles (Poulter, 2014), it was decided that the sole use of topographic data was not adequate. Given the remarkable correlation between Roman roads and the distribution of cultural elements, such as sites or finds (Orenco and Palet, 2010), data from different repositories, including HE, RCAHMS, the Early Medieval Corpus of Coin Finds (EMC) and the Portable Antiquities Scheme (PAS) (the data are available upon request to the relevant authorities), were plotted on GIS and employed to generate a cost surface for LCR analysis. The data were classified according to typology (settlements or sites where given more weight than, for example, finds) and spatial accuracy. All these elements acted as attractors according to their specific weight and, therefore, the route delineated the best possible way to explain the distribution of cultural elements of Roman origin between two known stretches of a Roman road. Once the gaps in the Roman road system were filled in and the navigable river network of Britain (data modified from those published by Ellis Jones, 2012) was joined in, the transport system was transformed into a network fit for GIS-based analysis. This was achieved by correcting the network topology, repairing split, isolated or duplicate links, adding directionality to the links and creating junction information at every link crossing. No assumptions as to which routes were used were made but instead the entire navigable river transport network and all the available land transport system were included. This allowed interrogation of the network with the aim to identify which of these routes were actually in use for the movement of exotics.

2.2. Distributing exotics

The distribution of introduced food plants during the Roman period serves as an excellent proxy for the study of commerce along the network. The exotics' dataset has some advantages to other types of material: archaeobotanical remains are not reused as, for instance, pottery or metal and, accordingly, they reflect a dispersal pattern based on consumption and/or distribution. Information on the presence of exotic food plants were retrieved from a bank of 669 archaeobotanical reports collected through bibliographical search

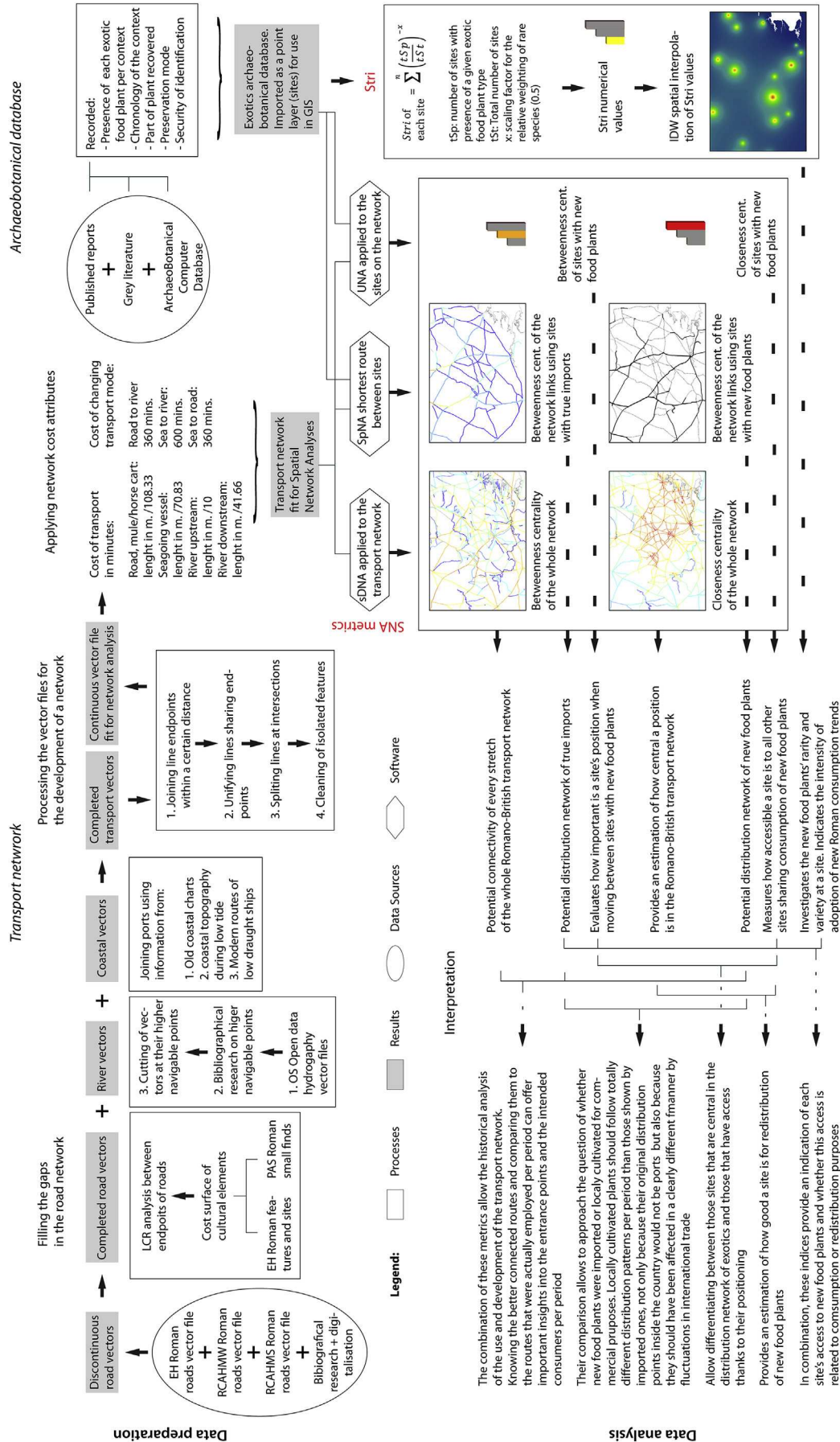


Fig. 1. Workflow developed for the analysis of the distribution of exotics using the Romano-British transport system.

personal contacts and use of the Ancient Monuments Laboratory reports from English Heritage, an updated version of the ArchaeoBotanical Computer Database (ABCD) (Tomlinson and Hall, 1996) and the environmental archaeology bibliography (for details on the methodology see Livarda, 2008, 2011, 2013; Van der Veen et al. 2008). The data were divided into three phases, early (ER: 1st century AD including up to early 2nd century AD), middle (MR: 2nd and 3rd centuries AD) and late (LR: 4th century AD including those starting in the 3rd century AD) Roman, and were plotted accordingly into the GIS. In total, the presence and distribution of 39 introduced plants (Supplementary material, Table 1) were used in the analysis (apples and pears were combined as one category and so did the cherries due to the difficulty in their identification to species level and, hence, the variability in their reporting in the archaeobotanical literature). The recording of the introduced species took into account only their presence per site due to the variability of the quantification methods encountered in the literature that did not allow otherwise standardisation of the dataset. In addition, for the purposes of this research absolute quantification was not necessary, as the mere presence of a taxon at a site would dictate its transit by trade routes. Other contextual data recorded included the preservation mode/s of each species, the security of its identification, and the part of the plant recovered (for a detailed discussion on the potential biases of the dataset see Van der Veen et al. 2008; Livarda, 2011). The distribution of sites with exotics per period showed a positive correspondence with that of habitation nuclei as recorded in the UK's national heritage repositories except for the area of Wales, where fewer archaeobotanical reports were available (see also Van der Veen et al., 2007).

In order to build a robust model for the spatial distribution of exotics certain parameters needed to be taken into account. Many of them would have been imported from outside Britain and, consequently, their local supply would be achieved through usage of the available transport system. Others could have been potentially taken up to local cultivation, but of these the ones that remain archaeobotanically very rare for the period under study are considered to represent potential imports, after investigating taphonomic parameters. This presented a second problem: a site containing only one such one-off import might not be fully participating into the exotics' network. Thus, sites that included several exotics could provide a more accurate picture for the circulation of these goods. To accommodate all the above the dataset was divided into two categories: (1) true exotics (those species that could have not been taken up to local cultivation). The distribution of sites with presence of true exotics was only employed for the development of SpNA shortest routes (see below) since these could have only been imported; and (2) those food plants that were newly introduced in Britain during the Roman period (which included both true imports and those potentially cultivated). This category was employed as a comparison with that of true imports. This comparison provides a measure of the distribution of the potentially locally cultivated plants and an assessment of their incorporation into the trade patterns of each period. For this category, instead of using single species distributions, an index was developed to allow investigation of exotics' assemblage densities across Britain, while minimising the input of both common species that could have been taken up to local cultivation and single sites with one-off species occurrences. This was the Site Rarity Index 'Stri', an expression of these species' rarity and variety at a site by period. The Stri takes into account the whole assemblage of new species in each site and is a reliable indicator of the intensity of adoption of new Roman consumption trends (for a detailed description of the index see Livarda and Orenco, 2015; see also Fig. 1). The Stri for all sites was interpolated using an Inverse Distance Weighted (IDW) method (see, for instance, Carreras, 1994 for

an interpolation of exogenous material in Britannia) and, combined with the distribution of true exotics that could have only been imported, provided a representation of the spatial distribution of new food plant species in Britain for each period, highlighting important consumption and (re)distribution areas in the network.

2.3. Social and spatial network analysis

To analyse the transport system, social network analysis (SNA) and GIS-based spatial network analysis (SpNA) were employed using a purpose-built workflow (Fig. 1). SNA has been used in archaeology mainly to study the structure of relationships (represented as links) between individual actors (or nodes) by allowing the generation of hypotheses about sites' hierarchy or the expansion of human groups or ideas (for various examples covering diverse time periods, cultures and types of applications see Knappett, 2013). These SNA applications, however, have not been exempt from criticism due to the subjective nature of the links (or relationships) between the different nodes of the network, often based on shared items of material culture, or the reduced availability of evidence linking them (see Sindbæk, 2013 for the application of SNA to archaeological distributions, Isaksen, 2008 and Graham, 2006 on ancient itineraries, Dicks, 1972 and Carreras and de Soto, 2013 on Roman road networks). In this study the inherent subjectivity in the development of the network is partially overcome by the use of a spatial network that reflects transport routes on physical space. Thus, the SNA results reflect real connectivity limited only by the network quality and the parameters of transport time adopted. Additionally, the transport network is independent of the archaeological data employed to analyse it, in this case the distribution of exotics. Although both the transport network and the exotics' distribution are necessarily incomplete datasets with potential impact on archaeological interpretations, they are independent variables that they do not affect each other, in contrast to those used in traditional SNA approaches.

The use of the physical network had a second advantage over traditional SNA approaches: it allowed the development of a transportation network analysis that included vehicle routing problems, and could be used to model the best route between two or more nodes taking into account time and other resource allocation parameters. Despite its potential, SpNA has been infrequently used in archaeology (Wheatley and Gillings, 2002: 122) presumably due to the lack of complete enough data on ancient transport systems (but see Scheidel et al. 2012; Carreras and de Soto, 2013; De Soto, 2010a).

For the development of a transport network apt to be analysed using SNA and SpNA, the ways in which exotics were transported and distributed needed first to be considered. Exotic imports were arriving to the British archipelago by sea from the Continent. Seagoing ships' tonnage prevented them from following upstream river routes, and thus, their cargo was unloaded or transferred to smaller ships. The nature of most exotics, such as spices and herbs, meant that their trade would normally involve low weights and small sizes, allowing for their transport alongside other bulkier goods in very diverse cargoes (Fulford, 1978: 68). In fact, several exotic imports to Britannia were traded in small quantities even in their first port of entry, for instance in Egypt (e.g. Van der Veen, 2011: 62), from where they would later be redistributed to Rome and the rest of the Empire. In Britain, once in the port, these species would have been distributed to neighbouring towns and settlements using the available transport system. Terrestrial transport has been considered particularly adequate for the movement and distribution of valuable and small sized merchandise (Frayn, 1993; Berry, 1987: 579, Hendrickson, 2011: 452). Medieval records, such as the Southampton's Brokage Books, reveal the importance of cart

distribution of the merchandise arriving by sea, which reached places as distant as London, Coventry or Kendal (Hicks, 2015). These also show how the more valuable and exotic the product the more distance it was likely to travel by road (Hare, 2015: 28). Conversely, bulk transfers, such as those of wheat, by the crown in the fourteenth century would make use of river transport whenever possible (Masschaele, 1993). Therefore, it could be argued that river transport would have been mostly used for the bulk transport of exotics, normally organised by a central authority or large company and more rarely for distribution to the final consumption places or by individual entrepreneurs. Upriver transport could be much slower than cart and for the quantities of cargo involved would hardly be worthwhile. Downriver transport, although faster, would have also involved an element of delay while waiting for an adequate ship to arrive, unload, load and depart from the harbour, and would also include extra payment for the transport (Laurence, 1999: 100–1). Furthermore, it is likely that the distribution of exotics would have followed pre-established routes, involving several stops, and therefore, it would be inconvenient to alternate the transport means between river and road stretches.

The attributes of the Romano-British transportation network were built to reflect the aforementioned parameters with different time values for road, upstream and downstream river and sea movement and extra cost for the change of transport mode (Fig. 1). Although, change of transport would be almost impossible to model due to the large quantity of factors involved (tonnage of the cargo ship, position of the goods inside the hull, the container used to transport the goods, facilities and personnel available at the port of entry, etc.), minimum hypothetical values were adopted (see Fig. 1) to, at least, reflect some extra cost. In regards to the cost of transport itself, many values have been developed in the archaeological literature. Notably Carreras (1994) updated the values provided by Duncan Jones (1982) and Deman (1987), employing the later version of Diocletian's price Edict discovered at Aphrodisias (Roueché, 1989) which were used also in other recent works (e.g. De Soto, 2010a, Carreras and de Soto, 2013). However, these values are conceived for the cost of movement of bulk cargo and would not be adequately applied to model the movement of small quantities of merchandise. Consequently, cost of movement between nodes was represented in terms of time (in minutes) according to transport method, which can more adequately reflect food plant distribution costs. The speed values for the different transport methods were obtained from the aforementioned works (see Fig. 1).

On a first level of analysis, Spatial Design Network Analysis (sDNA), developed by the Cardiff School of Planning & Geography and the Sustainable Places Research Institute (Cooper et al. 2011; Cooper and Chiaradia, 2015) was employed to derive SNA metrics (closeness and betweenness centrality) for the whole of the Romano-British network according to transport time parameters (Fig. 2). sDNA allowed to compute SNA metrics assigning a custom weighting to each link, which in this case was the time that would cost to transit them according to transport type. The use of sDNA aimed at exploring the potential degree of connectivity of the different links of the Romano-British transport network using realistic parameters. Previous approaches (see, for example, Dicks, 1972 for Britain, Isaksen, 2008 for Baetica province, De Soto, 2010b for NW Hispania) produced centrality measures for each node or link of the network according to the number of total links connected to it instead of real distances or transit times. Here the first metric used was betweenness centrality, which, counts the number of times that a stretch of road or navigable river lies on the shortest route between all the other segments of the network. Closeness centrality was the second metric and this computes for each road stretch the sum of the distances to all other linked segments, providing an estimation of how central a position in the network is and, thus, how convenient for redistribution purposes.

On a second level of analysis closeness and betweenness metrics were calculated for each site participating in the exotic food plant trade using Urban Network Analysis Toolbox for ArcGIS (UNA), developed by the City Form Lab from the Singapore University of Technology & Design in collaboration with MIT (MIT, 2011). UNA's derived closeness centrality measures how accessible a site is to all other sites while betweenness evaluates the likelihood of a site's position to be transited when moving between other sites with access to exotics using the transport network. These complement the study of the whole network provided by sDNA by analysing the connectivity between sites for every period given their location on the Roman transport network. The selection of UNA as an analysis tool for the connectivity of sites inside the network arose for the need to analyse a real transport network instead of a conceptual SNA graph. UNA provides three main advantages to traditional SNA approaches: (1) just as sDNA does, it accounts for geometry and impedance attributes, which here is the transit time according to transport type, instead of the usual count of number of connections available to each node; (2) It takes into account the relative position of other sites to calculate centrality metrics. In this way their centrality will change in accordance to the distribution of sites with new food plants in the different periods even if the layout of the Roman transport system remains essentially the same. In this regard, UNA offers an important complement to the static measures for the whole transport network provided by sDNA. This is an important distinction as the network links' metrics provide a picture of the potential of communication for every stretch but the sites' centrality is determined also by the relative position of other sites in the network. Although these tend to be related (links with better communication potential tend to attract more sites), the variety in terms of size and function of sites and the adoption of a multi-temporal approach that implies changes in the distribution and function of sites, renders the separate SNA of the network and that of the sites inside the network imperative. Only in this way a meaningful analysis of site locations in relation to their potential for communication can be made; (3) UNA overcomes an important problem when applying SNA to a real transport network instead of a conceptual network: in a physical transport system sites do not necessarily need to be graph nodes, that is, placed at intersections of links, and traditional SNA software only accounts for the network's nodes and edges. UNA allows the inclusion of elements (in this case sites) which are used as spatial units of analysis for all measures. This is an important development because many of the sites are not located in intersections of the network and do not correspond to nodes in the classical SNA sense but also because two sites located at different positions of the same network segment will output different accessibility results.

Lastly, SpNA was used to model the shortest routes regarding transport time between sites with true exotics and sites with all new introductions separately. The modelled routes do not necessarily need to have been used to transport exotics, but depict those routes more convenient to communicate sites with presence of exotics. Since it is impossible to know which sites were related to exotics' redistribution and which ones were their final consumption place, they were all treated as a single category, that is, they were considered as nodes in the exotic food plant distribution network without further differentiation. The results allowed measuring the relative importance of transport network sections in the commerce of such exotics using the most densely transited routes connecting them. The differences between the centrality metrics of the whole network (reflecting potential transport in Roman Britain) and the ones obtained from the distribution of sites with true imports (directly related to commerce), together with the Stri density mapping and numeric values using sites with all exotics (informing on the diversity,

size and spatial dispersion of exotic food plant assemblages) provided insights into the nature of this commerce. The use of a multi-period dataset allowed the study of its development during the Roman period.

3. Measuring the Romano-British transport network

The combined results of closeness and betweenness centrality metrics (Fig. 2) provide interesting new insights into the character of the Romano-British transport network, which was already formed by the end of the 1st century AD.

sDNA-derived closeness centrality (network quantity penalised by distance) shows a significant deviation from the network's geometric centre towards the southeast of Britain. London, although in a marginal geometric position, shares a very high degree of centrality due to its connection to the sea, while being reasonably inland, and to its connection to Thames, providing access to the west of the island. Its association to several important roads, according to the results of the betweenness centrality metrics, is particularly significant and relevant for the analysis of products, such as exotics, that might have been transported by road. Aided by such central geographical position, the commercial and cosmopolitan nature of London since its establishment was the key factor that determined its prominence (Wacher, 1997), and possibly, thus, prompted development of the transport network around it, boosting its connectivity (as also noted by Dicks, 1972 and Carreras and de Soto, 2013 among others). The centrality of the south-eastern sector of Britain might have been related also to the presence of important Iron Age nuclei and paths joining them in the area but, most importantly, to its early Roman annexation in AD 43. This might explain an earlier and denser development of the road network in this area, joining pre-Roman nuclei and expanding following the conquest.

Betweenness centrality values for the British transport network provide information on the most accessible and, probably, thoroughly used routes. It is hardly surprising that coastal sea routes exhibit particularly high values, as these connected multiple coastal locations and inland cities with navigable rivers in less time than any other transport means. It is interesting to note that important nuclei sat at the intersection of roads with high betweenness values. This might have been a consequence of the layout of the road network, which initially was related to military campaigns and their need to access native centres, such as Calleva (Silchester), Camulodunum (Colchester) and Verulamium (St. Albans). Many of the first century Roman foundations, however, seem to have been selecting stretches with high betweenness values. Notable is also the correspondence of high betweenness routes with those of the Antonine Itinerary (AI), indicating that their importance should be related to their connectivity. Some examples include the routes connecting Londinium with Venonis and Deva (AI route II) through Watling Street, with Calleva through Portway (AI route VII) and Corinium through Ermin Street (AI route XIII) and with Lindum (Lincoln) and Eboracum (York) through Ermine Street (parts of AI routes V and VIII). The seemingly limited connectivity of some Antonine routes, such as route XV linking Calleva with Venta and Isca Dumnoniorum (Exeter), might be related to the higher connectivity attributed to coastal transport, and therefore, does not necessarily imply reduced role of road travel as indicated in Fig. 2. The high value of the road/s associated to Hadrian's Wall can be explained by being the shortest path linking the east and west coasts and, to a lesser extent, by its connection to the most transited north-south road, while allowing access to the northernmost territories.

4. Networking exotics

The results of the application of these methodologies by period are provided in Figs. 3 and 4, (see also Fig. 2 and Supplementary Tables 2 and 3) which show significant differences between the early, middle and late Roman periods. These are explored in the following sections. The aim is not to provide a comprehensive analysis of the transport of imported food plants but rather to generate an overall picture to illustrate the potential of employing network approaches in combination with distributions of imported material culture and, in doing so, highlight in a general way long-term trends in the import and distribution of exotic food plants in Roman Britain.

Distributions of ceramic types with the same chronology than that of each study phase have been employed in order to test hypotheses on the distribution of exotics. The datasets used include the online database of 'Roman Amphoras in Britain' (Tyers, 1996a) and 'Potsherd: an atlas of Roman pottery in Britain' (<http://potsherd.net>, an online resource developed from Tyers, 1996b). Pertinent published material on the distribution of ceramics in Britannia was also employed and quoted where relevant.

4.1. Early Roman (1st to early 2nd century AD)

During this period there is a strong presence of exotics in coastal areas and ports accessible to seagoing ships. In terms of land distribution, SpNA seems to point towards a prominent use of the south-western and southern routes compared to the Middle Roman period (see below). From Isca Dumnoniorum a route with north-east direction, following the Foss Way through Corinium (Cirencester), Ryknild Street and north through Bremetennacum (Ribechester), shows great potential to connect sites with access to new food plants and seems to be one of the focal points in the ER exotics' distribution network by road. Most importantly, Calleva seems to act as a redistribution centre, 'concentrating' those routes coming from southern coastal locations from Isca to Noviomagus (Chichester). This site shows high values of betweenness and closeness centrality but average Stri values, indicating a prominent role of the city in the distribution of exotics. This may not be a coincidence as several exotics have been identified at the Late Iron Age oppidum at Calleva (Lodwick, 2014), which may imply the establishment of an early node in their trade in account of its strategic position (Cunliffe, 2012: 20, Laurence, 2001: 88). Data on imported pottery can also attest to Calleva's strong links with the Continent, which during the pre-conquest period includes an impressive array and quantity of Central Gaulish wares and during the ER period shows a more diverse source of imports than that of London (Timby, 2012: 132-5). Calleva also has a strong connection with Londinium, which at this stage, despite being a clear focal node, does not seem to play a central role in the distribution of exotics, but given its high Stri value can be considered a consumption site, which seems to be reflected in the regular acquisition of all types of introduced food plants found within the city (Livarda and Orengo, 2015). Importation of a wide range of exotic food plants to Londinium has been identified (Sidell, 2008; Livarda and Orengo, 2015) and its role as a commercial centre during this phase is well established (e.g. Millett, 1994). Interestingly, however, despite suggestions that London initially developed as an entrepôt for the supply of the military (e.g. Perring, 2011: 252), our analysis suggests that in the case of exotic food plants, those that entered into the town were mainly intended for its cosmopolitan and diverse inhabitants. Our results are in agreement with Wallace's research (2013), who argued that in the pre-Boudican period London's traders had rather weak ties to British trade networks compared to those of Gaul and Germany.

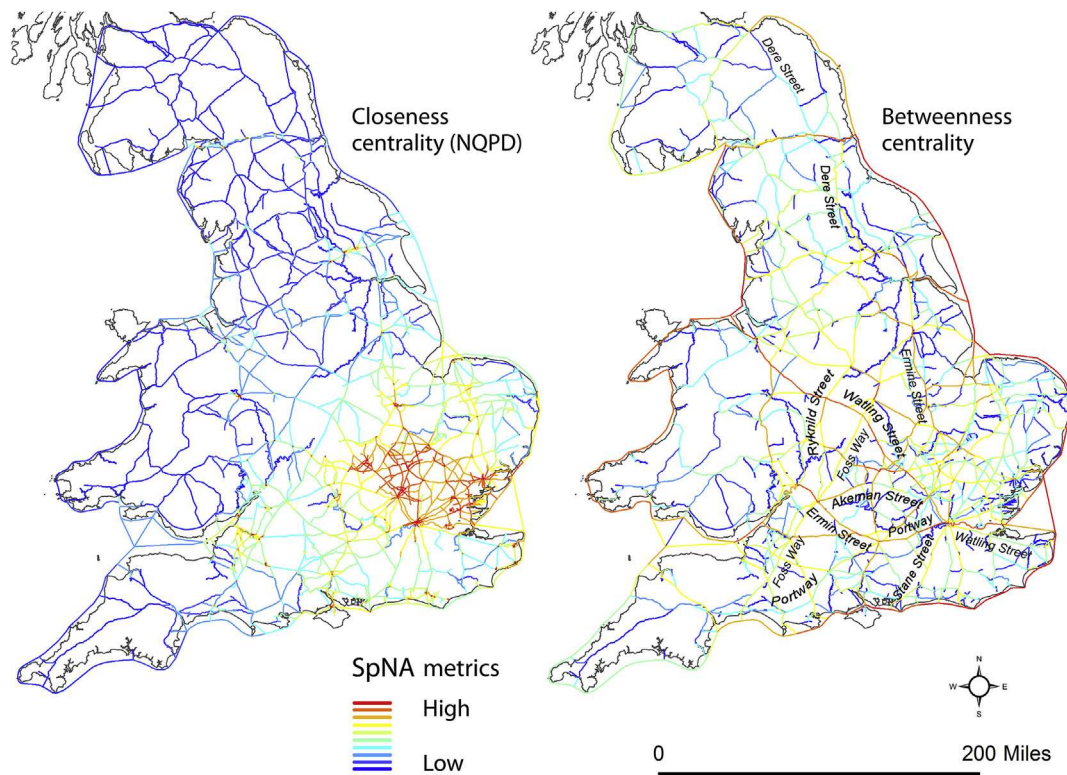


Fig. 2. Results of SNA metrics of the Romano-British transport network as a whole.

From Calleva an important route headed north up to Ratae (Leicester) where it connected to the route heading towards Bremennacum, reaching finally the area of the later Hadrian's Wall at the height of Luguvalium (Carlisle) and to the Foss Way and Ermine Street. A second north-south axis joined south-eastern nuclei, such as Londinium and Camulodunum (Colchester), with northern nuclei like Castleford and Eboracum through Ermine Street. This route seems also to have been the most important route for the distribution of exotics north of Hadrian's Wall following Dere Street, where the highest Stri values are concentrated, finally reaching the area where the Antonine wall would be built.

Another interesting observation is the high closeness centrality values at the end of the navigable stretch of the Thames around the modern cities of Oxford and Didcot. The low Stri numerical value, however, indicates that despite the concentration of exotics in this area these are not particularly diverse or rare in individual sites. This concentration might be thus related to the bulk transport of exotics via Thames to reach a central position for redistribution purposes. Stri together with the low connectivity value attributed to the river by sDNA calculations, indicate that reaching this central position halfway between the east and west coasts would have been achieved by upriver ship transport. This would only be cost-profitable if relatively large quantities of exotics would be transported or they travelled as part of other cargo. This area was also crossed by the main route coming from Silchester and distributing exotics towards the north. The position of London would have been a major factor in its high Stri interpolation and numerical values. Londinium was controlling the exotics' access through a major river route towards the geographical centre of Britain, it was receiving imports from southern ports through the much faster downriver Thames route, and it had access to seagoing ships and road connections. Apart from London other consumption centres, according to their high Stri values during this period, include the forts of Eboracum and Bre-

metennacum, and those at the area of the later Hadrian's Wall where Roman garrisons would be concentrated.

The presence of exotics in this phase shows a very similar distribution to that of amphorae of similar chronologies, such as Haltern 70 and Camulodunum 189 'carrot' amphorae (Fig. 5), which included in their contents exotics, such as olives and dates, but also London 555, Dressel 2-4 and Dressel 7-11. Both Haltern and Carrot amphorae are mostly found in military sites (Fig. 5), which imply a state-controlled distribution of products in bulk. In this regard the correlation of both types of finds close to navigable rivers (Fig. 5) supports the transport of both exotic food plants and amphorae in bulk (although the importance of river transport might also be connected to the incipient state of Roman roads during the first stages of this phase). As amphorae were unsuitable for land transport due to their weight (Carreras, 1994: 179, Tchernia, 1986: 85-87) their correlation with navigable rivers is stronger but their contents, just as the exotics, had to make use of the road network to reach their final destination in many cases. While the exotics' presence does not show such a strong correlation with military sites they might have been part of the cargo transporting these amphorae (in some cases as amphora contents). The high Stri values of military sites seem to confirm such a hypothesis although the presence of exotics in non-military sites and the important Stri value of some native oppida like Calleva and Aquae Sullis seem to indicate that their consumption was open to local elites and other non military individuals. This seems to coincide with the nuanced quantitative analysis of pottery assemblages in south-east Britain by Pitts, which concludes that at the last third of the first century AD 'the consumption of imported pottery in the province was determined by state-driven supply networks rather than market forces' (2008: 504). However, he also suggests that settlements of pre-Roman origin probably had access to these imports and notes how they were more common in nuclei close to the road network.

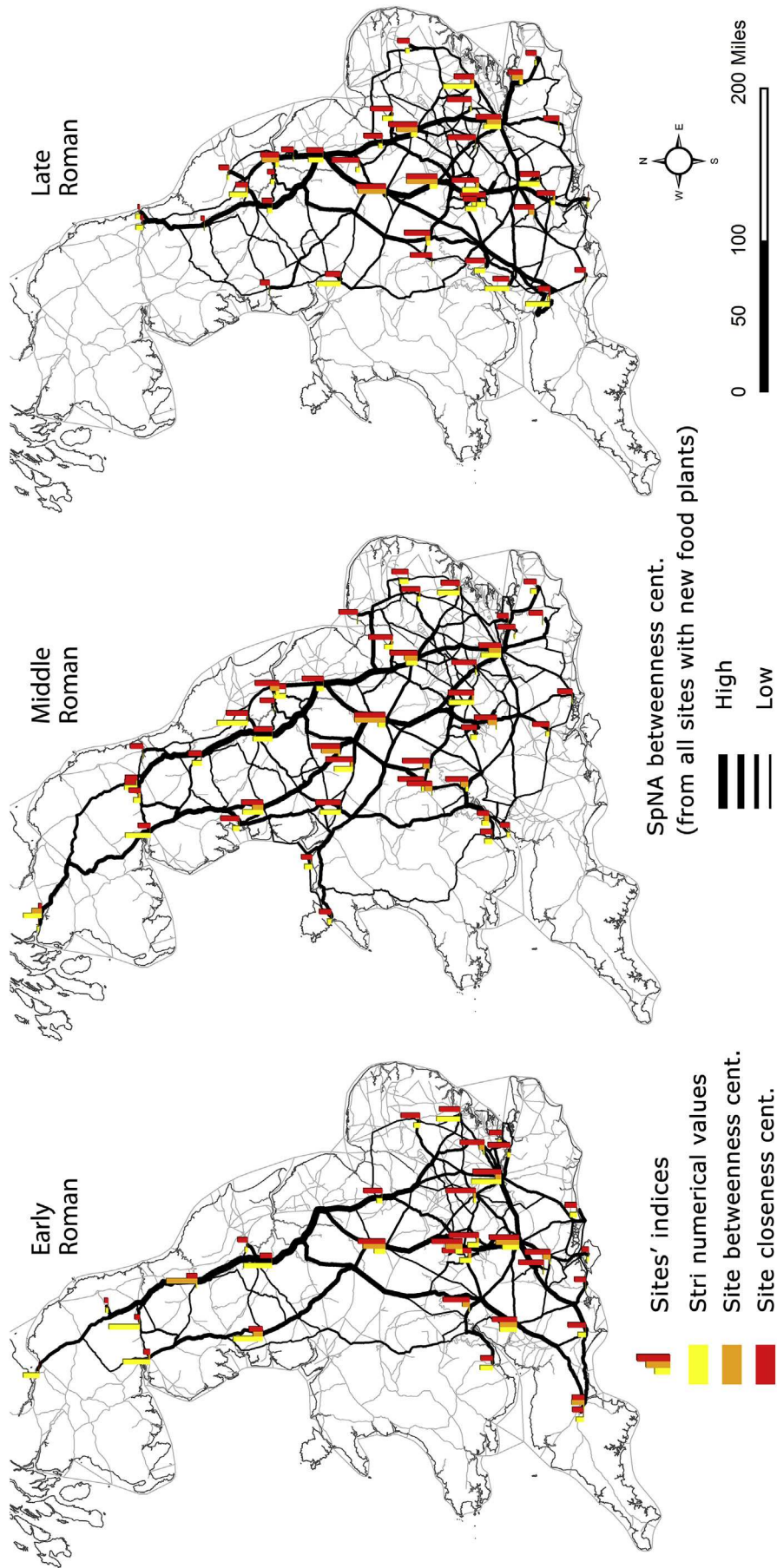


Fig. 3. The combined site indices (Stri numerical values, closeness, and betweenness centrality) and SpNA betweenness centrality routes between all sites with new food plants by period.

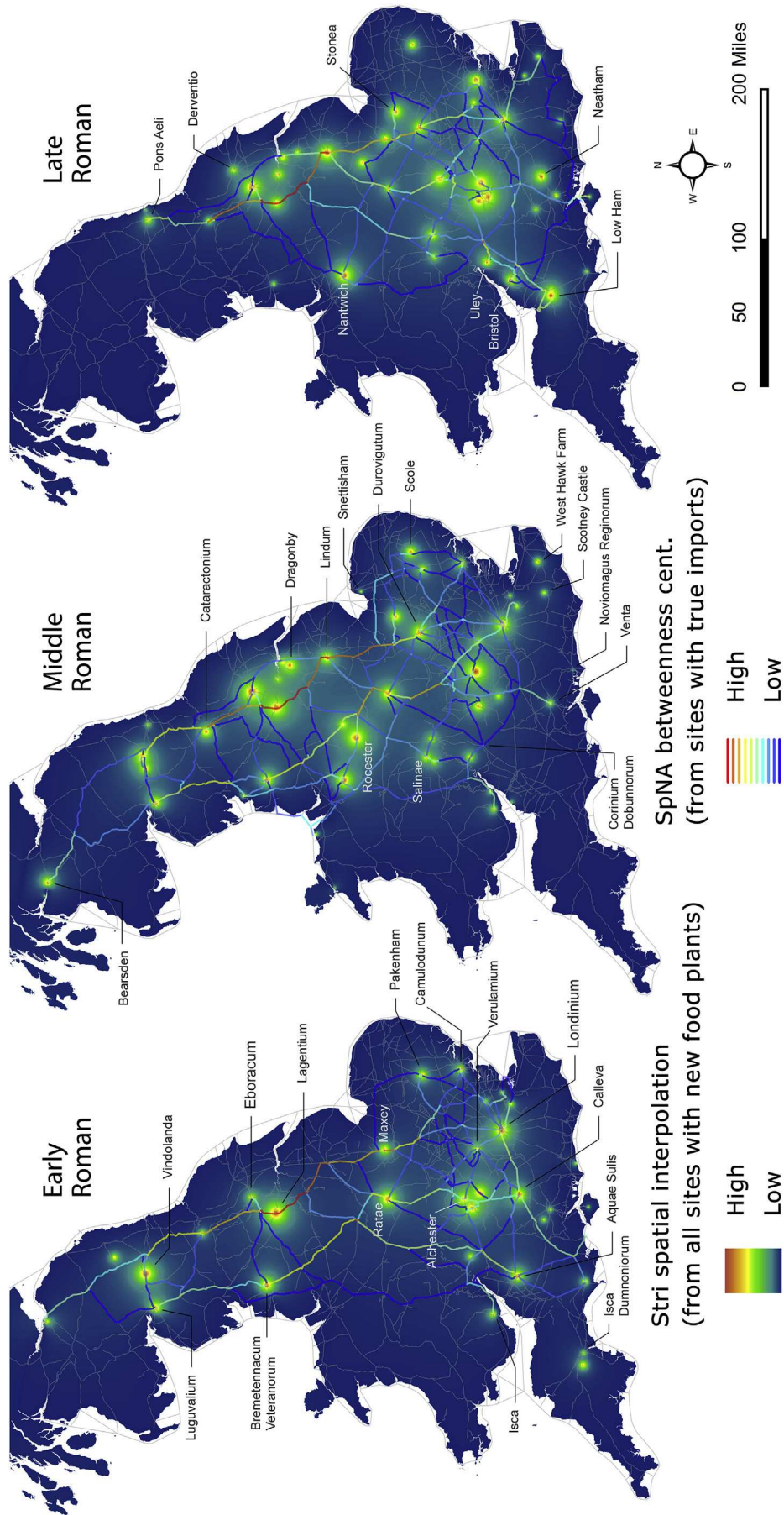


Fig. 4. The combined Stri spatial interpolation and SpNA between centrality routes between sites with true imports by period.

4.2. Middle Roman (2nd and 3rd centuries AD)

During this period a rather different picture emerges. The most significant difference is the increased importance of London as a redistribution centre, which now exhibits a characteristic star shaped radiocentric network, typical of central nodes. The presence of exotics in south-western coastal sites is much reduced despite the increase of data for this period. As also indicated by the distribution of East Gaulish Samian ware (Fulford, 2007: 64), SpNA suggests that London was the principal port of entry of exotics. From there these were distributed to sites inside its radiocentric network and to parts of south-eastern Britannia. The significant decrease of Londinium's Stri numerical value confirms this: despite the high presence of exotics in the city as attested by its Stri interpolation values, this was not solely their final place of consumption but chiefly a redistribution node. The distribution of exotics within the city shows a much higher presence in the entrance/exit points of the city than that of the ER phase, while the reclamations and new revetment constructions on both banks of the waterfront during this period (Rowsome, 2008: 30-31) seem to have helped boosting its commercial capacity (for more details see Livarda and Orenge, 2015). This can be also appreciated by the significant decrease in Stri values at sites located at the end of the navigable stretch of the Thames. During this phase Londinium would have been the final port for redistribution of exotics in south-eastern Britannia and the Thames route might have lost importance in their distribution compared to the previous phase. This, nevertheless, does not deny its importance as a trade route for bulky heavy goods; in fact the change of sources in Calleva's imported pottery, which was now supplied from central Gaul and the Rhineland (Timby, 2012: 135-8), might be related to their redistribution from London via Thames. This change of trade focus from southwest to east is well attested in the archaeological literature linked to the increase of trade with Gaul and changes in the Continental river transport system (e.g. Ellis Jones, 2012: 21-22; Mattingly, 2006: 68). With an equivalent chronological span to that of the Middle Roman phase and produced at Colchester and some other sites around the Thames estuary close to Londinium, Black Burnished 2 ware (BB2) distribution (Fig. 6) can be useful in assessing the importance of Londinium as redistributive centre. In fact, its distribution shows a very similar pattern to that of exotics and they might have been circulated using the same radiocentric road network around London. Without denying previous hypotheses based on changes on Continental transport, our analysis suggests that, at least for exotics, the increase of imports in the southeast can also be linked to the growth of London as the main redistributive centre for south-east Britain.

York, which in the previous phase had a relatively unimportant role in terms of exotics, acquires high Stri interpolation and numerical values. This increase might be due to its position at the main south-north road and on the intersection between two rivers, Ouse and Foss, which allowed easy access to the sea. The decrease in Stri values of the eastern sites of Hadrian's Wall, which are connected to York through Dere Street, could also be related to the concentration of exotics in York. This might suggest that, contrary to London, York acted mainly as a consumption rather than redistribution centre. It is likely that its status as Colonia and the capital of Britannia Inferior later in the MR phase would have encouraged importation of exotics, for instance for the VI Vitrix legion established there during this period, for local elites and the occasional imperial courts. Its reduced redistribution role may be also related to a shift in the defensive importance of Hadrian's Wall towards Antonine Wall, which seems to be supplied with exotics principally through a coastal route, although the use of Dere Street must have remained important. According to Fulford

(1977: 58) York might have had direct sea access to the Continent during the second century, as suggested by its high proportion of East Gaulish Samian. The analysis of BB2 can help in suggesting an alternative hypothesis. Beyond the radiocentric network of London, BB2 pottery also appears in York, and is a common occurrence in both Hadrian and Antonine Walls (Fig. 6), comparable to the high Stri values for exotics in these areas. This further confirms that BB2 used the same routes and distribution methods than those of exotics distributed from the eastern ports. The presence of multiple sites with exotics around York associated with the rivers Ouse, Trent and Aire, navigable to some extent by seagoing ships during high tide in the Roman period, could be related to the transport of bulk cargoes to York to supply the provincial administration. These might have first arrived at London for an initial distribution of exotics, where they would have acquired other products such as BB2 pottery, to then move up the east coast to York and continue to the ports of Hadrian and Antonine Walls. This would explain the strong presence of BB2 pottery at these three points but also at Caister-On-Sea and Brancaster military ports, two of the earlier forts of the Saxon Shore (Cleere, 1978), and the little evidence for its distribution in intermediate inland areas.

Lastly, the analysis suggests a possible entrance of exotics through the Mouth of the Severn, beyond the reach of Londinium's distribution network. Significantly, BB2 pottery was not circulated in this area. The presence of exotics is also documented in the north-west coast associated to military ports, such as Lancaster and Caernarvon, probably related to a coastal distribution of bulk cargoes for military supply. Although these never reached an importance comparable to that of the eastern ports at Londinium and Eboracum, the activation of north-western coastal ports is probably related to the expansion and higher stability of Roman rule in Britannia and the new emphasis on the north, which became a separate province.

4.3. Late Roman (4th century AD including records starting in the 3rd century AD)

This phase, although does not witness a significant decrease in the presence of exotics, sees important changes. The most evident is perhaps the intensification of activity in the southern coast and the Mouth of the Severn, which might be related to the change in the provenance of ceramic imports during the second half of the 4th century, coming from the south of Gaul and the Mediterranean instead of the Rhineland and the Low Countries (Fulford, 1978: 68). This increase of activity is proportional to the decrease of activity in the northern west coast, where a significant reduction in the distribution of exotics is observed. Overall, a 'lambda' pattern by Ryknild Street, the Foss Way and Dere, Ermine and Watling Streets seems to emerge. As a consequence of the southern ports' increase of activity, Calleva recovers its centrality as a node, connecting Portway, Ermin Street and the route from Venta to Dorchester, Alchester and finally Ratae, where it joins the Foss Way. In general, a pattern more similar to the ER than to the MR period emerges, which has been also noted for the commerce of pottery (Fulford, 1977: 57). Amphorae imports of the same period, such as North African, Kapitän II and British B4, show a very similar pattern but are restricted to coastal areas and navigable rivers (Fig. 7), where amphora contents might have been changed to lighter containers for land transport. Exotics (and amphora contents) would have followed a road distribution after their arrival to port, as suggested by the important presence of exotics in inland areas related to road transport. Therefore, despite the similarity in their patterns, in the LR phase the distribution of exotics does not seem to be related to river transport as seen in the ER phase. This might be a consequence of the disruption of the imperial economy: upriver

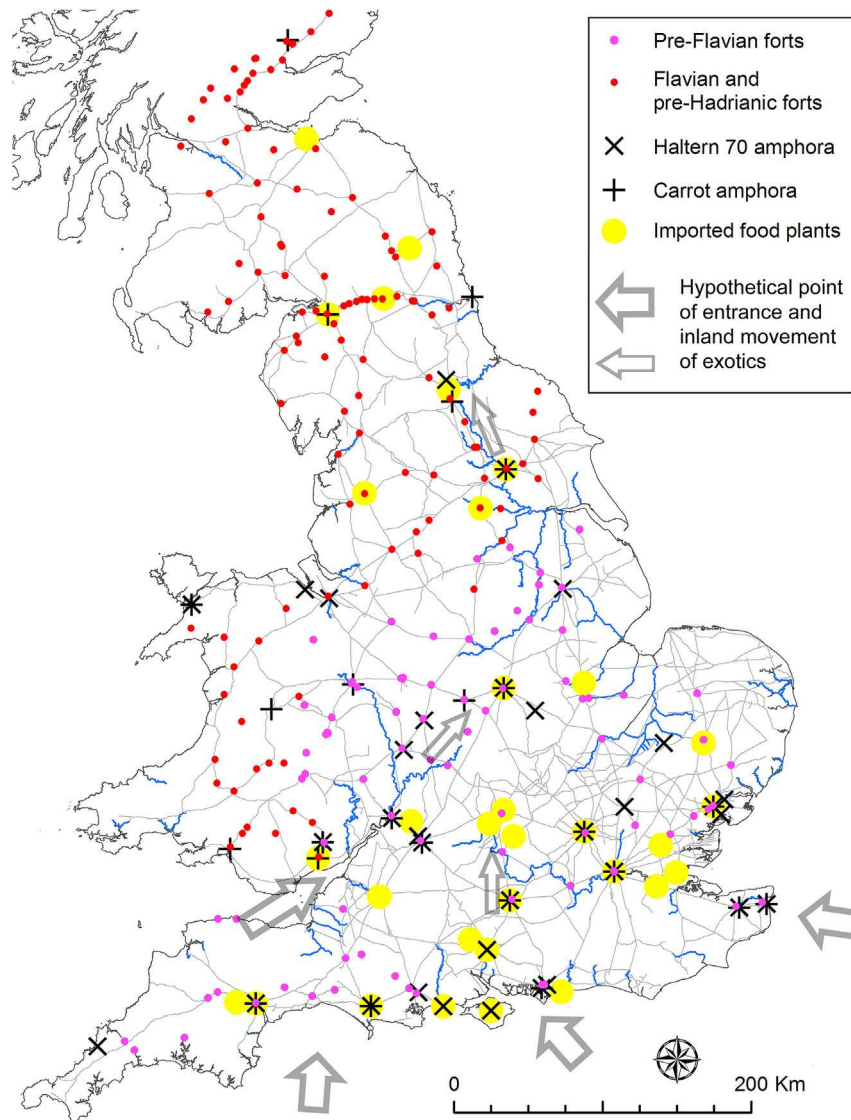


Fig. 5. Comparison of the distribution of exotics in the Early Roman phase to that of Haltern 70 and Camulodunum 189 'carrot' amphorae (following Tyers, 1996a) and Early Roman Forts (from Bishop, 2014).

transport was profitable during the ER phase due to the transport of supplies in bulk for the army and important administrative centres but the lack of a central authority organising or financing the distribution of large cargoes of bulk produce during the LR period would have made upriver transport unusual as it was unprofitable for individual traders specialised in specific products, such as spices. In this phase, a similar type of commerce to that reflected in the Medieval Brokage Books seems to emerge where exotics seem to move by road after their arrival to port.

Although the preponderance of the southern entrance ports during this phase should have reduced the role of Londinium in the transport network, as witnessed in the ER phase where the road network was still incipient, this does not seem to be the case. The reason may be London's acquired central position in the Roman road network, already completed towards the end of the first century. During this phase Londinium seems to lose its role as the main port of entry and the centre of the distribution of exotics. Its Stri value increases as well as those of the areas around it, pointing towards a focus on local consumption rather than redistribution. The exotics seem to be coming from the southern ports, but the particular

star-shape layout of the Roman road network with London at its centre seems to force transit through London to access northern areas and the Thames, important to reach the centre and west of Britain. London's high SNA closeness centrality shows its importance as a distribution centre during the MR phase while its high betweenness centrality helped maintaining its significance during the LR period. These changes might be reflected on the distribution of exotics within London, which in this phase are concentrated in the eastern and western suburbs, previously marginal areas in terms of exotics' consumption (Livarda and Orenge, 2015). The western sector, in particular, might have accommodated native population as indicated by the presence of pre-Roman traditional roundhouses during earlier phases (Roberts, 2004). These changes might be related to Fulford's (2008: 45) suggestion that the disturbance and changes in the south-east from the mid- 3rd century onwards could be related to the end of the Roman elite and its replacement by a new one. In the case of London this might have been reflected in the changes in the consumption of exotics within its townscape.

The increase in Stri values of the sites along the Mouth of the

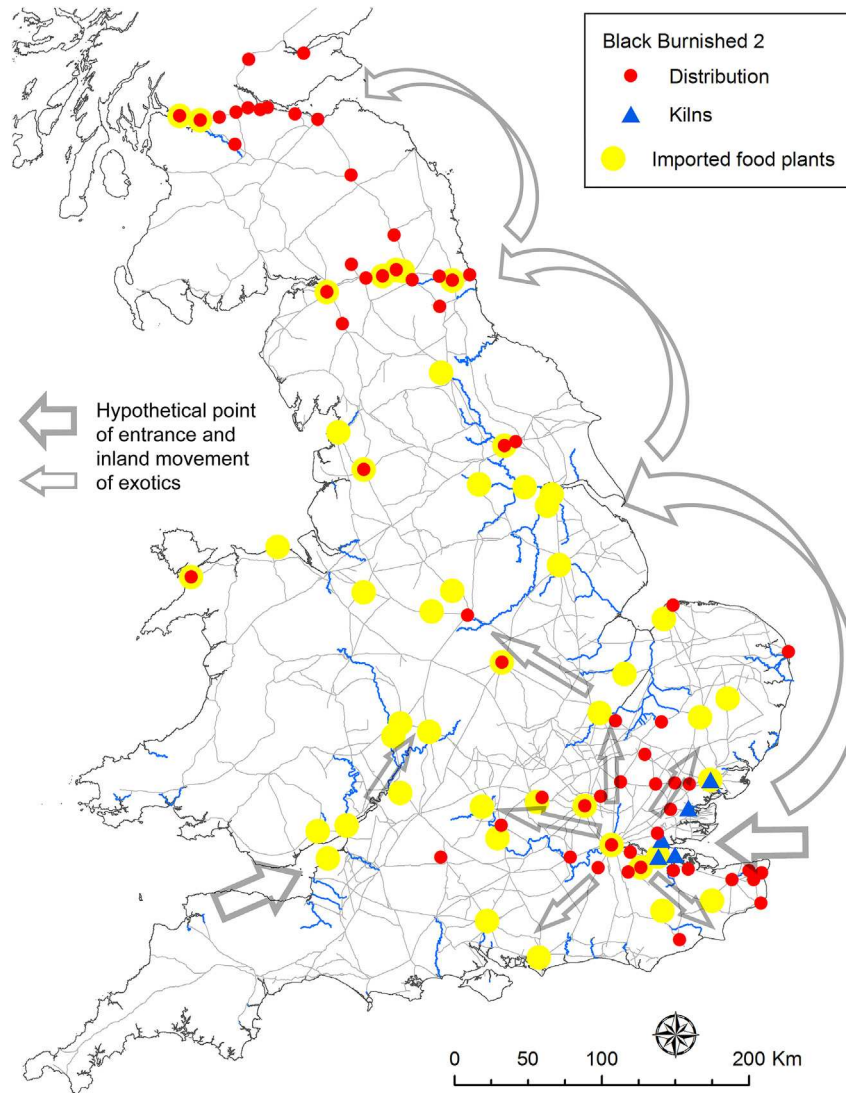


Fig. 6. Comparison of the distribution of exotics in the Middle Roman phase to that of Black Burnished 2 ware and its production sites (following Tyers, 1996b).

Severn and the southern ones confirm the picture of a more regional consumption of exotics. Only the eastern south-north route remains active for the distribution of exotics. Although according to ceramic evidence the north is not linked to the Continent by direct sea routes during the LR period (Fulford, 1977: 58), this route and those coming from the Mouth of the Severn seem to join at York, giving this city high centrality values, as it granted access to the northernmost distribution sites along the eastern part of Hadrian's Wall. The possibility that York could be receiving exotics in bulk cargoes from Londinium using the coastal military supply route inherited from the MR period should also be considered given the continuing presence of exotics close to the Humber estuary and the Ouse and several occurrences of amphorae along the eastern coast at the Saxon Shore sites of Brancaster and Caister-On-Sea.

As indicated by the type of transport mode employed and the distribution of exotics within Britain and Londinium, the disruption of the imperial economy in the LR phase and the recovered importance of the southern and south-western ports might have potentiated a change in the consumption of imports and other exotics linked to the emergence of local, well-connected, individuals or groups, who took over the control of this commerce, recovering traditional ports of entry and commercial practices but

employing the Roman road system. The evidence on the trade of exotics seems to agree with Perring's (2002: 216-7) analysis of 4th century architecture and mosaics and that of Pitts (2008) of pottery assemblages, suggesting the persistence of underlying native structures of elite power in the LR phase inherited from the pre-Roman period.

5. The global market through local consumption: a globalised Roman economy

The military's and, probably, the Roman administration and local elites' ample use of exotics as attested by the high Stri and much lower centrality values of military sites in the ER and MR periods, and the importance of local oppida, such as St. Albans, Calleva and Camulodunum during the ER, hint at a state-controlled distribution of food imports. This seemed to be related to military use during the first stages of Roman rule. However, our results also show that exotics had an extensive distribution across Britannia employing a variety of transport route types and means according to the intended destination and social sector, the supplier interests, the layout of the transport network and the socio-economic background, reaching a wide variety of sites and habitation nuclei well beyond the areas of

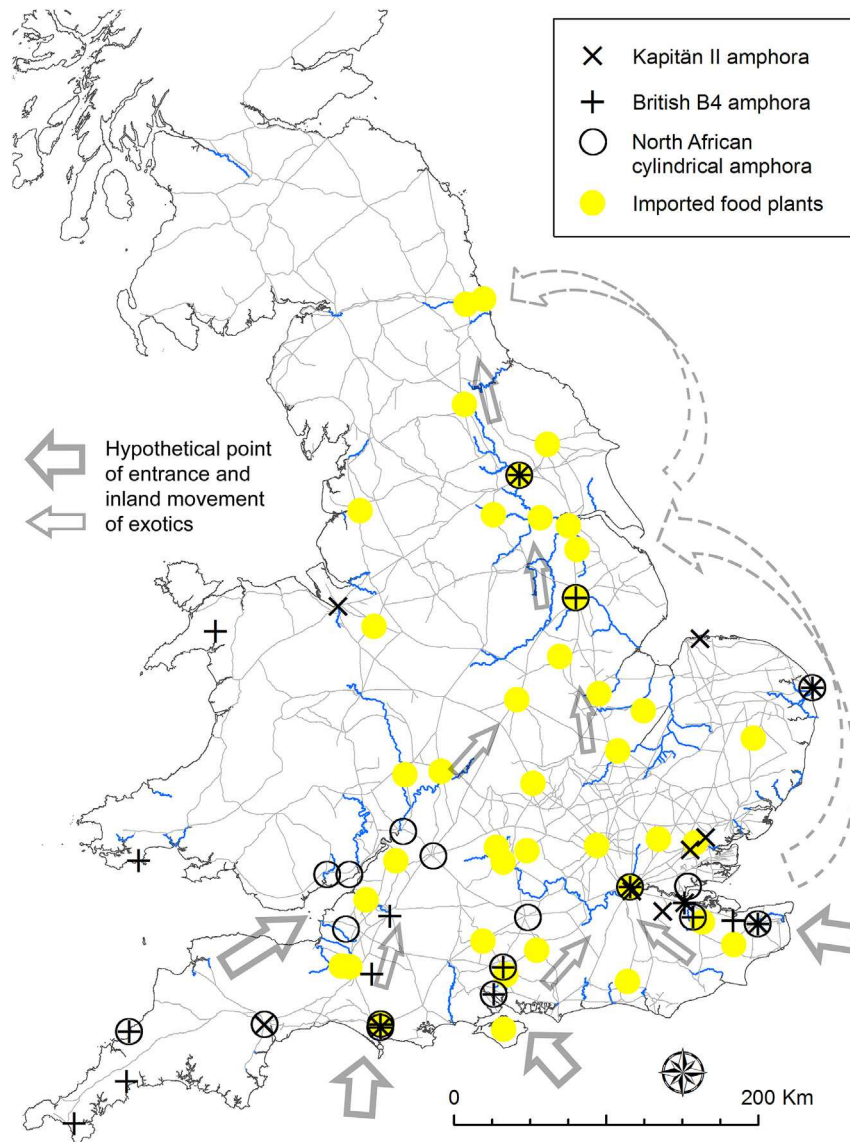


Fig. 7. Comparison of the distribution of exotics in the Late Roman phase to that of North African, Kapitän II and British B4 amphorae (following Tyers, 1996a).

military activity. It seems therefore that, parallel to the military supply, the distribution of exotic food plants followed a market economy where the private entrepreneurship had a prominent role in the distribution of exotics by road from the ports of entrance to local and regional markets. This is also indicated by the importance of the use of roads after the ER phase in comparison with that of rivers, which are better fit for bulk transport and with a prominent role in state-controlled distribution of resources as seen for example in the distribution of Baetican olive oil in Britannia (Carreras, 1994). Despite the low time values given to the change of transport mode, rivers (at least those whose transit would imply a change of transport mode from the seagoing ships in which exotics were imported) do not seem to be employed for the inland distribution of exotics after the ER phase. An exception is the case of the Thames during the LR period, which is probably related to the transport of exotics as part of bulk cargoes destined to reach the innermost point from which they could be distributed by road. As seen for BB2 pottery and the distribution of exotics in the MR period, the distribution of finds is much dependent on the production area or port of arrival.

The strong similarities shown in the SpNA-derived routes for the distribution of true imports and for other newly introduced food plants clearly suggest that these were following the same routes and distribution patterns. This similarity could have very difficultly been achieved if the newly introduced food plants would have been largely produced locally in Britain. In this case the use of a completely different distribution network would have been necessary. It seems, therefore, that sites where tastes for the introduced food plants had been developed are likely candidates for importation of other exotics. This seems to be in accordance with other studies highlighting the globalised nature of Roman economy, which reinforces intensive specialised production of specific goods at the most suitable areas for their manufacturing, followed by long-distance distribution (Orengo et al. 2013). This is also a typical commercial strategy of colonising states where the import of produce creates ties of dependency, as in the case, for instance, of the common practice of provincial Roman administrations of using tax revenues to lend money at low interest to local elites (Pliny the Younger, Ep. X, 54-55; lex Imitana ch. 79-80 in González and Crawford,

1986, see other examples in Temin, 2012: 175). This strategy also provided an important source of benefits for trade associations or societates (which in the Roman case were formed by members of the politically empowered classes) while the local self-supply was discouraged. It is also important to note here that some societates had state contracts for military supplies (Temin, 2012: 172) and others were specialised in large-scale maritime commerce (Rathbone, 2003: 211-13).

6. Conclusions

This study has demonstrated the great potential of the spatial contextualisation of networks and their contrast against independent distribution data in overcoming traditional limitations of network analysis. Such an approach can provide a powerful tool for, not only, the analysis of commerce and the distribution of goods along a transport network, but also for the analysis of movement, contact and transmission of ideas between groups of people. The results of this project show how the combination of spatially-enabled SNA, SpNA and Stri permit the generation of hypotheses of great relevance for the analysis of the development of towns, transport and commerce within wide geographical areas over long periods of time. At the same time the methodologies employed shed new light into the circulation of exotics, and their key consumption foci, which can contribute to more thorough insights into the Roman social network and its foodways.

Having developed a solid framework for the exotics and the road network the next stages of this research necessitates detailed studies of the exotics' distribution within key nodal sites (see Livarda and Orenco, 2015 for London). These allow investigating how the changes in the whole network are both reflected on and influenced by single nodes forming sub-networks and exploring their significance within their particular historical context. Future detailed analysis of the Roman transport network through testing of different models of transport and distribution can also lead to a more nuanced picture of its constraints and strengths, which will contribute towards a better understanding of Britannia's economy and society.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at: <http://dx.doi.org/10.1016/j.jas.2015.12.003>.

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