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Symploke and *Complexio*
Entangling and Dis-Entangling the Networks of the Roman Empire of the East in the Early Medieval World, Fourth-Ninth Century CE

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Abstract The paper synthesises and develops further several attempts to model aspects of the complexity of the infrastructure and administrative organisation of the Roman Empire between the 4th and 8th century CE based on evidence from historiography, historical geography, sigillography and archaeology. It provides a short introduction into concepts and analytical tools of network theory. Furthermore, the paper combines this approach with a visualisation of the spatial range of Roman power and maps based on mobility and perceptions of contemporaries. Thereby, the already successful integration of the 'relational turn' to Byzantine studies shall be demonstrated.

Keywords Complexity theory. Network analysis. Roman infrastructure. Roman administration. Late antiquity. Early Medieval Mediterranean.

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Per Ewald Kislinger
in occasione del suo 65esimo compleanno.

1 Introduction

This paper synthesises and continues some 'experiments' I have undertaken to approach aspects of the complexity of the infrastructure and organisation of the Roman Empire from the fourth century CE onwards with the help of concepts and tools of network theory. It aims to demonstrate both the potential (and theoretical basis) of these methods as well as the possibility to apply them even to a period identified as poor in sources or even as a 'dark age' in earlier scholarship. Furthermore, it illustrates how these more abstract models can be connected to perceptions of Roman power, and the entanglements it caused, by contemporaries. Finally, this paper is based on the important pioneering contributions from scholars of Byzantium and Late Antiquity to what has been called the 'relational turn' in social and historical studies.[1]

2 Interweaving the World through Roman Power

In the first Greek historiographical work devoted entirely to the Roman Empire, the starting point for Polybios (c. 200-120 BCE) is the unprecedented 'interweavement' (in Greek *symploke*, in Latin *complexio*; see Walbank 1975; Davies 2019) of the three continents of Africa, Asia and Europe around the Mediterranean by Roman power:

> Previously the doings of the world had been, so to say, dispersed, as they were held together by no unity of initiative, results, or locality; but ever since this date history has been an organic whole, and the affairs of Italy and Libya [i.e. Africa] have been interwoven with those of Greece and Asia [*symplekesthai te tas Italikas kai Libykas praxeis tais te kata ten Asian kai tais Hellenikais*], all leading up to one end. And this is my reason for beginning their systematic history from that date. For it was owing to their defeat of the Carthaginians in the Hannibalic War that the Romans, feeling that the chief and most essential step in their scheme of universal ag-

1 Such as Mullet 1997; Ruffini 2008; Schor 2011; Arthur, Imperiale, Muci 2018; see also Preiser-Kapeller 2020a for an overview. An exhaustive and constantly updated bibliography of historical network research can be found here: `https://historicalnetworkresearch.org/bibliography`. The same website provides an introduction to the first steps towards applying these methods: `https://historicalnetworkresearch.org/first-steps`.

> gression had now been taken, were first emboldened to reach out their hands to grasp the rest and to cross with an army to Greece and the continent of Asia. (Plb. 1.3.3-6 [transl. Paton 1922-27])[2]

Already before Polybios, for Herodotos (fifth century BCE) for instance the expansion of the Persian Empire had provided a framework to entangle the histories of various regions on all three continents. The Roman imperial project, however, for the first (and last) time would integrate all areas of the 'Oecumene' around the Mediterranean in one polity (Marincola 2007, 171-9; Dillery 2011, 171-218; Potter 2011, 316-45).

In the imagination of later imperial panegyrics, Roman power would range even far beyond this Mediterranean core, as in a Latin eulogy of Latinius Pacatus Drepanius on Emperor Theodosius I from 389 CE (see also Turcan-Verkerk 2003):

> For your guidance, Emperor, had frightened not only those people divided from our world by swathes of forest or rivers or mountains, but those which Nature has separated, made inaccessible by perpetual heat, set apart by unending winter, or cut off by intervening seas. The Indian is not protected by Oceanus, nor the man from Bosphorus by the cold, nor the Arab by the equatorial sun. Your empire (*imperium*) reaches places that the name of Rome has hardly reached before. (*Panegyrici Latini* 2.22.2 [ed. and transl. Mynors 1964, 99])

A similar scope of Roman power is still evoked in the twelfth century by Anna Komnene in the *Alexias*:

> For there was a time when the limits of the Roman rule [*tes ton Rhomaion hegemonias*] were the two pillars which bound east and west respectively, those on the west being called the "pillars of Heracles", those on the east the "pillars of Dionysus" somewhere near the frontier of India. It is hardly possible to define the Empire's former width. Egypt, Meroë, all the Troglodyte country, and the region adjacent to the torrid zone; and in the other direction far-famed Thule, and the races who dwell in the northern lands and over whose heads the North Pole stands. (Anna Komnene, *Alexias* 6.11.3 [ed. Reinsch, Kambylis 2001, 1: 193; transl. Sewter, Frankopan 2009, 176])

The Komnenian princess, however, had also to contrast this former glory with the sad state of the Roman Empire in the late eleventh

2 The translation is available online: `https://penelope.uchicago.edu/Thayer/E/Roman/Texts/Polybius/1*.html`.

century, at the nadir of crisis confined even to a mere corner of the Mediterranean and only partly restored by her father Alexios I Komnenos (1081-1118) despite his efforts:

> But in these later times the boundary of the Roman sceptres [*ton Rhomaion skeptron*] was the neighbouring Bosporus on the east and the city of Adrianople on the west. Now, however, the Emperor Alexios by striking with both hands, as it were, at the barbarians who beset him on either side and starting from Byzantium as his centre, enlarged the circle of his rule, for on the west he made the Adriatic Sea his frontier, and on the east the Euphrates and Tigris. And he would have restored the Empire to its former prosperity, had not the successive wars and the recurrent dangers and difficulties hindered him in his purpose (for he was involved in great, as well as frequent, dangers). (Anna Komnene, *Alexias* 6.11.3 [ed. Reinsch, Kambylis 2001, 193; transl. Sewter, Frankopan 2009, 176-7])

If modern scholars try to capture aspects of the swaying of Roman power from antiquity to the late Middle Ages with novel concepts such as 'networks', 'entanglements' and 'complexity', they follow the footsteps of earlier historians of the empire to a certain degree. New digital tools applied to data from written evidence, archaeology, and historical geography, however, allow to survey, visualise, measure, and even model the empire's *symploke* or *complexio* as well as the properties and dynamics of underlying structures beyond mere metaphors.

3 Networks of Routes and Imperial Ecologies

One enduring infrastructure for the entanglement of the regions around the Mediterranean through Roman power was the road system, into which the administrators and later the emperors invested heavily. Roman roads were built especially for military purposes (beginning with the Via Appia in 312 BCE leading from Rome to Capua and in 190 BCE expanded towards Brundisium at the Adriatic Sea, from where maritime routes led to the Greece). Finally, across the entire empire, the maximum extent of the road network was between 80,000 and 100,000 km.[3] For the transport of bulk goods, however, maritime links were even more important and became increasingly vital for the provision of the growing capital. Since 123 BCE, the city of Rome became dependent on consignments of grain from North Africa, which at that time were financed with the taxes from

3 Kolb 2000; Sauer 2006; Schneider 2007, 72-5, 89; Ruffing 2012, 42-3; Klee 2010.

the recently acquired territories in Western Asia Minor, thus establishing an early triangle of flows of the 'imperial ecology' (Erdkamp 2005; Ruffing 2012, 98-9; Sommer 2013, 90-1).

The concept of 'imperial ecology' was introduced by Sam White (2011, 17) in his study on the Ottoman Empire in the sixteenth and seventeenth century CE; he defined it as the "particular flows of resources and population directed by the imperial center" on which its success and survival depended. Within the web of the imperial ecology, the supply of the imperial centre can be identified as a core element (González de Molina, Toledo 2014; Forman 2014; Schott 2014). Another analytical framework for this supply is the concept of 'urban metabolism'; its content and implications (for what has been called the 'colonisation of nature') have been described as follows:

> The concept [of urban metabolism] looks at resources which are essential for the reproduction of a city on both the level of physical reproduction of the urban residents (including animals), i.e. their 'biological' metabolism as well as collective reproduction of the city as a social, economic and cultural system, i.e. the construction and maintenance of houses, collective buildings such as churches, streets, walls etc., the material production of goods for the needs of the urban residents themselves or for trade to import necessary resources from other places. The focus of this concept lies on material flows and their transformation over time. The concept of 'colonization of nature' brings further dynamic temporal as well as spatial dimensions into this relationship: If cities and their population grow […] they will need to reach beyond their immediate surroundings in order to fulfil their basic needs. They will tend to exercise either political dominance by extending the territory they control, or use market power to attract production surpluses from further distant regions. Thus cities mobilize in a variety of ways resources of an ever widening hinterland for their social metabolism. (Schott 2014, 172-3)

In 2014, Brian J. Dermody and his team modelled the imperial ecology of the Roman Empire as a "virtual water network" (Dermody et al. 2014), in which precipitation (or Nile floods) were transported across the Mediterranean in the form of agrarian surplus – with the urban metabolism of Rome at its centre, feeding on grain form North Africa and Egypt or olive oil from the south of the Iberian Peninsula, for instance. Regarding its dependency on the scale and reach of these networks, Peter Baccini and Paul H. Brunner made clear that the city of Rome in the imperial period had become

> an example of a system that could only maintain its size […] on the basis of a political system that guaranteed the supply flows. The

> drastic shrinking [of Rome from the fifth century onwards] was not due to an ecological collapse but to an institutional breakdown. The metabolism of such large systems is not robust because it cannot maintain itself without a huge colonized hinterland. It has to reduce its population to a size that is in balance with its economically and ecologically defined hinterland. (Baccini, Brunner 2012, 58; see also Morley 1996; Fletcher 1995)

The characteristics, cohesion, and robustness of such webs of infrastructures can be approached with the help of digital network models. The most exhaustive network model of historical sea and land routes of the Roman Empire in the fourth century CE so far is the "ORBIS Stanford Geospatial Network Model of the Roman World", developed by Walter Scheidel and Elijah Meeks in 2014 to estimate transport cost and spatial integration within the Roman Empire (Scheidel et al. 2014). ORBIS is based on a network of roads, riverine and sea routes (in total 1,104 links) between 678 nodes (places, mostly cities), weighted according to the costs of transport. Since it covers the entirety of the empire's traffic system, ORBIS is less detailed on the regional and local level than network models for smaller areas already existing or under development (Orengo, Livarda 2016). Nevertheless, it is useful as a heuristic tool to reflect upon the structures (cores and peripheries, over-regional and regional cluster) and robustness of such a complex system 'entangling' three continents under pre-modern transport conditions, as I have demonstrated in several papers (Preiser-Kapeller 2015d; 2020c; 2021). Before summing up and developing further these findings however, it is necessary to introduce some basic concepts and tools of complexity theory and network analysis.

4 Excursus. A Short Introduction to Complexity Theory and Network Analysis

It has been argued that

> complexity is not a theory but a movement in the sciences that studies how the interacting elements in a system create overall patterns, and how these overall patterns in turn cause the interacting elements to change or adapt. (Arthur 2015, 3; see also Beaudreau 2011)

Complex systems are understood as large networks of individual components, whose interactions at the microlevel produce 'complex' changing patterns of behaviour of the whole system at the macrolevel (Mainzer 2007; Miller, Page 2007; Mitchell 2009).

Network models are one possible tool to capture elements and linkages of a complex system. Network theory assumes "not only that ties

matter, but that they are organised in a significant way, that this or that (element) has an interesting position in terms of its ties" (Lemercier 2012, 22). One central aim of network analysis is the identification of structures of relations. These structures emerge from the sum of interactions and connections between individuals, groups, or sites; at the same time, they influence the scope of (inter)actions of everything and everyone entangled in such relations. For this purpose, data on the categories, intensity, frequency and dynamics of interactions and relations between entities of interest (people, objects, places, semantic entities etc.) are systematically collected, allowing for further mathematical analysis. This information is organised in the form of matrices (with rows and columns) and graphs (with nodes [representing the elements to be connected] and edges [or links, representing the connections or interactions of interest]). Matrices and graphs are not only instruments of data collection and visualisation, but also the basis of further mathematical operation.[4]

A quantifiable digital network model created on this basis allows for a structural analysis on three levels (Collar et al. 2015). At the level of single nodes, respective measures consider the immediate 'neighbourhood' of a node – such as 'degree', which measures the number (or accumulated strength) of direct links of a node to other nodes.[5] 'Betweenness' measures the relative centrality of a node within the entire network due to its position on many or few possible paths between nodes otherwise unconnected. Betweenness can be interpreted as potential for intermediation; nodes with high betweenness provide cohesion and connectivity within the network.[6] A further possible measure of node centrality is 'closeness', which determines the length of all paths between a node and all other nodes (i.e. how many intermediary nodes would be necessary to get a message from one node to another node). The 'closer' a node is, the lower is its total and average distance to all other nodes. Closeness can also be used as a measure of how efficiently resources or information can be distributed from a node to all other nodes or how easily a node can be reached (and supplied with signals or material flows) from other nodes (Wassermann, Faust 1994, 184-8; Prell 2012, 107-9; see **[fig. 1]** for an example).

4 Wassermann, Faust 1994, 92-6; Prell 2012, 9-16; Barabási 2016, 42-67; Brughmans 2012; Knappett 2013; Collar et al. 2015; Brughmans, Collar, Coward 2016.

A short 'manual' on how to collect and to put network data on a map with the help of easily available software tools can be found can be found in Preiser-Kapeller 2019. Further tutorials can be found here: `https://historicalnetworkresearch.org/external-resources`.

5 Wassermann, Faust 1994, 178-83; de Nooy, Mrvar, Batagelj 2005, 63-5; Newman 2010, 168-9; Prell 2012, 96-9.

6 Wassermann, Faust 1994, 188-92; de Nooy, Mrvar, Batagelj 2005, 131-3; Newman 2010, 185-93; Prell 2012, 103-7; see **[fig. 2]** for an example.

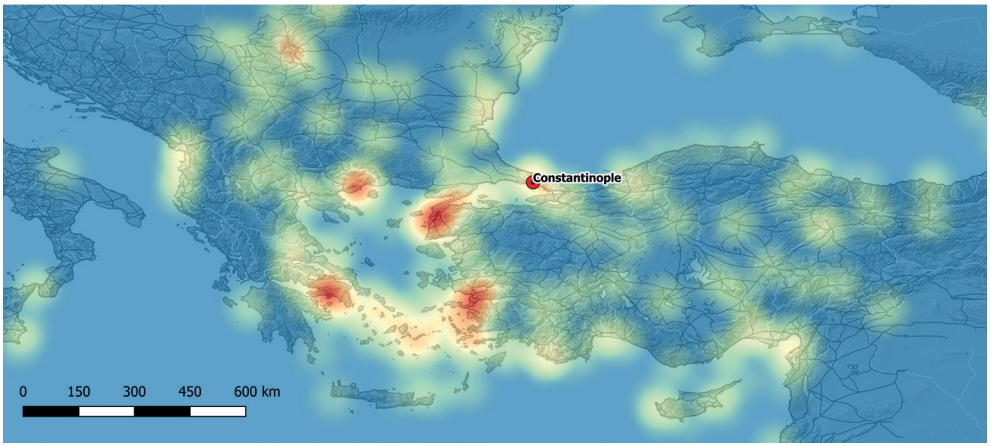

Figure 1 Spatial distribution of closeness centrality among nodes in the modified ORBIS-network model of routes confined onto the Roman territories after the mid-7th century (data: Scheidel et al. 2014; calculations and visualisation: J. Preiser-Kapeller)

At the level of substructures of nodes, one approach is the identification of 'clusters', meaning groups of nodes more densely connected among each other than to the rest of the network (the number and/or strength of connections between them is stronger than on average between nodes within the network). A measure of the amount to which nodes in a graph tend to cluster together is the "clustering coefficient" (with values between 0 and 1) (Wassermann, Faust 1994, 254-7). To detect such clusters, an inspection of a visualisation of a network can be already quite helpful, since common visualisation tools arrange nodes more closely connected near to each other and thus provide a good impression of such substructures (Krempel 2005; Dorling 2012: see **[fig. 3]** for an example). For exact identification, there exist various algorithms of 'group detection', which aim at an optimal 'partition' of the network. A high 'clustering' within a network equally provides more opportunity for nodes to act as intermediaries between otherwise disconnected subgroups, thus providing them with high betweenness (see above). On the other hand, such a network could also tend towards fragmentation in case such connecting nodes or essential links fail or are destroyed.[7]

At the level of the entire network, possible measurements are the total numbers of nodes and of links, the maximum distance between two nodes (expressed in the number of links necessary to

7 de Nooy, Mrvar, Batagelj 2005, 66-77; Newman 2010, 372-82; Prell 2012, 151-61; Kadushin 2012, 46-9.

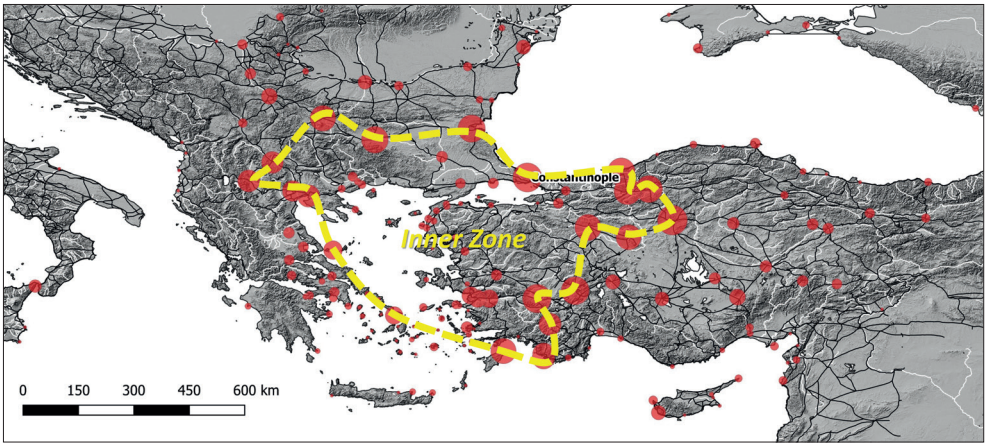

Figure 2 Spatial distribution of betweenness centrality among nodes in the modified ORBIS-network model of routes confined onto the Roman territories after the mid-7th century (data: Scheidel et al. 2014; calculations and visualisation: J. Preiser-Kapeller)

find a path from one to the other) and the average distance (or path length) between two nodes. A low average path length among nodes together with a high clustering coefficient can be characteristic of a 'small world network', in which information or resources between most nodes can be distributed via a relatively small number of links (the famous 'six [or even less] degrees of separation') (de Nooy, Mrvar, Batagelj 2005, 125-31; Prell 2012, 171-2; Watts 1999). 'Density' indicates the ratio of possible links actually present in a network: theoretically, all nodes in a network could be connected to each other (this would be a density of '1'). A density of '0.1' indicates that 10% of these possible links exist within a network. The higher the number of nodes, the higher the number of possible links in a network. Thus, in general, density tends to decrease with the size of a network, since not all nodes in a large-scale network are directly connected. Therefore, it only makes sense to compare the densities of networks of (almost) the same size. Density can be interpreted as one indicator for the 'cohesion' of a network, since a high density also implies a relative redundancy of connections (Prell 2012, 166-8; Kadushin 2012, 29). Other measurements are based on the equal or unequal distribution of centrality values such as degree, betweenness or closeness among nodes. A high 'degree centralisation' for instance indicates that many links are concentrated on a relatively small number of nodes (Prell 2012, 168-70). These distributions can also be statistically analysed and visualised for all nodes (by counting the frequency of single degree values) and used for the comparison of networks. Highly unequal degree distribution patterns have been interpreted

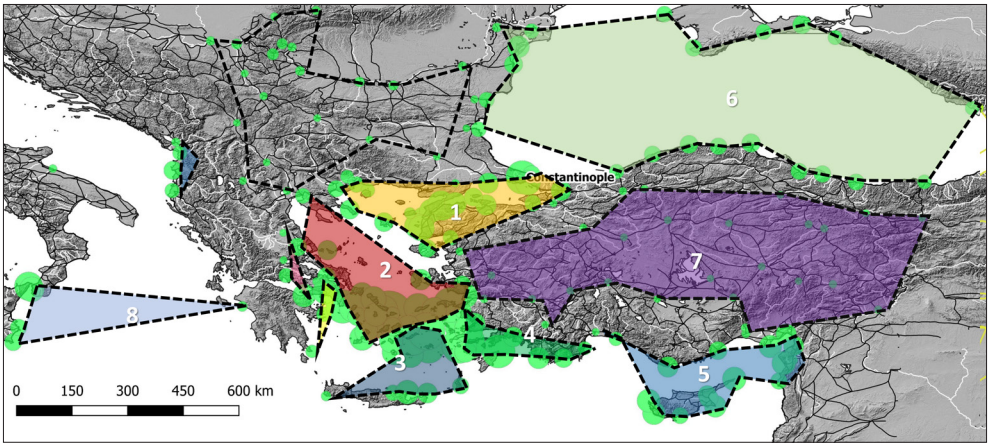

Figure 3 Spatial distribution of degree centrality among nodes in the modified ORBIS-network model of routes confined onto the Roman territories after the mid-7th century and identification of clusters (subgroups of nodes) by internal connectivity within the network (data: Scheidel et al. 2014; calculations and visualisation: J. Preiser-Kapeller)

as 'signatures of complexity' of a network, since they also suggest underlying (non-random) dynamics which privilege certain, already relatively well-connected nodes when it comes to the formation of new links during the growth of a network. Such patterns may also reflect strategies of individual actors, who try to link themselves to already well-connected individuals who may serve as intermediaries to as many other nodes as possible (Newman 2010, 243-61; Preiser-Kapeller 2020b).

In cases of networks of cities (such as the ORBIS model), certain places may serve as special attractors of interactions and connections due to locational advantages (being positioned at the intersections of important sea, riverine and land routes) and/or institutional privileges because of their functions as administrative centres, for instance. The modelling of networks of routes between places equally demands further specifications. Links in such a model are both weighted (meaning that a quantity is attributed to them) and directed (for instance, a link leads from point A to point B). Thereby, aspects of 'transport friction' are integrated into calculations (Isaksen 2008). Otherwise, the actual costs of communication and exchange between sites, which influenced the frequency and strength of connections, would be ignored in network building. Links can be, for instance, weighted by using the inverted geographical distance between them; thus, the shorter the distance, the stronger is a link between two nodes (what has been called 'distant decay'). If possible, existing historical information on the (temporal or economic) costs

for using specific routes could be included (as Walter Scheidel and his team did for ORBIS by integrating data from the maximum price edict of Emperor Diocletian on freight charges, for instance; Scheidel et al. 2014). Furthermore, cost calculation stemming from a modelling of terrain and routes with the help of Geographical Information Systems (GIS) software can be integrated (as Scheidel et al. 2014 also did). In riverine transport networks, directed links leading upstream (from point A to point B) are weighted differently from links leading downstream (from point B to point A), again reflecting different energy and time investments to overcome distance.[8]

Networks 'in real life' are dynamic: relationships can be established, maintained, modified, or terminated; nodes appear in a network and disappear (also from the sources). The common solution to capture at least part of these dynamics is to define 'time-slices' (divided through meaningful caesurae in the development of the object of research) and to model distinct networks for each of them. Yet, for infrastructure networks, a relative long-term stability of core elements can be assumed and the use of one static model can thus be justified.[9] Furthermore, routes and infrastructures are only one 'layer' of the various networks spanning across an imperial space, such as webs of ties of administration, commerce, or religion. All these categories of connections could be integrated as different (but often overlapping) network layers into a 'multi-layer' network model. Yet unfortunately, we do not possess the same density of evidence for these webs across the entire empire as we have for the routes. At the same time, flows of people and ideas were much more volatile than the infrastructural web, on which all these other categories of linkages in turn were depending.[10]

8 Rodrigue, Comtoi, Slack 2013, 307-17; Taafee, Gauthier 1973, 100-58; Ducruet, Zaidi 2012; Barthélemy 2011; Carter 1969; Pitts 1978; Gorenflo, Bell 1991; Graßhoff, Mittenhuber 2009; Leidwanger et al. 2014; van Lanen et al. 2015; Preiser-Kapeller 2015e; 2020c; 2020e.

9 de Nooy, Mrvar, Batagelj 2005, 92-5; Lemercier 2012, 28-9; Batagelj et al. 2014; Preiser-Kapeller 2020c.

10 Collar 2013; Auyang 2015; Bianconi 2018; Preiser-Kapeller 2015a; 2015b; 2015c; Preiser-Kapeller, Mitsiou 2019.

5 Network Models for the Fragmentation and Re-Integration of the Roman Empire, Fourth-Eighth Centuries

One of the earliest studies in the field of historical network research was published by F.W. Carter in 1969. He created a network model of the route system in the Serbian Empire of Stefan Uroš IV Dušan (1331-55), using the most important urban centres as nodes and the main trade routes as links. Carter's paper considered the actual geographical distances between places; one of its main aims was to "learn more about the position" of the "successive capitals" within the route network of the Serbian Empire and "whether Stefan Dušan made the right choice in Skopje as his capital". According to Carter´s calculations, Tsar Dušan residence of choice did not rank among the most central nodes in the network model. Other places would have been better situated, Carter argued, and would have provided better opportunities for economic development, the ease of "troop movement" or the flows of materials, thus central aspects of the "imperial ecology" (Carter 1969, 54-5).

Following Carter's pioneering study, I analysed the various network measures of centrality for the city of Rome within the ORBIS-model in an earlier study (Preiser-Kapeller 2020c). Results indicate high connectivity, especially regarding betweenness (i.e. the position as intermediary and connector), for which the value of Rome is four times higher than the average one. In total, however, Rome is not the most central hub in the network model. If we compare its centrality measures with the ones of cities selected as imperial residences in the fourth and fifth centuries CE, some such as Milan, Aquileia, Sirmium or Serdica, they match or even outperform Rome regarding their betweenness and closeness values. In terms of urban scale and population size, however, these places of course could not compete with Rome, which remained privileged regarding the inflows of supplies from across the Mediterranean (Erdkamp 2005; Scheidel, Morris, Saller 2007, 651-71).

Only Constantinople, inaugurated as the new capital by Emperor Constantine I in 330 CE, would eventually outperform the old capital on the Tiber also in these aspects over the course of the fifth century CE. Constantinople is also the only one among the eleven imperial capitals I analysed, which ranks in the ORBIS-network model among the top ten in all three centrality measures of degree (more than six times the average value), betweenness (more than six times the average value) and closeness (the values usually have a smaller spread, but Constantinople is equally among the top nodes). Following Carter's ideas on the "Medieval Serbian Oecumene", this multidimensional centrality may contribute to an explanation of Constantinople's longtime 'success' as imperial centre within the Mediterranean Oecumene

over almost 1,600 years until 1923 (the fall of the Ottoman dynasty), much longer than Rome itself (Preiser-Kapeller 2020c; 2021).

During these centuries, however, Constantinople experienced several cycles of imperial dis- and re-integration and of shrinking and re-expansion of the territories under its control. At certain times, core regions of the wider 'hinterland' for its 'urban metabolism' were lost (such as Egypt in the seventh century), and the entire imperial ecology had to be re-organised (Preiser-Kapeller 2021). A similar fragmentation of the Western Roman sphere in the fifth century resulted in a dramatic urban decline of Rome, as discussed above. A recent palaeobotanical study on Portus, the main harbour of Rome, by Tamsin C. O'Connell and her team identified the mid-fifth century, with the loss of North Africa to the Vandals and their plunder of Rome in 455, as the decisive turning point in Rome's urban metabolism. After this time, the share of the wheat cultivars imported from North Africa in the sample declined from more than 90% to less than 20% (O'Connell et al. 2019).

Such a scenario can be supported by a test of robustness I executed on the ORBIS network model in the already mentioned earlier study (Preiser-Kapeller 2020c). Step by step, I deleted all links in the network above a threshold of a calculated travel time of five, three or two days and finally one day. This, of course, leads to a steady decline of measures of 'connectedness' within the network model, where also the potential reach of diffusion of information or resource within the web decreases. The modified network model shows a 'disentanglement' of large parts of the Roman traffic system, especially in the West of Europe, in the interior of the Balkans or also between the North and South coasts of the Mediterranean (Preiser-Kapeller 2020c). The model is of course only an appropriation towards certain structural parameters of the web of transport links within the Roman Empire. Nevertheless, we observe some parallels to actual historical processes of the fifth to seventh century. Chris Wickham for instance described a partial "micro-regionalisation" of the Roman "world-system" during this period due to a contraction of long-distance connections (Wickham 2004; see also McCormick 2001, 270-7, 385-7). Within Italy, however, in the modified network model the (former) imperial residences of Rome and Ravenna are located within intact medium-sized clusters of connectivity (Preiser-Kapeller 2020c). In the fifth century, with the fragmentation of its former imperial sphere and the maritime axis to North Africa disturbed by the Vandals, the city of Rome contracted significantly and painfully, as we have discussed. Yet after a stabilisation of political conditions in Italy, especially with the establishment of the Ostrogothic Kingdom of Theodoric in 493, this smaller Rome could be supplied within an 'imperial ecology' reduced to Italy (with Sicily as an important asset), as also the results of my 'experiment' with the modified ORBIS-net-

work suggest. Further urban decline, however, came about with the devastations of the Gothic Wars between 534 and 554 and the outbreak of the so-called 'Justinianic Plague', which first reached Rome and Italy in 543 (Stathakopoulos 2004, 291-4; Wiemer 2018, 264-9, 433-5, 463-7).

Despite recently renewed doubts on the demographic impact of the pandemic (Mordechai et al. 2019, but see now Sarris 2021), the plague equally played a role in the decline of Constantinople's population from its peak of maybe 500,000 inhabitants in the early reign of Justinian before 542. Like Rome after the crisis of the fifth century, the smaller Constantinople of the seventh century was easier to supply within an imperial ecology dramatically reduced with the loss of Egypt (which maintains its internal connectivity as resilient cluster in the modified ORBIS-model; see also Wickham 2005, 759-69) first to Sasanian troops and then permanently to the Arabs, and of other rich provinces in the Levant and later in North Africa. As John Haldon and others have demonstrated in several studies, various regions of Asia Minor, in Central Greece and Sicily stepped in as sources of grain and other supplies for Constantinople (Howard-Johnston 1995, 136-7; Brubaker, Haldon 2011, 563; Haldon 2016).

In the reduced ORBIS network model, in which all connections that 'cost' more than one day's journey are deleted, the largest still fully connected component is in the Eastern Mediterranean between the Tyrrhenian Sea and the Levant, with its centre in the Aegean (Preiser-Kapeller 2020c). This would correspond to the central regions and communication routes, which remained under control of the Roman Empire after the loss of its eastern provinces to the Arabs in the seventh century CE, at the end of an actual process of increasing fragmentation of the (post)Roman world (Brubaker, Haldon 2011; Vaccaro 2013; Haldon 2016). A determination of centrality measures within such as reduced network locates all regions with the highest closeness values (those with the best accessibility within the entire network) in the Aegean, either along a West-East axis from Central Greece via the Cyclades to Western Asia Minor, or along the routes leading either along the coast of Central and Northern Greece or of Western Asia Minor to the Dardanelles and eventually to Constantinople (see **[fig. 1]**; on these sea routes see also Kislinger 2010). Equally, all nodes with the highest intermediary potential (betweenness centrality) are located at maritime or land routes leading to the capital and can be found in a wide circle around the centre of the empire (see **[fig. 2]**), marking something like an 'Inner Zone' of connectivity, again around the Aegean and the Sea of Marmara (for such a notion see also Koder 2001). A further analysis of the reduced Roman route network identifies clusters of increased internal connectivity mainly on the basis of maritime connections: one around Constantinople and the Sea of Marmara (cluster 1 in **[fig. 3]**), one ranging from Northern

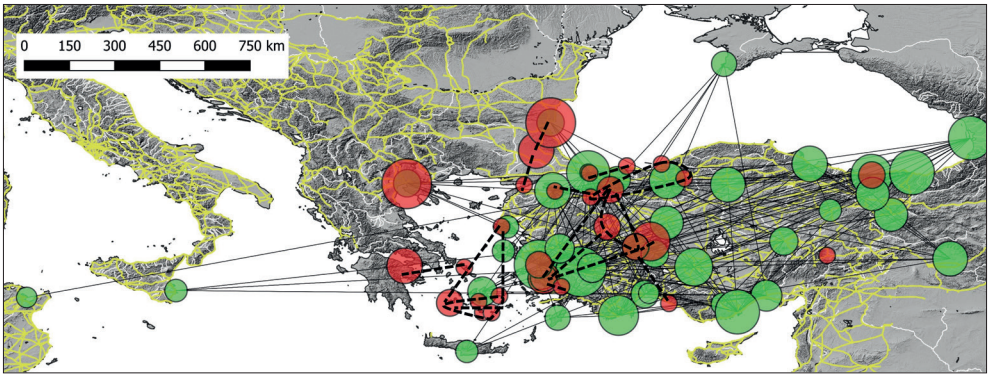

Figure 4 Network models of connectivity among provinces and places based on the data from the seals of the *genikoi kommerkiarioi* (673-728 CE; green circles and thin black lines) and from the seals of the *basilika kommerkia* (730-775 CE; red circles and bold black dotted lines) (data: Brandes 2002; calculations and visualisation: J. Preiser-Kapeller)

and Central Greece across the Central Aegean to Western Asia Minor (cluster 2), one entangling the Southern Aegean and Crete (cluster 3), one connecting the coast of Southwestern Asia Minor from Caria to Lycia (cluster 4), one linking the coasts of Pamphylia and Cilicia with Cyprus (cluster 5, an area where Roman authority was contested by the Arabs), and a cluster 6 of the coastal cities in the Black Sea. In contrast, cities in inland Asia Minor are all attributed to one landlocked cluster (7). Smaller clusters are identified by the algorithm in Central Greece and in the Peloponnese; another bigger maritime cluster (8 in **[fig. 3]**), however, connects the Peloponnese with Southern Italy and Sicily, correlating with one important axis of flows of resources from Sicily to the centre in the modified imperial ecology of the late seventh and early eighth century CE (Kislinger 2001; Vaccaro 2013).

This re-orientation of the imperial ecology is reflected in the activities of the so-called *genikoi kommerkiarioi* (documented only on their lead-seals), who between 650 and 730 acted as official 'managers' for the provision of armies and of Constantinople. These activities often integrated into one operational area several of the empire's remaining provinces and mobilised personnel between them, especially in Asia Minor, but also across the Mediterranean, under the supervision of one or two cooperating *kommerkiarioi* and their collaborators – for the purpose of resource transport between these

areas or the distribution of troops or prisoners of war, for instance.[11] By surveying these linkages between provinces and combining them into another network model, we gain insights into the complexity of the imperial ecology of the Roman Empire during what is considered the political and socioeconomic nadir in the early medieval period. From a series of lead seals from the years 673 to 728, I extracted a network of 157 links between 40 nodes (= provinces) (see **[fig. 4]**) based on their joint assignment to the same *kommerkiarios*. The structural analysis identifies some focal points of connectivity, indicated by the degree values of nodes, that is (in this model) the accumulated strength of the ties of one node to all other nodes due to the number of movements to this province (see **[tab. 1]**). Constantinople, however, has the highest betweenness centrality in the model, which may reflect its significance as a centre of coordination and redistribution of personnel and resources (see **[tab. 1]**). In any case, the model suggests a continuing web of 'metabolic' flows of people and resources across the entire (remaining) empire, which with regard to its range and complexity is at least beyond anything we can observe for post-Roman polities in the West during this period (Wickham 2005; Vaccaro 2013).

Table 1 Provinces and places (nodes) and their centrality measures in the network model for the *genikoi kommerkiarioi*, 673-728

Apotheke of	Betweenness	Degree
Africa	0.0	2
Aigaion Pelagos	0.0	1
Armenia II	4.59	3
Armenia IV	9.20	16
Asia	84.71	46
Bithynia	4.95	6
Blattion	6.93	4
Cappadocia	3.43	8
Caria	63.49	44
Chersonesos	4.11	5
Chios	0.0	3
Cilicia	26.48	11
Constantinople	273.36	30
Crete	4.59	3
Dekapolis	4.27	3

11 Brandes 2002, 281-426; Brubaker, Haldon 2011, 682-95; Haldon 2016; see also Prigent 2014, 195-7, for replacing earlier notions that the *genikoi kommerkiarioi* would have mainly collected taxes in kind with a scenario that they "managed vast operations of monetised public purchase".

Apotheke of	Betweenness	Degree
Galatia II	0.91	14
Helenopontus	11.24	17
Hellespontus	126.84	18
Honorias	52.93	18
Isauria	29.65	32
Kamacha	3.17	14
Kerasus	0.0	27
Koloneia	3.17	14
Lazika	10.00	31
Lesbos	0.0	3
Lycaonia	28.48	21
Lycia	58.92	24
Lydia	24.46	9
Mesembria	1.05	7
Nesoi	11.13	9
Pamphylia	41.20	7
Paphlagonia	14.93	16
Phrygia Pakatiane	24.46	9
Phyrgia Salutaria	4.95	6
Pisidia	41.20	7
Rhodos	4.11	5
Sikelia	0.12	3
Syllaion	0.0	2
Thessalonike	0.12	7
Trebizond	6.00	33

Both the network model for the data on the *genikoi kommerkiarioi* as well as the reduced ORBIS-network model suggest a continuity of a maritime axis from Sicily via Southern Italy to Greece, the Aegean and ultimately Constantinople (see **[fig. 3]** and **[fig. 4]**). It was via this axis that in 747 the bubonic plague once again reached the capital, coming from Sicily via Calabria and the Peloponnese (Monembasia) to the Bosporus, as Theophanes Confessor (*Chronicle* A.M. 6238 [ed. de Boor 1883-85, 422-3]) reports (see also McCormick 2001, 502-8, 565-9; Kislinger 2001; Stathakopoulos 2004, 384-5). Both Theophanes and Patriarch Nikephoros write that Constantinople became "almost unpopulated" due to the plague; therefore, Emperor Constantine V "populated it by transferring to it a multitude of people from the lands and the islands subject to the power of the Rhomaioi" (Nikephoros, *Short History* ch. 67-8 [ed. and transl. Mango 1990, 138-41]). Theophanes adds that the emperor "brought families from the islands, Hellas, and the southern parts [*ton katotikon meron*] and made them dwell in the City so as to increase the population"; furthermore,

he "transferred to Thrace the Syrians and Armenians whom he had brought from Theodosioupolis and Melitene" in campaigns across the frontier to the Arabs (Theophanes, *Chronicle* A.M. 6247 [ed. de Boor 1883-85, 429; transl. Mango, Scott 1997, 593-4]).

These measures must have successfully contributed to a repopulation of the capital and its hinterland, since some 20 years after the plague during a drought in 766/767, the demand for water in Constantinople could only be met by a repair of the aqueduct system destroyed during the Avar siege in 626. For 140 years, the failure of this infrastructure had not been regarded as a major problem; now, however,

> the emperor set about restoring Valentinian's [actually, Valen's] aqueduct [*agogon*] […]. He collected artisans from different places and brought from Asia and Pontos 1,000 masons and 200 plasterers, from Hellas and the islands 500 clay-workers, and from Thrace itself 5,000 labourers and 200 brickmakers. He set taskmasters over them including one of the patricians. When the work had thus been completed, water flowed into the City. (Theophanes, *Chronicle* A.M. 6258 [ed. de Boor 1883-85, 440; transl. Mango, Scott 1997, 600-1])

Equally, Patriarch Nikephoros reports about the drought and the renewal of the aqueduct at the order of the emperor; furthermore,

> avaricious as he was, Christ's enemy Constantine proved to be a new Midas, who stored away all the gold. As a result, the taxed people, hard pressed as they were by the exaction of imposts, sold cheaply the fruit and produce of the earth, so that 60 modii of wheat and 70 of barley could be bought for one nomisma and many (other goods) were sold for very small sums. This was considered by the senseless as a sign of the earth's fertility and abundance of commodities, but by the wise as the result of oppression and avarice and inhuman sickness. (Nikephoros, *Short History* ch. 85 [ed. and transl. Mango 1990, 160-1])

In his third Antirrhetikos, Nikephoros provides another description of Constantine V as

> strict and relentless tax collector [*phorologos*], who weighed down the yoke of taxpayers as much as possible with frequent and annual surcharges on taxes; he oppressed all the peasants and squeezed them out so badly in all illegal ways that one could easily have bought a man's entire property for a nomisma. I have seen people myself who got into misery because of taxes and were hung by their hands on tall and tall trees so that they dangled in the air for a long time. And they endured this bitter and severe punish-

> ment because they could not pay the taxes to the treasury. (Nikephoros, *Antirrh*. 3.75 [ed. *Patrologia Graeca* 100, 513D-516 A, cited in Brandes 2002, 382])

In fewer words, also Theophanes Confessor describes these measures of Constantine V:

> he also at this time made commodities cheap in the City. For, like a new Midas, he stored away the gold and denuded the peasants who, because of the exaction of taxes, were forced to sell God's bounty at a low price. (Theophanes, *Chronicle* A.M. 6259 [ed. de Boor 1883-85, 443; transl. Mango, Scott 1997, 611])

Despite the allegations of Theophanes and Nikephoros, the latter has to concede that the supply policy of Constantine V for the capital was quite successful and popular among the inhabitants of Constantinople, who profited from a sufficient flow of commodities at good prices – even in times of population increase and drought. These measures not only indicate a reorganisation of taxation but anticipate a 'policy of provision' visible in the regulations of the *Book of the City Eparch* from the reign of Leo VI (886-912, ed. Koder 1991), through which quantity, quality, and prices of foodstuffs such a bread, fish or meat were maintained at an acceptable level for the metropolitan population (Preiser-Kapeller 2021). Paul Magdalino (2002, 532), for instance, has identified these measures of Constantine V as the "beginning of a revival" of Constantinople in terms of demography and economy "that continued until 1204".

These policies (as well as those of Constantine V's father Leo III) can also be connected with the activities of the *basilika kommerkia*, which became prominent on lead seals in succession (or replacement) of the *genikoi kommerkiarioi* from the 730s onwards (Brandes 2002, 365-83, esp. 382-3; Prigent 2014). If we map the geographical distribution of the provinces, cities and islands mentioned on the seals of the *basilika kommerkia* for the period between 730 and 775 (see **[fig 4]**), we see a concentration of their activities first in Western Asia Minor, then in the Aegean, Thessalonike and the Thracian hinterland of Constantinople. Again, the operational areas of some of these official institutions entangled several regions or places, including provinces now integrated within the same *thema* (Brandes 2002, 383-94, 552-60). As in the case of the *genikoi kommerkiarioi*, these seals indicate the reorientation and working of an imperial ecology restricted to a significantly smaller space than the circum-Mediterranean empire of the sixth century, but still providing for over-regional flows of people and material and generating an impressive *symploke* or *complexio* (for a network study on this period based on archaeological evidence coming to similar conclusions see Arthur, Imperiale, Muci 2018).

The anthropologist Joseph Tainter in an article of 2000 identified the Byzantine Empire of the seventh century as a rare case of a deliberate "decreasing of the complexity and costliness of problem solving" (Tainter 2000, 27-9). His interpretation was largely based on a selective reading of (by then and now) outdated secondary literature. John Haldon and other members of the Princeton University Climate Change and History Research Initiative on the contrary most recently argued that Byzantium of course contracted in term of spatial extent between the sixth and the seventh century, but that otherwise

> the state maintained an extremely effective central administrative apparatus that was able to efficiently extract, distribute and coordinate the consumption of what resources remained to the empire to best advantage

and that "systemic complexity was retained at all levels, except at that of spatial extent" (Haldon et al. 2020, 23-5; see also Prigent 2014).

Our experiments to model aspects of this systemic complexity of the imperial ecology with the help of network graphs very much confirm this statement and add a further dimension to this research.

6 Conclusion. The Scope of the Roman World by the Eighth and Ninth Century

The spatial contraction after the mid-seventh century centred the empire even more than before onto Constantinople and severed previous flows of the imperial ecology such as, for instance, between Egypt and the capital. It did not, however, impede a continuity of the mobility of individuals and groups between the remaining empire and centres now outside of the imperial borders. Within the framework of the FWF-Wittgenstein-project "Moving Byzantium. Mobility, Microstructures and Personal Agency" headed by Claudia Rapp (Vienna),[12] we have started a systematic survey of the movement of people across the empire's new borders after the Arab expansion. An invaluable basis is the data collected in the Prosopographie der mittelbyzantinischen Zeit (PmbZ 2013)[13] for this period. We extracted information on the itineraries of individuals travelling or migrating from or to certain economic, political, or religious centres formerly located within the empire in the period after the mid-seventh century. As selected examples, I put data on a map for the eighth century for Egypt, Jerusalem, and Rome (see **[fig. 5]**). In all three cases, the

12 https://rapp.univie.ac.at.

13 https://www.degruyter.com/database/pmbz/html?lang=de.

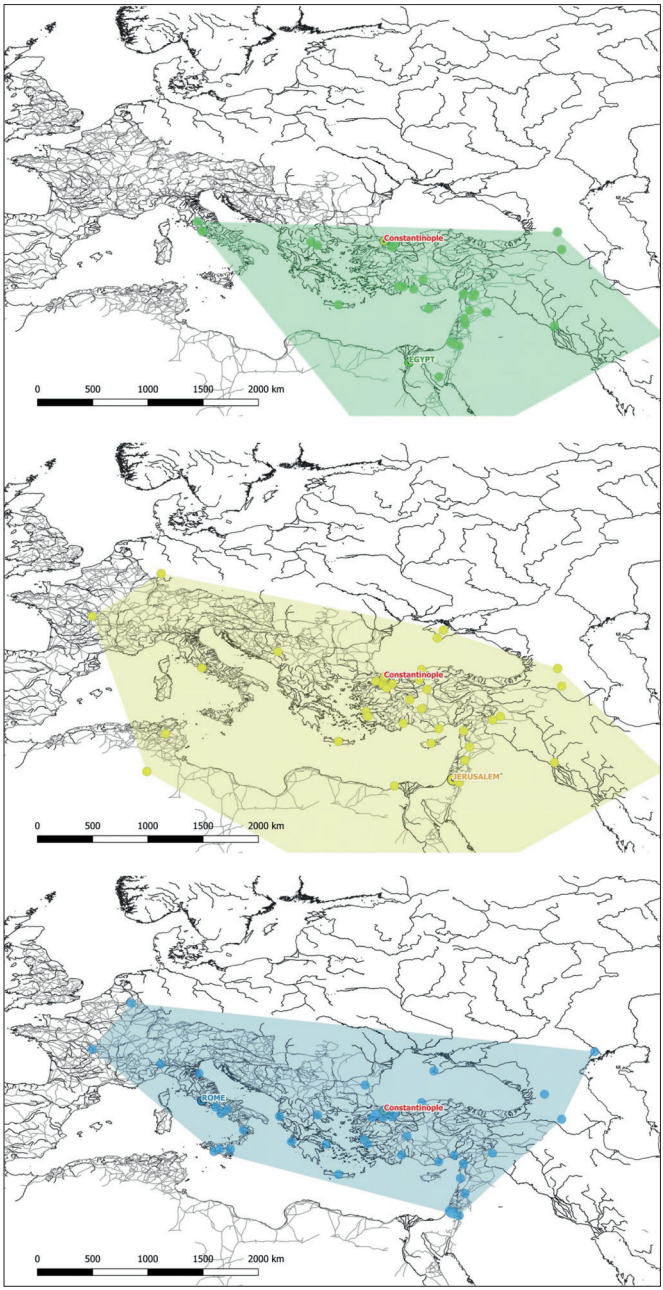

Figure 5 Places in and spatial range of the itineraries of individuals and groups mentioned in the PmbZ in the 8th century CE and travelling to or from Egypt (green), Jerusalem (yellow) and Rome (blue) (data: PmbZ; visualisation: J. Preiser-Kapeller)

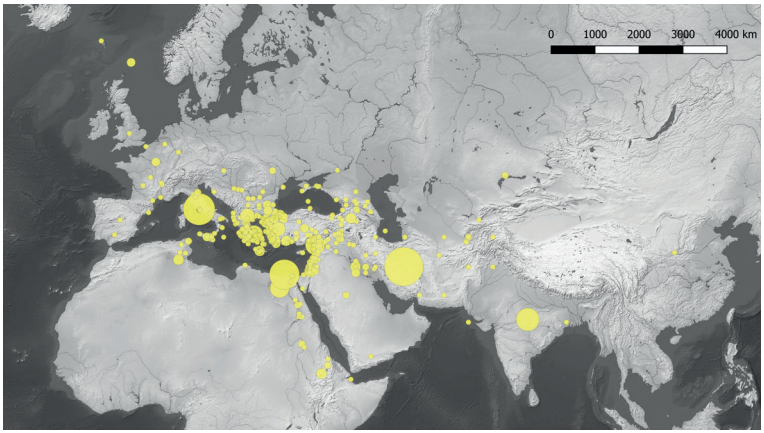

Figure 6 Frequency of toponyms and ethnonyms mentioned in the Bibliotheke of Photios, 9th century CE (data: Bibliotheke, ed. Henry 1959-1991; calculation and visualisation: J. Preiser-Kapeller)

geographical range of mobility coming from or to these places within and beyond the former Mediterranean core of the Roman world was still significant in the years 700 to 800. All three maps equally show an overlap of coverage on Constantinople and the territories of the reduced Roman Empire in Asia Minor and around the Aegean (see **[fig. 5]**).

As discussed in earlier studies (Preiser-Kapeller 2015a; 2020d; 2020e, 357-79), this can be understood within the framework of 'stigmergy': earlier travels and exchanges have an enduring effect both in the form of material manifestations such as roads or harbours as well as of immaterial ones such as navigational or commercial know how, mental maps or religious imaginations (e.g Jerusalem as a destination of pilgrimage). They in turn serve as anchor points for a continuation or renewal of connectivity at the medium and long range even after the fragmentation of imperial formations. On this basis, Constantinople served as attractor and exerted (political, religious, cultural) influence far beyond its shrinking borders even in later periods (Preiser-Kapeller 2015a; 2020e, 357-79).

The geographical information and imagination of earlier centuries equally served as source of knowledge for educated Romans after the crisis of the seventh century. Such information was to be found in the hundreds of ancient books whose 'reviews' Patriarch Photios of Constantinople (c. 810/820-893) included in his *Bibliotheke* (or *Myriobiblion*, ed. Henry 1959-91). His text provides us with the potential extent of the 'mental map' of a scholar of the ninth century (see **[fig. 6]**) (Schamp 1987). To put these toponyms on a modern map ranging all the way to China, however, can be misleading. Al-

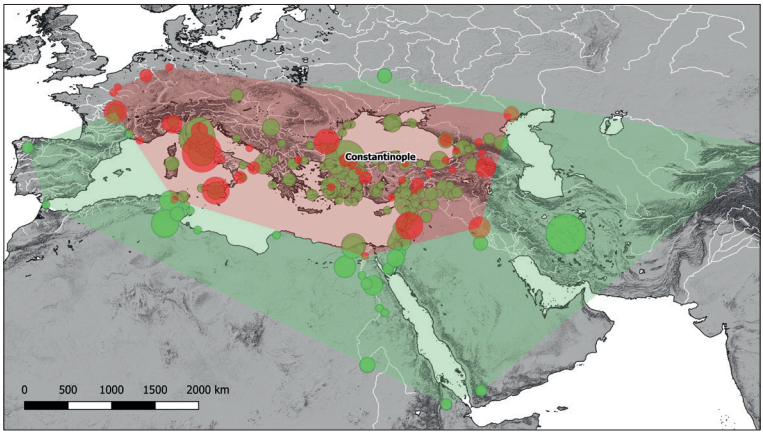

Figure 7 Places of destination of Roman imperial charters and delegations (sized by the number of attested documents) between 527 and 578 CE (green) and between 700 and 800 CE (red) (data: Lounghis, Blysidou, Lampakes 2005; Müller, Preiser-Kapeller, Riehle 2009; calculation and visualisation: J. Preiser-Kapeller)

though the reading list of Photios (who himself took part in a diplomatic mission to Baghdad)[14] included texts of authors who had visited faraway places like Persia or India (such as Ktesias, fifth century BCE, or Kosmas Indikopleustes, sixth century CE), the actual knowledge about these areas had become blurred in Constantinople. The term 'India' for instance could refer to various lands along the Western Indian Ocean, from East Africa via South Arabia to India itself (Darley 2013; Kominko 2013).

Furthermore, the actual horizon of the Roman empire's political interaction (and therefore also of most of its historiography and scholarship) was already in the sixth century more confined to polities and peoples around the Mediterranean and adjacent regions up to Persia or western Central Asia (see **[fig. 7]**). After the mid-seventh century, the geographical range of Constantinople's diplomacy was even more restricted to the more or less immediate geopolitical neighbourhood in the (Eastern) Mediterranean (see **[fig. 7]**; see also Drocourt 2015). Thus, the Roman Empire was still among the most complex polities of the later first millennium CE; but its actual power to 'interweave' (s*ymplekesthai*) the affairs of Europe, Africa and Asia was now dwarfed by new 'superpowers' such as the Caliphate or the Chinese Empire of the Tang dynasty (Preiser-Kapeller 2018a; Scheidel 2019). Their imperial ecologies have also been recently approached with the help of network models (Preiser-Kapeller 2020c; Romanov 2021), inviting to comparative studies on the complexity of empires

14 https://www.degruyter.com/document/database/PMBZ/entry/PMBZ17454/html.

of the past in the near future, which will again be based on the already significant network analytical work on the Roman Empire of ancient and medieval times.

Bibliography

Primary sources

de Boor, C. (Hrsg.) (1883-85). *Theophanis chronographia*. Leipzig: Teubner.
Henry, R. (éd.) (1959-91). *Photius: Bibliothèque*. 9 vols. Paris : Les Belles Lettres.
Koder, J. (Hrsg.) (1991). *Das Eparchenbuch Leons des Weisen*. Wien: Verlag der Österreichischen Akademie der Wissenschaften.
Reinsch, D.R.; Kambylis, A. (Hrsgg) (2001). *Annae Comnenae Alexias*. Pars prior, *Prolegomena et Textus*. 2 Bde. Berlin; New York: De Gruyter. Corpus Fontium Historiae Byzantinae 40.
Mango, C. (ed. and transl.) (1990). *Nikephoros, Patriarch of Constantinople. Short History*. Washington, D.C.: Dumbarton Oaks.
Mango, C.; Scott, R. (transl.) (1997). *The Chronicle of Theophanes Confessor. Byzantine and Near Eastern History A.D. 284-813*. Oxford: Clarendon Press.
Mynors, R.A.B (ed.) (1964). *XII Panegyrici Latini*. Oxford: Clarendon Press.
Paton, W.R. (transl.) (1922-27). *Polybius: The Histories*. https://penelope.uchicago.edu/Thayer/E/Roman/Texts/Polybius/home.html.
Sewter E.R.A.; Frankopan, P. (transl.) (2009). *Anna Komnene: The Alexiad*. New York: Penguin.

Secondary sources

Arthur, P.; Imperiale, L.; Muci, G. (2018). "Amphoras, Networks, and Byzantine Maritime Trade". Leidwanger, J.; Knappett, C. (eds), *Maritime Networks in the Ancient Mediterranean World*. Cambridge: Cambridge University Press, 219-37. https://doi.org/10.1017/9781108555685.010.
Arthur, W.B. (2015). *Complexity and the Economy*. Oxford: Oxford University Press.
Auyang, S.Y. (2015). *The Dragon and the Eagle. The Rise and Fall of the Chinese and Roman Empires*. Abingdon; New York: Routledge.
Baccini, P.; Brunner, P.H. (2012). *Metabolisms of the Anthroposphere. Analysis, Evaluation, Design*. Cambridge (MA); London: The MIT Press.
Barabási, A.-L. (2016). *Network Science*. Cambridge: Cambridge University Press.
Barthélemy, M. (2011). "Spatial Networks". *Physics Reports*, 499, 1-101. https://doi.org/10.1016/j.physrep.2010.11.002.
Batagelj, V. et al. (2014). *Understanding Large Temporal Networks and Spatial Networks. Exploration, Pattern Searching, Visualization and Network Evolution*. Chichester: Wiley.
Beaudreau, B.C. (2011). "On the Emergence and Evolution of Economic Complexity". *Modern Economy*, 2(3), 266-78. https://doi.org/10.4236/me.2011.23030.
Bianconi, G. (2018). *Multilayer Networks. Structure and Function*. Oxford: Oxford University Press.

Brandes, W. (2002). *Finanzverwaltung in Krisenzeiten. Untersuchungen zur byzantinischen Administration im 6.-9. Jahrhundert*. Frankfurt am Main: Löwenklau Gesellschaft.

Brubaker, L.; Haldon, J. (2011). *Byzantium in the Iconoclast Era c. 680-850. A History*. Cambridge: Cambridge University Press.

Brughmans, T. (2012). "Thinking through Networks. A Review of Formal Network Methods in Archaeology". *Journal of Archaeological Method and Theory*, 20(4), 623-66. https://doi.org/10.1007/s10816-012-9133-8.

Brughmans, T.; Collar, A.; Coward, F. (eds) (2016). *The Connected Past. Challenges to Network Studies in Archaeology and History*. Oxford: Oxford University Press.

Carter, F.W. (1969). "An Analysis of the Medieval Serbian Oecumene. A Theoretical Approach". *Geografiska Annaler. Series B, Human Geography*, 51(1), 39-56. https://doi.org/10.1080/04353684.1969.11879331.

Collar, A. (2013). *Religious Networks in the Roman Empire. The Spread of New Ideas*. Cambridge: Cambridge University Press.

Collar, A. et al. (2015). "Networks in Archaeology. Phenomena, Abstraction, Representation". *Journal of Archaeological Method and Theory*, 22(1), 1-31. https://doi.org/10.1007/s10816-014-9235-6.

de Nooy, W.; Mrvar, A.; Batagelj, V. (2005). *Exploratory Social Network Analysis with Pajek*. Cambridge: Cambridge University Press.

Darley, R. (2013). *Indo-Byzantine Exchange 4th-7th Centuries. A Global History* [PhD dissertation]. Birmingham: University of Birmingham.

Davies, S.H. (2019). "Weaving a Map of 'Global' Empire. The Second-Century BCE Origins of Mediterraneanism". *Mediterranean Studies*, 27(1), 1-35. https://doi.org/10.5325/mediterraneanstu.27.1.0001.

Dermody, B.J. et al. (2014). "A Virtual Water Network of the Roman World". *Hydrology and Earth System Sciences*. http://www.hydrol-earth-syst-sci.net/18/5025/2014/hess-18-5025-2014.html.

Dillery, J. (2011). "Hellenistic Historiography". Feldherr, A.; Hardy, G. (eds), *The Oxford History of Historical Writing*. Vol. 1, *Beginnings to AD 600*. Oxford: Oxford University Press, 171-218. https://doi.org/10.1093/acprof:oso bl/9780199218158.003.0009.

Dorling, D. (2012). *The Visualization of Spatial Social Structure*. Chichester: Wiley.

Drocourt, N. (2015). *Diplomatie sur le Bosphore. Les ambassadeurs étrangers dans l'empire byzantin des années 640 à 1204*. 2 vols. Leuven: Peeters.

Ducruet, C.; Zaidi, F. (2012). "Maritime Constellations. A Complex Network Approach to Shipping and Ports". *Maritime Policy and Management*, 39(2), 151-68. https://doi.org/10.1080/03088839.2011.650718.

Erdkamp, P. (2005). *The Grain Market in the Roman Empire. A Social, Political, and Economic Study*. Cambridge: Cambridge University Press.

Fletcher, R. (1995). *The Limits of Settlement Growth. A Theoretical Outline*. Cambridge: Cambridge University Press.

Forman, R.T.T. (2014). *Urban Ecology. Science of Cities*. Cambridge: Cambridge University Press.

González de Molina, M.; Toledo, V.M. (2014). *The Social Metabolism. A Socio-Ecological Theory of Historical Change*. Heidelberg; New York: Springer.

Gorenflo, L.J.; Bell, Th.L. (1991). "Network Analysis and the Study of Past Regional Organization". Trombold, Ch.D. (ed.), *Ancient Road Networks and Set-*

tlement Hierarchies in the New World. Cambridge: Cambridge University Press, 80-98.

Graßhoff, G.; Mittenhuber, F. (Hrsgg) (2009). *Untersuchungen zum Stadiasmos von Patara. Modellierung und Analyse eines antiken geographischen Streckennetzes*. Bern: Bern Studies.

Haldon, J. (2016). *The Empire That Would not Die. The Paradox of Eastern Roman Survival, 640-740*. Cambridge (MA); London: Harvard University Press.

Haldon, J. et al. (2020). "Demystifying Collapse. Climate, Environment, and Social Agency in Pre-Modern Societies". *Millennium*, 17(1), 1-33. https://doi.org/10.1515/mill-2020-0002.

Howard-Johnston, J. (1995). "The Siege of Constantinople in 626". Mango, C.; Dagron, G. (eds), *Constantinople and Its Hinterland. Papers from the 27th Spring Symposium of Byzantine Studies*. Aldershot: Ashgate, 131-42.

Isaksen, L. (2008). "The Application of Network Analysis to Ancient Transport Geography. A Case Study of Roman Baetica". *Digital Medievalist*, 4. https://doi.org/10.16995/dm.20.

Kadushin, Ch. (2012). *Understanding Social Networks. Theories, Concepts and Findings*. Oxford: Oxford University Press.

Kislinger, E. (2001). *Regionalgeschichte als Quellenproblem. Die Chronik von Monembasia und das sizilianische Demenna. Eine historisch-topographische Studie*. Wien: Verlag der Österreichischen Akademie der Wissenschaften.

Kislinger, E. (2010). "Verkehrsrouten zur See im byzantinischen Raum". Kislinger, E.; Koder, J.; Külzer, A. (Hrsgg), *Handelsgüter und Verkehrswege. Aspekte der Warenversorgung im östlichen Mittelmeerraum*. Wien: Verlag der Österreichischen Akademie der Wissenschaften, 149-74.

Klee, M. (2010). *Lebensadern des Imperiums. Straßen im Römischen Weltreich*. Stuttgart: Theiss.

Knappett, C. (ed.) (2013). *Network-Analysis in Archaeology. New Approaches to Regional Interaction*. Oxford: Oxford University Press.

Koder, J. (2001). *Der Lebensraum der Byzantiner. Historisch-geographischer Abriß ihres mittelalterlichen Staates im östlichen Mittelmeerraum*. Wien: Fassbaender Verlag.

Kolb, A. (2000). *Transport und Nachrichtentransfer im Römischen Reich*. Berlin: De Gruyter.

Kominko, M. (2013). *The World of Kosmas. Illustrated Byzantine Codices of the Christian Topography*. Cambridge: Cambridge University Press.

Krempel, L. (2005). *Visualisierung komplexer Strukturen. Grundlagen der Darstellung mehrdimensionaler Netzwerke*. Frankfurt; New York: Campus Verlag.

Leidwanger, J. et al. (2014). "A Manifesto for the Study of Ancient Mediterranean Maritime Networks". *Antiquity. A Review of World Archaeology*. http://journal.antiquity.ac.uk/projgall/leidwanger342.

Lemercier, C. (2012). "Formale Methoden der Netzwerkanalyse in den Geschichtswissenschaften. Warum und Wie?". Müller, A.; Neurath, W. (Hrsgg), *Historische Netzwerkanalysen*. Innsbruck; Vienna; Bozen: Studien Verlag, 16-41.

Lounghis, T.C.; Blysidou, B.; Lampakes, S. (Hrsgg) (2005). *Regesten der Kaiserurkunden des oströmischen Reiches von 476 bis 565*. Nikosia: Zyprisches Forschungszentrum.

Magdalino, P. (2002). "Medieval Constantinople. Built Environment and Urban Development". Laiou, A. (ed.), *The Economic History of Byzantium. From*

the Seventh through the Fifteenth Century. Washington, D.C.: Dumbarton Oaks, 529-37.

Mainzer, K. (2007). *Thinking in Complexity. The Computational Dynamics of Matter, Mind, and Mankind*. Berlin; Heidelberg: Springer.

Marincola, J. (2007). "Universal History from Ephorus to Diodorus". Marincola, J. (ed.), *A Companion to Greek and Roman Historiography*, vol 1. Malden; Oxford: Wiley-Blackwell, 155-63.

McCormick, M. (2001). *Origins of the European Economy. Communications and Commerce AD 300-900*. Cambridge: Cambridge University Press.

Miller, J.H.; Page, S.E. (2007). *Complex Adaptive Systems. An Introduction to Computational Models of Social Life*. Princeton (NJ): Princeton University Press.

Mitchell, M. (2009). *Complexity. A Guided Tour*. Oxford: Oxford University Press.

Mordechai, L. et al. (2019). "The Justinianic Plague. An Inconsequential Pandemic?". *Proceedings of the National Academy of Sciences*, 116(51), 25546-54. https://doi.org/10.1073/pnas.1903797116.

Morley, N. (1996). *Metropolis and Hinterland. The City of Rome and the Italian Economy 200 BC-AD 200*. Cambridge: Cambridge University Press.

Müller, A.; Preiser-Kapeller, J.; Riehle, A. (2009). *Regesten der Kaiserurkunden des oströmischen Reiches, 565-1453, ed. F. Dölger*. Teil 1, Bd. 1, *Regesten für die Jahre 565-867*. 2nd revised ed. München: C.H. Beck.

Mullett, M. (1997). *Theophylact of Ochrid. Reading the Letters of a Byzantine Archbishop*. Aldershot: Ashgate.

Newman, M. (2010). *Networks. An Introduction*. Oxford: Oxford University Press.

O'Connell, T.C. et al. (2019). "Living and Dying at the *Portus Romae*". *Antiquity*, 93(369), 719-34. https://doi.org/10.15184/aqy.2019.64.

Orengo, H.A.; Livarda, A. (2016). "The Seeds of Commerce. A Network Analysis-Based Approach to the Romano-British Transport System". *Journal of Archaeological Science*, 66, 21-35. https://doi.org/10.1016/j.jas.2015.12.003.

Pitts, F.R. (1978). "The Medieval River Trade Network of Russia Revisited". *Social Networks*, 1(3), 285-92. https://doi.org/10.1016/0378-8733(78)90025-4.

PmbZ (2013). *Prosopographie der mittelbyzantinischen Zeit Online*. Berlin; Boston: De Gruyter. https://doi.org/10.1515/pmbz.

Potter, D.S. (2011). "The Greek Historians of Imperial Rome". Feldherr, A.; Hardy, G. (eds), *The Oxford History of Historical Writing*. Vol. 1, *Beginnings to AD 600*. Oxford: Oxford University Press, 316-45. https://doi.org/10.1093/acprof:osobl/9780199218158.003.0014.

Preiser-Kapeller, J. (2015a). "Calculating the Synod? New Quantitative and Qualitative Approaches for the Analysis of the Patriarchate and the Synod of Constantinople in the 14th Century". Blanchet, M.-H.; Congourdeau, M.-H.; Mureşan, D.I. (éds), *Le Patriarcat oecuménique de Constantinople et Byzance hors frontières (1204-1586) = Actes de la table ronde organisée dans le cadre du 22e Congrès International des Études Byzantines* (Sofia, 22-7 août 2011). Paris : De Boccard, 159-71.

Preiser-Kapeller, J. (2015b). "Liquid Frontiers. A Relational Analysis of Maritime Asia Minor as Religious Contact Zone in the 13th-15th Century". Peacock, A.; de Nicola, B.; Nur Yıldız, S. (eds), *Islam and Christianity in Medieval Anatolia*. Aldershot: Ashgate, 117-46.

Preiser-Kapeller, J. (2015c). "Calculating the Middle Ages? The Project 'Complexities and Networks in the Medieval Mediterranean and the Near East'". *Medieval Worlds*, 2, 100-27. https://doi.org/10.1553/medievalworlds_no2_2015s100.

Preiser-Kapeller, J. (2015d). "The Maritime Mobility of Individuals and Objects. Networks and Entanglements". Preiser-Kapeller, J.; Daim, F. (eds), *Harbours and Maritime Networks as Complex Adaptive Systems*. Mainz: Römisch-Germanisches Zentralmuseum Verlag, 119-40.

Preiser-Kapeller, J. (2015e). "Thematic Introduction". Preiser-Kapeller, J.; Daim, F. (eds), *Harbours and Maritime Networks as Complex Adaptive Systems*. Mainz: Römisch-Germanisches Zentralmuseum Verlag, 1-24.

Preiser-Kapeller, J. (2018a). *Jenseits von Rom und Karl dem Großen. Aspekte der globalen Verflechtung in der langen Spätantike, 300-800 n. Chr.* Wien: Mandelbaum.

Preiser-Kapeller, J. (2018b). "Central Peripheries. Empires and Elites across Byzantine and Arab Frontiers in Comparison (700-900 CE)". Drews, W. (Hrsg.), *Die Interaktion von Herrschern und Eliten in imperialen Ordnungen*. Berlin; Boston: De Gruyter, 91-113.

Preiser-Kapeller, J. (2019). *How to Put Network Data on a Map (with Excel, ORA, GoogleEarth and QuantumGIS) – A Practical Manual*. https://www.academia.edu/38786691/How_to_put_network_data_on_a_map_a_practical_manual_.

Preiser-Kapeller, J. (2020a). "Letters and Network Analysis". Riehle, A. (ed.), *Companion to Byzantine Epistolography*. Leiden; New York; Cologne: Brill, 431-65.

Preiser-Kapeller, J. (2020b). "The Ties that Do not Bind. Group Formation, Polarization and Conflict within Networks of Political Elites in the Medieval Roman Empire". *Journal of Historical Network Research*, 4, 298-324. https://doi.org/10.25517/jhnr.v4i0.81.

Preiser-Kapeller, J. (2020c). "Networks and the Resilience and Fall of Empires. A Macro-Comparison between the Imperium Romanum and Imperial China". *Siedlungsforschung. Archäologie – Geschichte – Geographie*, 36, 59-98.

Preiser-Kapeller, J. (2020d). "Aristocrats, Mercenaries, Clergymen and Refugees. Deliberate and Forced Mobility of Armenians in the Early Medieval Mediterranean and Near East (6th to 11th Century)". Preiser-Kapeller, J.; Reinfandt, L.; Stouraitis, Y. (eds), *Migration Histories of the Medieval Afroeurasian Transition Zone. Aspects of Mobility between Africa, Asia and Europe, 300-1500 C.E.* Leiden; Boston: Brill, 327-84. https://doi.org/10.1163/9789004425613_013.

Preiser-Kapeller, J. (2020e). "Small Worlds of Long Late Antiquity. Global Entanglements, Trade Diasporas and Network Theory". Guidetti, F.; Meinecke, K. (eds), *A Globalised Visual Culture? Towards a Geography of Late Antique Art*. Oxford: Oxbow Books, 357-80. https://doi.org/10.2307/j.ctv13pk7vx.18.

Preiser-Kapeller, J. (2021). "The Medieval Roman Empire of the East as Spatial Phenomenon (300-1200 CE)". Pines, Y.; Biran, M.; Rüpke, J. (eds), *The Limits of Universal Rule. Eurasian Empires Compared*. Cambridge: Cambridge University Press, 141-79. https://doi.org/10.1017/9781108771061.006.

Preiser-Kapeller, J.; Mitsiou, E. (2019). "Mercantile and Religious Mobility between Byzantines, Latins and Muslims, 1200-1500. On the Theory and

Practice of Social Networks". *Medieval Worlds*, 9, 187-216. https://doi.org/10.1553/medievalworlds_no9_2019s187.

Prell, Ch. (2012). *Social Network Analysis. History, Theory and Methodology*. Los Angeles; London: SAGE Publications.

Prigent, V. (2014). "The Mobilisation of Fiscal Resources in the Byzantine Empire (Eighth to Eleventh Centuries)". Hudson, J.; Rodríguez, A. (eds), *Diverging Paths? The Shapes of Power and Institutions in Medieval Christendom and Islam*. Leiden; Boston: Brill, 182-229. https://doi.org/10.1163/9789004277878_011.

Rodrigue, J.-P.; Comtoi, C.; Slack, B. (2013). *The Geography of Transport Systems*. London; New York: Routledge.

Romanov, M. (2021). *Al-Ṭurayyā Gazetteer and Geospatial Model*. https://al-raqmiyyat.github.io/althurayya.

Ruffing, K. (2012). *Wirtschaft in der griechisch-römischen Antike*. Darmstadt: Wissenschaftliche Buchgesellschaft.

Ruffini, G.R. (2008). *Social Networks in Byzantine Egypt*. Cambridge: Cambridge University Press.

Sarris, P. (2021). "New Approaches to the 'Plague of Justinian'". *Past & Present*, 254(1), 315-46. https://doi.org/10.1093/pastj/gtab024.

Sauer, V. (2006). "Straße (Straßenbau)". Sonnabend, H. (Hrsg.), *Mensch und Landschaft in der Antike. Lexikon der Historischen Geographie*. Stuttgart; Weimar: J.B. Metzler, 518-24.

Schamp, J. (1987). *Photios historien des lettres. La Bibliothèque et ses notices biographiques*. Liège: Presses Universitaires de Liège.

Scheidel, W.; Morris, I.; Saller, R. (eds) (2007). *The Cambridge Economic History of the Greco-Roman World*. Cambridge: Cambridge University Press.

Scheidel, W. et al. (2014). *ORBIS. The Stanford Geospatial Network Model of the Roman World*. http://orbis.stanford.edu.

Scheidel, W. (2019). *Escape from Rome. The Failure of Empire and the Road to Prosperity*. Princeton; Oxford: Princeton University Press.

Schneider, H. (2007). *Geschichte der antiken Technik*. München: C.H. Beck.

Schor, A.M. (2011). *Theodoret's People. Social Networks and Religious Conflict in Late Roman Syria*. Berkeley: University of California Press.

Schott, D. (2014). "Urban Development and Environment". Agnoletti, M.; Neri Serneri, S. (eds), *The Basic Environmental History*. Heidelberg: Springer, 171-98. https://doi.org/10.1007/978-3-319-09180-8_6.

Sommer, M. (2013). *Wirtschaftsgeschichte der Antike*. München: C.H. Beck.

Stathakopoulos, D. (2004). *Famine and Pestilence in the Late Roman and Early Byzantine Empire*. Aldershot: Ashgate.

Taaffe, E.J.; Gauthier, H.L.Jr. (1973). *Geography of Transportation*. Englewood Cliffs (NJ): Pearson Education.

Tainter, J.A. (2000). "Problem Solving. Complexity, History, Sustainability". *Population and Environment. A Journal of Interdisciplinary Studies*, 22(1), 3-41. https://doi.org/10.1023/A:1006632214612.

Turcan-Verkerk, A.-M. (2003). *Un poète latin chrétien redécouvert. Latinius Pacatus Drepanius, panégyriste de Théodose*. Bruxelles: Éditions Latomus.

Vaccaro, E. (2013). "Sicily in the Eighth and Ninth Centuries AD. A Case of Persisting Economic Complexity". *Al-Masaq*, 25(1), 34-69. https://doi.org/10.1080/09503110.2013.767011.

van Lanen, R.J. et al. (2015). "Best Travel Options. Modelling Roman and Early-Medieval Routes in the Netherlands Using a Multi-Proxy Approach".

Journal of Archaeological Science. Reports, 3, 144-59. https://doi.org/10.1016/j.jasrep.2015.05.024.

Walbank, F.W. (1975). "Symploke. Its Role in Polybius' Histories". Kagan, D. (ed.), *Studies in the Greek Historians*. Cambridge: Cambridge University Press, 197-212. https://doi.org/10.1017/cbo9780511933769.011.

Wassermann, S.; Faust, K. (1994). *Social Network Analysis. Methods and Applications, Structural Analysis in the Social Sciences*. Cambridge: Cambridge University Press.

Watts, D.J. (1999). *Small Worlds. The Dynamics of Networks between Order and Randomness*. Princeton; Oxford: Princeton University Press.

White, S. (2011). *The Climate of Rebellion in the Early Modern Ottoman Empire*. Cambridge: Cambridge University Press.

Wickham, Ch. (2004). "The Mediterranean around 800. On the Brink of the Second Trade Cycle". *Dumbarton Oaks Papers*, 58, 161-74. https://doi.org/10.2307/3591384.

Wickham, Ch. (2005). *Framing the Early Middle Ages. Europe and the Mediterranean, 400-800*. Oxford: Oxford University Press.

Wiemer, H.-U. (2018). *Theoderich der Große. König der Goten. Herrscher der Römer*. München: C.H. Beck.