Christoph Schäfer (ed.)

Connecting the Ancient World

Mediterranean Shipping, Maritime Networks and their Impact

Pharos

Studien zur griechisch-römischen Antike
Band 35

Herausgegeben von
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und Wolfgang Spickermann

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Connecting the Ancient World

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Verlag Marie Leidorf GmbH · Rahden/Westf.

2016

x und 249 Seiten

Bibliographische Informationen der Deutschen Nationalbibliothek

Christoph Schäfer (ed.):
Connecting the Ancient World. Mediterranean Shipping, Maritime Networks and their Impact
Rahden/ Westf.: Verlag Marie Leidorf, 2016
(Pharos – Studien zur griechisch-römischen Antike, Bd. 37)
ISBN 978-xxxxx

Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie.
Detaillierte bibliografische Daten sind im Internet unter http://dnb.d-nb.de abrufbar.

Gedruckt auf alterungsbeständigem Papier

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Verlag Marie Leidorf GmbH
Geschäftsführer: Dr. Bert Wiegel
Stellerloh 65 . D-32369 Rahden/Westf.
Tel: +49/(0)5771/ 9510-74
Fax: +49/(0)5771/ 9510-75
E-Mail: info@vml.de
Internet: http://www.vml.de

ISBN 978-xxxxxx
ISSN 1435-6457

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Redaktion, Satz, Layout: Dr. Christian Rollinger, Trier
Druck und Produktion: Druckhaus Köthen GmbH & Co. KG, Friedrichstraße 11/12, D-06366 Köthen

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Tyler V. Franconi

Climatic influences on riverine transport on the Roman Rhine

Introduction

Roman connectivity is often discussed in a (Mediterranean) maritime context, but it is important to understand how inland regions fitted into and benefitted from these connections. Maritime trade was only one element of ancient transport, and rivers and roads allowed for non-coastal communities to connect to the wider Roman world. These connections must be situated within a wider, integrated transportation network.[1] Unfortunately, the logistics of riverine transport in the Roman period are poorly understood, mainly due to a lack of detailed documentary evidence.[2] It is often assumed that river transport was easy and widespread, but this view is heavily influenced by the modern world where motorized ships and canalized rivers remove many natural hazards and problems that had previously plagued river shipping. Simply put, the view that rivers were always amenable to easy, cheap transport is wrong. Riverine transport was far from easy and was vulnerable to climatic and environmental changes that Romans could not always control or manage. We must come to grips with these realities in order to truly understand the place of riverine transport in the Roman world.

Understanding rivers in antiquity is a complicated task that requires an interdisciplinary approach, uniting historical sources, archaeological data, and geomorphological research in order to fully understand the relationship between man and river. Though a narrative of exploitation or control is often preferred when discussing Romans and their environment,[3] it is important to recognize that Romans were vulnerable to environmental change, and that these changes had important repercussions for society.[4]

Such an approach is key when considering riverine transportation in antiquity. There is no doubt that rivers were important elements of local and long-distance connectivity in the Roman Empire, but there is certainly more to be understood beyond acknowledging their utility. Rivers were constantly changing features of the landscape, and these changes had important repercussions for riparian life. The how and why of this relationship has not been explored within

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1 ADAMS 2012; HITCHNER 2012.
2 Though see BONNARD 1913; DEMAN 1987; DE IZARRA 1993; COOPER 2011.
3 CAMPBELL 2012; PURCELL 2012; KEENAN-JONES 2013.
4 The relationship between society and rivers is best discussed in EDGEWORTH 2011.

a Roman context, but it is a crucial element to understanding the logistics of inland connectivity.

This paper addresses these issues from the point of view of the Rhine River in the Roman period. The Rhine was one of the largest rivers in the Roman Empire, and functioned as the backbone of a key frontier zone of the Empire for nearly 500 years. The centrality of the river system to this region meant that any changes to the waterways resulted in changes to settlement and life along their banks. The evidence of these changes is diverse and extensive, and is crucial for understanding how the Rhine functioned as one element of an integrated transport system.

The Rhine

The Rhine basin covers 185,000 square km of land, draining the Northern Alps, Black Forest, Vosges, and Rhenish Massif in a northerly direction.[5] The river is 1,200 km long, with its source high in the Alps. From its source, the Alpine Rhine flows into Lake Constance and then west over the 23 m high Rheinfall on its way to Basel. From Basel, the river turns north, passing through a wide flood plain before reaching Mainz, where it shortly thereafter enters the gorged valley of the Middle Rhine. From Bonn to the Dutch border the river again flows through a wide flood plain, before splitting into three channels: the Waal, Lek, and Ijssel, that then each flow to the North Sea. The Rhine's major western tributaries are the Aare and Moselle, with the Neckar and Main to the east.

The upper stretches of the Rhine are influenced by winter snowfall in the Alps.[6] The flow regime of the Alpine and High Rhine shows the influence of winter snowfall and summer melt waters contributed by both the High Rhine and the Aare River from Switzerland. The Middle and Lower Rhine are more heavily dictated by spring and autumn rain, as well as the contributions of the Moselle, Neckar, and Main which each receive more rain than snow in the winter. This pattern continues into its delta before it splits into its distributaries. The Rhine discharges an average of 2,600 cubic meters per second into the North Sea, with the Waal River delivering approximately 65% of the volume.

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5 On the physical geography of the Rhine basin, see UEHLINGER *et al.* 2009. On changes to the river's delta see HENDRIKX 1986; VAN DINTER *et al.* 2013.

6 On the hydrology of the Rhine and its seasonal variation, see BELZ *et al.* 2006; UEHLINGER *et al.* 2009.

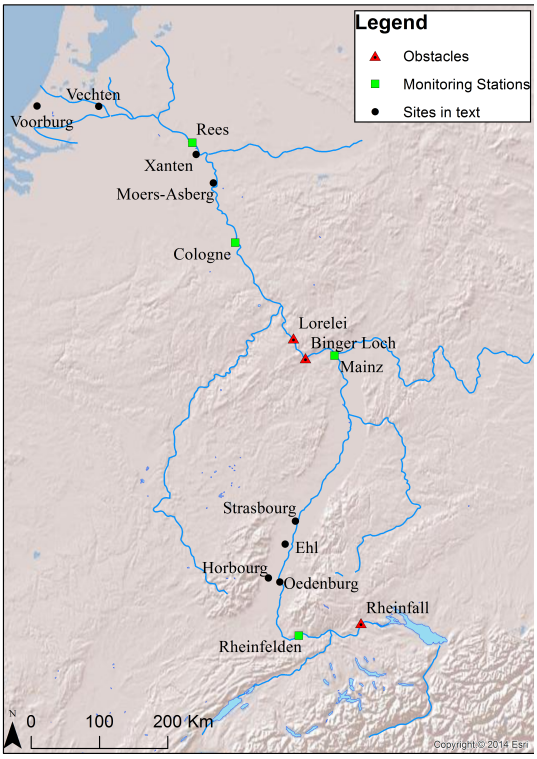


Figure 1. Map of Rhine basin with sites mentioned in text.

The course of the river and its tributaries offered numerous obstacles to shipping. The already mentioned Rheinfall on the High Rhine is the largest, but the stretch of the Upper Rhine from Strasbourg to Basel has long been known as the most dangerous section of the river due to a steep gradient and many rocky obstacles.[7] Downstream of Mainz near the confluence with the Nahe River, the so-called Binger Loch stone formation presented a serious obstacle for ships in all but the highest water.[8] A stone outcrop sitting just below the water level across the entire river meant that many ships had to be unloaded on one side and reloaded on the other prior to the 17th century.[9] The narrowest section of the river course is marked by the Lorelei rock, near St. Goar, where a strong current around a sharp

7 WICKERT 1908; CIOC 2006.
8 QUETSCH 1891. This formation was finally blasted out in the 17th century, with several successive widening projects to allow for larger ships to pass through.
9 QUETSCH 1891.

bend in the river directed unwitting ships towards rocks and sand bars.[10] Elsewhere, the river offered rapids, sand or gravel bars, alluvial islands, boulders, steep slopes, tight meanders, and fast flowing courses through narrow river gorges. Settlement along the river could impinge navigation: bridges, weirs, dams, mills, and toll stations have been constant problems for shipping throughout history.

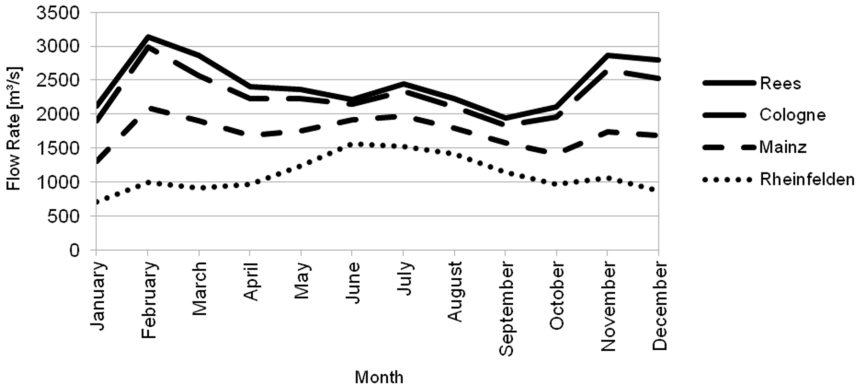


Figure 2. The hydrological regime of the Rhine River from four monitoring stations based on measurements from the 20th century, data courtesy of the Bundesanstalt für Gewässerkunde, Koblenz, after FRANCONI 2011, fig. 2.

The logistics of riverine transport

Riverine shipping required an intimate knowledge of the river. River captains relied on experience and skill to navigate obstacles such as those outlined above safely and to deliver cargoes to their end destinations. This was accomplished within a developed network of transportation infrastructure that included harbours, towpaths, canals, and warehouses. This physical infrastructure operated under an institutional structure that included both state and private interests, responsible for the collection of taxes and duties, the maintenance of infrastructure, the insurance of ships and goods, and the vetting of experienced shippers.[11] The details of these systems are too many to discuss fully, but some important points on the logistics of riverine transportation are highlighted here.

[10] QUETSCH 1891.
[11] FRANCE 2001; SCHMIDTS 2011.

The most common transport vessel for bulky cargoes was the barge, referred to in Latin as the *caudicaria*.[12] Many remains of these ships have been excavated throughout the Rhine basin and elsewhere in Western Europe, and many artistic depictions of these vessels exist in relief, painting, or mosaic. The barges were flat-bottomed vessels with straight sides, with some measuring up to 40 min length and 4.5 m wide.[13] The largest vessels could carry cargoes between 80-100 tons, and even with a full load only required a draught clearance of some 0.5 metres.[14]

These barges were often equipped with a sail, and some have preserved remains of oarlocks and benches.[15] Some scholars have thought that these ships could only move downstream, with many being purpose built to deliver building materials to the military sites of the Lower Rhine, but preserved examples throughout the rest of the Rhine basin demonstrate that they certainly could move upstream. The Wantzenau wreck from Alsace on the Upper Rhine is a case in point, with its cargo of Eifel basalt stones from far downstream.[16]

Upstream movement in such a vessel was difficult but not impossible. While barges on other rivers such as the Nile may have benefitted from strong winds for propulsion against the current,[17] barges on the Rhine had to be hauled from shore by man or beast. Ausonius describes this act in his fourth-century poem *Mosella*:

> "*For you two modes of voyaging are appointed: this, when boats move down the stream with current favouring and their oars thrash the churned waters at full speed; that, when along the banks, with tow-rope never slackening, the boatmen strain on their shoulders hawsers bound to the masts*."[18]

In the ninth century, Wandalbert von Prüm records an instance in the *Vita et Miracula Sanctis Goaris* of a Frisian merchant who was towed up the Rhine by his slaves, and his phrasing is indicative:

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12 CASSON 1965; HÖCKMANN 1994; BOCKIUS 2000.
13 BOCKIUS 2000; VOS *et al.* 2011.
14 BOCKIUS 2000, 480-82.
15 VOS *et al.* 2011, 111-12.
16 ELLMERS 1969, 92-5.
17 COOPER 2011; COOPER 2014.
18 *Mos.* 39-42.

> "*A merchant from the above-mentioned Frisian tribe led his ship up the Rhine and,* as is customary when navigating upstream [*author's emphasis*], *he left it to his slaves pulling the ship by rope from the shore*."[19]

Indeed, Roman art most often depicts manpower for hauling, with examples of depictions from Rome, Avignon, and Igel each showing a ship hauled by three men. Procopius mentions that oxen were used on the Tiber in the 6th century[20], but there is no clear evidence for animal-driven hauling on the Rhine before the middle ages.

We have no clear figures from the Roman period, but more recent data from the Rhine suggest that a man was capable of towing a ship of roughly one or one and a half tons.[21] A single horse was capable of towing between five and fifteen tons,[22] and teams of ten to twelve horses could haul a ship of 150 tons.[23] It is clear that hauling strength was relative to the speed of the river current: on the Moselle, a ship of 120 tons could be hauled by six horses due to the lower volume of water in the river.[24] The Upper Rhine above Speyer, meanwhile, required a doubling of hauling crews to counteract the steeper slope of the river.[25] Massive crews of men were required to haul heavy cargoes; teams of 100 to 200 men were common on the Rhône before the end of the fifteenth century.[26]

There was a large disparity between the time it took to go upstream and downstream. Sailing with the current, a ship could make between 60-70 km per day.[27] Moving upstream by hauling was much slower, with speeds between 5-15 km per day possible.[28] For example, medieval trips from Rotterdam to Cologne took five or six weeks, while the journey from Cologne to Rotterdam took about a week.[29]

Many scholars have attempted to use the evidence preserved in Diocletian's Price Edict to reconstruct the costs of riverine transport, especially relative to sea and land movement.[30] This work suggests that the relative costs of transportation by sea relative to downstream river, upstream river, and land was 1:5:10:34-42,

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19 *Vita et Miracula Sanctis Goaris* 29.2.
20 *History of the Wars* V.26.10-13.
21 ELLMERS 1972, 264; ROSSIAUD 2007, 217.
22 ELLMERS 1972, 264; BÖCKING 1980, 30; ROSSIAUD 2007, 217.
23 QUETSCH 1891, 64.
24 CERMAKIAN 1975, 50.
25 QUETSCH 1891, 64.
26 ROSSIAUD 2007, 217.
27 ROSSIAUD 2007, 213; SCHEIDEL, MEEKS, and WEILAND 2012, 23-24.
28 ROSSIAUD 2007, 219; SCHEIDEL, MEEKS, and WEILAND 2012, 23-24.
29 QUETSCH 1891, 68.
30 ROUECHE 1989, DELAINE 1992; LAURENCE 1999; ARNAUD 2007; RUSSELL 2008.

or estimated absolute costs at 1.2 *denarii* by sea, 5.9 *denarii* downstream, 12 *denarii* upstream, and 52 *denarii* by cart.[31] The accuracy of these estimates is debatable, especially with regard to the difference in upstream and downstream costs. If travelling against the current took six times as long as it took to go downstream, can we expect the trip to only cost twice as much? It is impossible to say, lacking better data.

Finally, riverine transport was seasonal. Winter was an inopportune time as ice flows, floods, and low water levels were all threats to safe travel. Likewise, high waters in spring and fall from rainfall could be dangerous, as were the lowest flows of August and September. Water levels and currents had to be sufficient to allow for the draught of ships while not being too fast moving to pose a threat. The exact rhythms of seasonality varied by river and by individual reach.[32] Early-modern records indicate that the Upper Rhine had peak traffic between June and August when the melt waters from the Alps were highest, while on the Middle Rhine travel in May was also possible.[33] The Lower Rhine and Delta, with their large volumes of water, could sometimes allow travel into September.[34] Transport on tributaries was less consistent and more prone to disruption from flooding or drought.[35]

This brief overview provides logistical context for the following discussion. Each of these elements of riverine transport was vulnerable to systemic changes, potentially increasing the labour, time, and cost involved in shipping. These changes are not mentioned in Roman historical sources, but more recent documentation makes this influence clear, even in the present day.[36]

Climate change and hydrological regimes

The viability of this system was heavily tied to its interannual consistency and reliability. While various specific instances of the ancient climate have been previously discussed,[37] it is only recently that a comprehensive overview of the

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31 DeLaine 1992, 208.
32 See Suttor 1986, 53-56 for the travel seasons on the Meuse and Rossiaud 2007, 219 for the Rhône.
33 Wickert 1903, 135.
34 Wickert 1903, 135.
35 Wickert 1903, 136; Eckoldt 1980.
36 Suttor 1986; Rossiaud 2007; Linde *et al.* 2011.
37 Klostermann 2000; Zolitschka *et al.* 2003; Glaser *et al.* 2005; Schmidt 2010.

Central European climate has been produced. In 2011, an international team of researchers published the results of a palaeoclimatological study of tree rings from over 7,000 oak samples in France, Germany, and Switzerland, making the study particularly relevant to the Rhine Basin.[38]

It is evident from these data that there was substantial climatic variation in the region between 100 BC and AD 500. The first and second centuries AD saw relative stability in both temperature and rainfall. Starting around the beginning of the third century, rainfall levels dropped and temperatures became more erratic. The fourth century became progressively colder and wetter, a trend which extended into the fifth before rainfall levels dropped again.

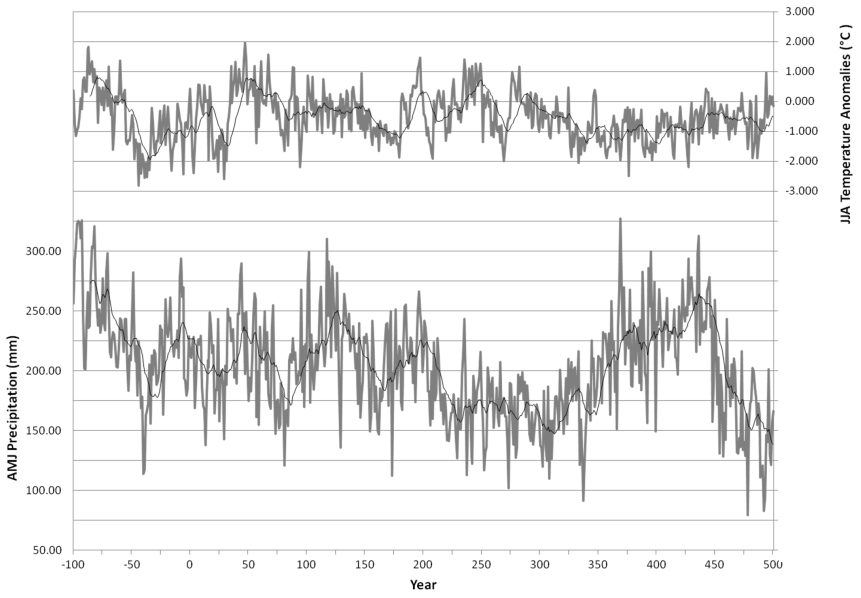


Figure 3. Dendrochronological climatic reconstruction for Rhine region, 100 BC – AD 500, showing April-May-June precipitation and June-July-August temperature variation, data from BÜNTGEN et al. 2011, after FRANCONI 2011, fig. 1.

[38] BÜNTGEN *et al.* 2011.

Hydrological activity is directly tied to climatic trends in precipitation and temperature.[39] Changes to these variables produce immediate effects within a river basin. Two very basic scenarios can be proposed: one in the event of warming, one in the event of cooling. For every one degree Celsius that the temperature increases within a given river system, total river flows will decrease between 5 and 15%, largely because of an increase in evapo-transpiration and a decrease in precipitation. Winter rains will replace snowfall and glaciers will recede causing an increase in melt water which, combined with winter rains, will cause an increase in winter flooding. Conversely, summer will be drier with higher risks of drought. Because of decreased run off, sediment loads will also decrease, increasing the likelihood that rivers will meander rather than braid, lengthening the course a river.

In the cooling scenario, the opposite occurs. Riverine flows increase, evaporation decreases, precipitation rises, and floods become more likely in spring and summer as a result of higher snowmelt. Drought conditions will become less common, and an increased sediment load caused by higher amounts of rain-driven runoff will increase river braiding, creating additional channels and sandbars.

Changes to the seasonal hydrological regime of the river system would have directly influenced shipping practices, which were intrinsically linked to the seasonal variation in water levels on the Rhine.

Hydrological change in the Rhine basin

Available archaeological and geomorphological evidence makes it clear that the Rhine River basin responded to environmental and climatic changes over the course of the Roman period. This evidence is available throughout the basin, with particular clusters of data from the Upper Rhine and Lower Rhine floodplains as well as the delta zone.

On the Upper Rhine and its tributary the Ill, flood deposits have been excavated at Oedenburg, Horbourg, Ehl, and Strasbourg.[40] At Oedenburg, four centennial-scale floods dated between AD 20-145 have been documented, but settlement persisted on the site until the fourth century when a rising water table

[39] ARNELL 2009.

[40] HATT 1954; HATT 1966; PROVOST 1984; BAUDOUX *et al.* 2002, 272, 317, 360, 364; OLLIVE *et* al. 2006; OLLIVE 2007; OLLIVE *et al.* 2008; REDDÉ and BOCKIUS 2011.

finally forced the vicus to be abandoned in favour of higher ground. The floods at Horbourg occurred between the late second and early third centuries, while those at Ehl were dated to AD 50-60 and AD 97-160, with a final flood at the end of the second century that led to the settlement's abandonment. Strasbourg saw the implementation of various anti-flood measures, but these did not protect all of the *canabae* settlement from the waters and some regions were abandoned in the late second century.[41]

On the Lower Rhine, the harbour of Cologne was initially situated on a side channel between an alluvial island and the riverbank. This channel silted up by the end of the second century, forcing the relocation of wharves and ships to the main channel of the river.[42] Downstream, the auxiliary fort of Moers-Asberg was built on the edge of a river meander under Augustus.[43] This meander was cut off in the middle of the second century, leaving the fort stranded on an oxbow inlet. The city of Xanten experienced similar issues. Excavations revealed flood deposits on the site dated to the years between AD 20 and 50.[44] Starting near AD 200, though, the Rhine began to migrate away from the city, eventually cutting the harbour off from the river entirely.[45]

Two final examples come from the delta region. The Augustan auxiliary fort at Vechten suffered flooding in the first century, and the side channel of the Rhine on which it was constructed began silting up in the second century.[46] The fort was eventually entirely cut off from the river and the site abandoned in the third century. To the south and west, the site of Voorburg was located on the canal of Corbulo that linked the Rhine and Maas rivers. Excavations of the harbour at Voorburg revealed that the canal channel received high levels of sedimentation in the second century, severing the link between the two rivers.[47] The town's southern access to the Maas delta was maintained through dredging into the third century, after which point the venture was abandoned.

These sites demonstrate clear instances of hydrological change throughout the Rhine Basin. A general trend towards early flooding was followed by a wide-

41 BAUDOUX *et al*. 2002, 272, 317, 360, 364.
42 NEU 1985; DIETMAR and TRIER 2006; LAUER *et al*. 2013; SCHÄFER 2014.
43 BECHERT 1989; GERLACH *et al.* 1993; ROGGENKAMP and HERGET 2014, 31-33.
44 PETRIKOVITS 1952, 158.
45 KLOSTERMANN 2000, 41; KLOSTERMANN 2008; GERLACH and MEURERS-BALKE 2014, 201-2.
46 POLAK 2014.
47 BUIJTENDORP 2010, 145; DRIESSEN 2014; KORT and RACZYNSKI-HENK 2014.

spread increase in sedimentation after the third century.[48] The change in river conditions occurred contemporaneously with the changing climate conditions shown in the dendrochronological data outlined above. While human settlement within the basin surely had a hand in these changes as well, the influence of the climate was inescapable and had basin-wide consequences. This is highlighted by a passage of Tacitus related to an event in the autumn of AD 69 at Krefeld (*Hist*. 4.26.9) when a ship ran aground in the Rhine during a drought, allowing Germans to seize the cargo and carry it off to their side of the river. Later in time, Ammianus Marcellinus reported (14.10.2) that flooded rivers in Gaul halted a grain shipment from Aquitania to the Rhine in AD 354. Constantius' troops nearly revolted over the delay.

Climatic influence on riverine transport

The available evidence for hydrological change is broad-brush and coarse, meaning that the wider importance must be inferred from the available data. Sporadic historical attestations make it clear that climatological and hydrological change existed in the Roman world and caused substantial, practical problems. Broadly speaking, worsening climatic and hydrological conditions resulted in four possible scenarios:

1.) **Siltation and alluviation:** Increased surface runoff will lead to a higher sediment level within a river, leading to the infilling and sedimentation of harbours, canals, and waterways. This problem required dredging and channel maintenance or the eventual movement of harbour infrastructure as occurred at Cologne. If this was not possible, access to waterways was lost, as is evident at Moers-Asberg, Xanten, and Vechten.
2.) **Channel degradation**: The deposition of sediment within the active river channel leads towards a shallower riverbed, prone to the formation of sandbars and alluvial islands that hinder navigation. Over time, a meandering river system will change to a braided pattern which is much more difficult for ships to pass through. This change is most obvious in the Lower Rhine

[48] Paralleled by geomorphological sequences published by HOFFMANN *et al.* 2009; DAMBECK and THIEMEYER 2004; DIKAU, HERGET, and HEINRICH 2005; DIX *et al.* 2005; TOONEN 2013, 137-50.

floodplain,[49] but also probably happened in the area near Oedenburg on the Upper Rhine.

3.) **Changes to seasonal regimes:** Floods and droughts, evident in both archaeological and historical evidence, posed serious problems for Roman riparian life. Changes to the annual patterning of these extremes altered the number of days available for transport. Moreover, colder winters meant increased ice flows, mentioned repeatedly in the 4th century by Ammianus Marcellinus.

4.) **Infrastructural decay**: Each of these problems contributed to the decay of riverine infrastructure. Examples can be found in silting harbours and canals, damage to wharves, towpaths, and riverside revetment from flooding and the erosion of bridge footings by currents.[50] These issues could be dealt with, but required money and labour to be accomplished. State involvement is evident in earlier periods, but many problems were evidently insurmountable in the later years of Roman rule on the Rhine.

All of this leads to a decline in the efficiency of riverine transport. Disruptions to the flow regime slow transport or make it more dangerous. More labour may be required for hauling or sailing, and this in turn results in higher prices. Scant literary references make it clear that Roman trade could suffer, and later evidence demonstrates that the impact could be quite large. Higher prices, slower transport, and increased labour all resulted in fewer imported goods and a shift to other modes of transport, if possible. These problems were compounded when goods need to cross between multiple river basins, as in the Rhône-Saône-Moselle-Rhine route.[51]

These four outcomes demonstrate the influence of climatic and environmental change over riverine trade in antiquity. The Rhine was not alone in experiencing these changes, and evidence from around the Empire shows that fluvial change was a universal problem. As further evidence of these changes is revealed, we must continue to think about how they affected the daily life of Roman society and which problems could be met and which could not.

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49 KLOSTERMANN 2000; KLOSTERMANN 2008.

50 See EDGEWORTH 2011 on this phenomenon.

51 On this route see PEACOCK 1978; DESBAT and MARTIN-KILCHER 1989.

Conclusions

Climatic change during the Roman period in the Rhine region had obvious and important repercussions on hydrology and riverine transport. The viability of river transport was directly tied to the seasonal and interannual variation of the river system. Climatic and hydrological downturns had a negative impact on many elements that were critical to the smooth functioning of riverine trade, and as a result riverine trade suffered. Such a climatic downturn is evident in dendrochronological data from the late third century onwards, and historical, archaeological, and geomorphological data show a direct correlation to the decay of riverine infrastructure in the same period.

The damage of this change is most obvious in the decay of infrastructural elements such as a canals and harbours, but also evident in the lack of many long-distance trade goods in the Late Roman period throughout the region. This is not to say that river trade became impossible in the face of a changing climate and environment, but rather Romans had to adapt and meet the challenges posed. Ausonius (*Ordo urb. nob*. 6.6-7) still comments that the Moselle brought many goods to Trier in the 4th c. AD, and the contemporaneous *Expositio Totius Mundi* similarly records that Arles gathered and sent all the goods of the world to Trier. It is unfortunate that we cannot fully quantify the volume of trade received over time, but the evidence available suggests declining volumes over the course of the Roman period.[52]

Roman connectivity required a complex and interlinked network, and there is no doubt that rivers were a key part of the transport network, especially in the Roman West. Much time, money, and effort went into improving the rivers of Gaul and Germany for trade and communication, but the Roman Empire could do little to counteract the climatic and hydrological changes outlined in this paper. These natural changes had a significant impact on the economic stability of Germany and played a part in the disintegration of the Late-Roman Rhine from the Empire-wide trade networks of the later fourth and early fifth centuries.

[52] MARTIN-KILCHER 1987; MARTIN-KILCHER 1994; EHMIG 2003; EHMIG 2007.

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