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The tracing of trade: exploring the patterns of olive oil production and distribution from Roman Baetica

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The tracing of trade

Exploring the patterns of olive oil production and distribution
from Roman Baetica

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Abstract The aim of this study is to explore economics dynamics in the production and distribution of olive oil trade in *Baetica* province (currently Andalusia). *Baetica* became an important production and distribution centre during the Roman Empire. However, it remains under debate about how this province was organised and whether it could be possible to identify patterns in the olive oil market.

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1
2 **Keywords** Roman Empire · amphora production · Dressel 20 · dissimilarity
3 index · Roman provinces
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1 Introduction

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8 The intensification of long-range trade was one of the most important traits of
9 the economy developed during the Roman Empire. The development of an ex-
10 tensive road network increased the connectivity between inland communities,
11 but most shipping continued being based on maritime routes particularly in
12 the Mediterranean basin (Temin 2001, Bevan 2014). The intensity of this trade
13 between distant regions can be observed both in archaeological and written
14 evidence (Remesal 1998).

15 The Empire developed a series of structures to support and organise this
16 long-range trade and specialised entire regions to massively produce specific
17 goods. An example of this process was the province of *Baetica* (currently
18 Andalusia, southern Spain) which became an important olive oil production
19 centre during the Roman Empire. Olive oil was an essential good for Romans
20 because it was used in almost every aspect of their daily life such as cooking,
21 hygiene or lighting (Mattingly 1988). This high demand required a huge in-
22 crease on the production which was distributed through amphorae shipped via
23 maritime routes to all the provinces and particularly to Italy and the hundreds
24 of garrisons that the Roman army deployed along its borders (Blázquez 1980).

25 The structure and processes associated with this massive olive oil produc-
26 tion have been extensively discussed over the last decades (Remesal 1977-1978,
27 Chic 1997, Berni 1998). However, the lack of written records has not made
28 possible to detect any indication of patterns in the olive oil market.

29 Our knowledge of this economic activity has benefited from new findings
30 and data sources, but despite all these advances several questions remain open:
31 How was amphora production organised during the Roman Empire? Can we
32 detect economic dynamics between provinces by analysing the distribution of
33 amphorae?

34 Advances in the research of the Roman studies have currently led an envi-
35 ronment with various interpretations on commercial dynamics (Duncan-Jones
36 1982, Temin 2006, Bowman & Wilson 2009).

37 The application of different quantitative approaches has allowed us to im-
38 prove our interpretation of the growing amount of archaeological evidence
39 and reveal the dynamics of Roman production (Brughmans & Poblome 2016,
40 Orengo & Livarda 2016, Rubio-Campillo et al. 2017, Coto-Sarmiento et al.
41 2018, Rubio-Campillo et al. 2018).

42 This work focuses on the debate about the dynamics of the distribution of
43 olive oil market in Roman provinces. Amphoric production in *Baetica* province
44 will help us identify links between production centres and consumption centres
45 in order to detect an economic pattern in the commerce by analysing stamps
46 amphorae finding in the provinces.

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The finding of amphoric stamps in different provinces has allowed us to know the importance of the distribution of olive oil within the Empire. Despite having archaeological evidence, no consensus has been reached: How was the economical relation between production and consumption centres? Did they follow an economical pattern to distribute olive oil in those provinces?

This paper aims to study the olive oil market connection between provinces by calculating the similarity of stamps. Specifically, our work pretends to detect regional processes focused on a commercial product from a specific province (Isaksen 2006). We want to understand the pattern of olive oil production linked to amphora workshops and amphoric stamps used to mark them. We focus here on exploring the economic relation between stamps and amphora production and distribution centres.

Two case studies have been studied in order to analyse the relation between production centres (*Baetica*) and consumption centres (*Britannia* and *Germania*) (see Figure 1).

In the case of *Baetica* province, we want to identify the role of the stamps in the organisation of the workshop; in Roman provinces, our aim is detecting groups of stamps concentrated in an area or if some groups have an important role for the exportation of olive oil in those provinces. This economic connection could be identified by different aspects: a) correlation between spatial distance and the sites based on the idea that closer workshops concentrate similar amphoric stamps in a specific area than the distant workshops and b) groups of similar stamps were concentrated in a specific province.

In particular, we study the distribution of amphoric stamps to identify a correlation between geographical distance and similarity. Based on this assumption, we proposed three hypotheses: a) we can identify a correlation between spatial distance and the distribution of stamps, b) stamps located in close workshops share similar traits and c) low mobility of amphoric stamps to other regions: stamps always stay in the same region.

This study proposes a robust baseline to explore the distribution of Baetican olive oil production by computing the spatial correlation between stamps. To do this, a population approach has been used to analyse the dispersion of stamps between amphora workshops (Rubio-Campillo et al. 2018). A way to analyse is to use a quantitative framework to measure the similarity between amphoric stamps. Here, we use an ecological approach based on three steps: a) to detect similarities between stamp codes, b) to explore a potentially spatial correlation and c) to establish a correlation between similarity of stamps and spatial distance. Stamps will be used to identify economic patterns by analysing their similarity. If workshops and provinces share stamps with similar traits, then we can identify connections. By contrast, if we do not detect similar stamps between workshops, then workshops worked independently.

The paper addresses these questions as follows: the next section introduces the historical context. Section two displays the dataset and the methods used for the analysis. Section three presents the results and the last section shows the discussion and the main conclusions of this work.

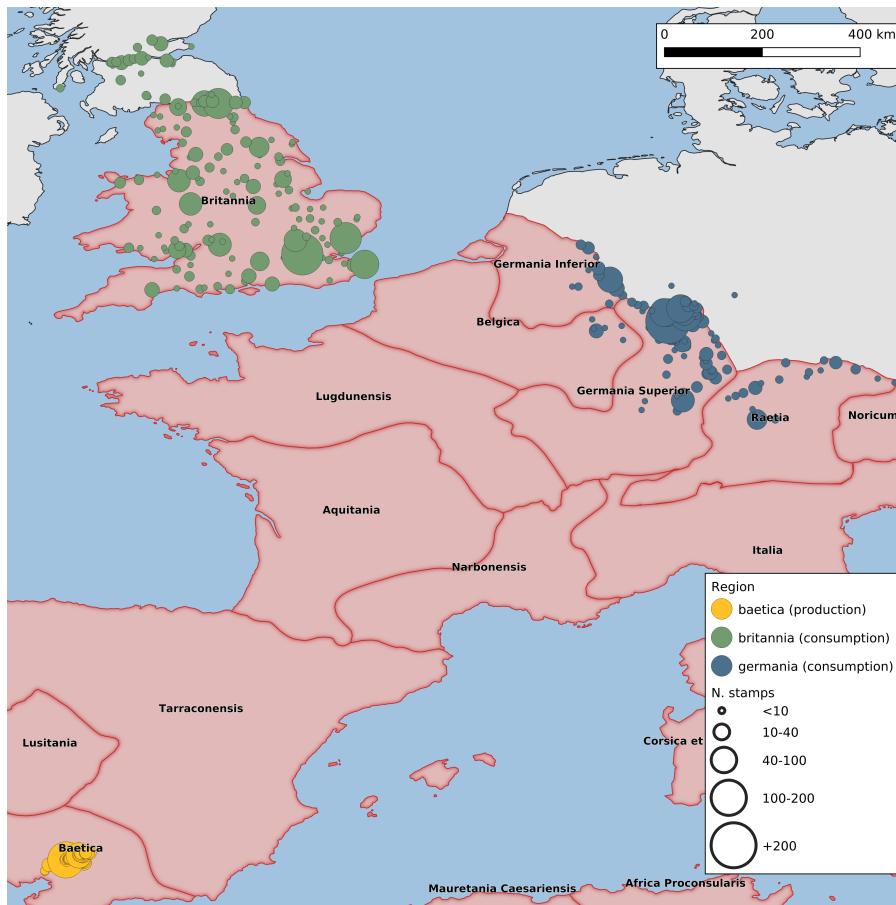


Fig. 1 Overview of the sites analysed in this paper. The colour defines the three different regions under study (*Baetica* as producer; *Germania* and *Britannia* as consumers) while the size of each dot highlights the number of Dressel 20 amphoritic stamps found on each of these sites

2 The Amphoritic production of Baetica

The landscape of the *Baetican* province was one of the best regions to face the increased demand for olive oil across the Roman provinces. For this reason, the area saw an increase in productivity as a massive infrastructure of olive oil production was gradually deployed. The production and distribution of olive oil increased from the first to the third centuries AD (Remesal 2011).

Hundreds of presses and amphora-making workshops were built near large extensions covered by olive trees. The workshops where amphorae were made and filled with olive oil were places along the rivers Guadalquivir and Genil riverbanks (see Fig. 2).

This strategic location allowed the transport of olive oil through riverine shipping towards the maritime routes that connected *Baetica* with Mediterranean and Atlantic trade routes towards the rest of the Empire (García Vargas 2010).

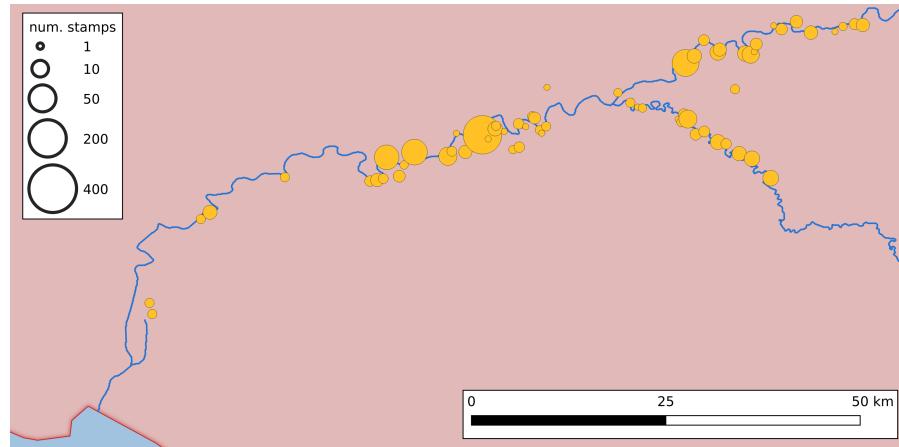


Fig. 2 Distribution of stamps found in Dressel 20 workshops along the Guadalquivir riverbank. The size of each point depends on the number of stamps found on each site

The chronology of the workshops is wide spanning from the first to the third centuries AD (Berni 1998, Remesal 1998, Chic 2005). This fact is shown by the archaeological evidence that displays a highly specialised production with a long activity (Remesal 2004). Thus, the specialisation of this production made amphorae with apparently few changes in their forms, reaching a high degree of standardisation.

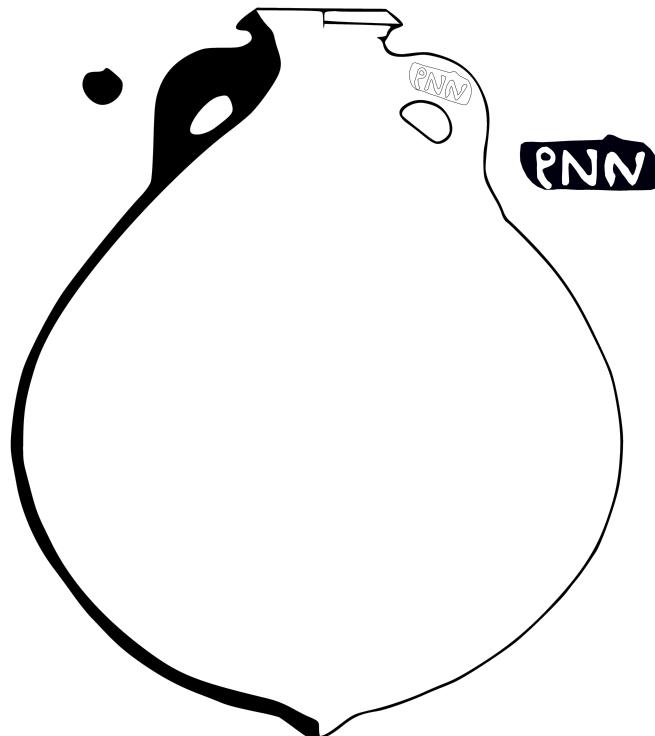
The importance of this olive oil trade is revealed by the massive amount of Dressel 20 type amphorae found across the Roman provinces (Dressel 1878, Berni 1998). This amphora has been commonly associated with the transportation of Baetican olive oil for supplying military camps and civil settlements (Berni 2008).

They have a recognisable globular form with a short neck and oval-shaped handles. Its capacity allowed to hold 70-75 litres of olive oil to be shipped and distributed throughout Empire (Berni & García Vargas 2016).

Dressel 20 amphorae display a lot of evidence, but some of it is still hard to interpret. A large percentage of Dressel 20 were marked with stamps, while they could also be inked with *tituli picti* or incised with *graffiti*. The interpretation for most of these inscriptions is still open due to the fragmentation of the material and the small sample size of well-preserved elements (Aguilera 2007, Rovira Guardiola 2007).

1 2 **3 A potential indicator of Roman economy: Dressel 20 stamps**

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4 Dressel 20 was the amphora most stamped during the Roman Empire (Berni
5 1998, 18). The large sample size of recovered Dressel 20 stamps is distributed
6 across all the western provinces of the Roman Empire. For this reason, there
7 are several publications of this type of evidence discussing its origin, its mean-
8 ing, its long period of use and its spatial distribution (Dressel 1878, Remesal
9 1977-1978, Chic 1985, Berni 1998, Remesal 2016) (Fig.3).



39 **Fig. 3** Dressel 20 were mostly marked with stamps of three letters called *tria nomina*

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41 Most stamps display a large activity of production that can be difficult to
42 date using an accurate chronology. They have been frequently dated with the
43 consular dating by studying *tituli picti* found in *Monte Testaccio* (Blázquez
44 Martínez & Remesal Rodríguez 1999, Berni 2008). Despite *tituli picti* contain
45 important information about chronology, they have been still found in few
46 quantities mostly concentrated in an only settlement such as *Monte Testaccio*.
47 In addition, the chronology of stamps could be also biased taking into account
48 that amphorae were deposited after being produced and consumed.
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The use of amphoric stamps can be a good proxy to explore the system of olive oil production and trade developed in *Baetica* province. These stamps are typically found on handles but they were also imprinted on rims and the amphora body (Berni 1998). The content information of the stamps is shown in different forms and letter content and it seems that there was not a unique criterion.

Stamps often displayed a code of three letters and they are known as *Tria Nomina* (Berni 1996). The three letters correspond to initial forms of a name but they can also appear complete.

Scholars agree that stamps are some type of identification mark, but there is no consensus on the meaning of these marks (Remesal 1998).

The stamp codes are interpreted based on three main ideas: content (olive oil), context (amphora workshop) and subject (individuals involved in the production). On the one hand, it seems that stamps could have been identified as the landowner of the olive groves (Remesal 1977-1978). On the other hand, they could also belong to the owner of the workshops where the amphorae were made or even to a group of amphora workers (Berni 2008).

Nevertheless, some challenges remain under discussion such as how this production was organised and whether it is possible to distinguish production patterns in the olive oil trade. Our questions will be focused on the distribution of amphoric stamps. Did they follow a distribution pattern? Did stamps share the same workshop?

4 Consumption centres: Britannia and Germania

The creation of new provinces required the Roman Empire the arrival of resources through Mediterranean and Atlantic routes.

This led to a gradual change in the economic and social structures the trade networks that supplied the Roman army became more complex. Augustus's administration created the figure of the *praefectura annonae* to organize wheat supply. The role of the *praefectura annonae* was mainly focused on providing through *frumentationes* a fixed monthly amount of wheat to each Roman citizen (Remesal 1986, 2011)

However, some hypotheses argue elsewhere that this same *praefectura annonae* could also have organised the supply of additional goods such as olive oil to the Roman legions (Remesal 1986, 1990)

Olive oil supply seems to be particularly intense in militarised provinces that functioned as the borders of the Empire such as *Britannia* and *Germania*. The high percentage of Dressel 20 amphorae found in sites nearby military garrisons suggests the existence of diverse supply dynamics as there were trade processes flowing from military sites to civil settlements (Remesal 1986, Carreras Monfort & Funari 1998).

An explanation for the interest to export olive oil for the military garrison in the Roman provinces is still unclear. The origin of this exportation may be related to two aspects: a) cultural consumption whose olive oil is used by

cultural reasons such as group identification or by habit and b) economical and political reasons to create a redistributive system mechanism to supply military camps (Carreras Monfort & Funari 1998, 69-70).

The Roman conquest in *Britannia* and *Germania* was a new opening to foreign trade in order to supply the military campaign. High demand for olive oil in both provinces stimulated an important trade network involving different agents and the Empire itself. *Baetica* became a strategic province for the production and distribution in both provinces since it can be detected by the high presence of amphoric stamps found in civil and military areas during this period.

4.1 Britannia

The evidence for olive oil consumption in *Britannia* is scarce before the Roman conquest (Funari 1996, Carreras Monfort & Funari 2003). The local population did not consume this product and it was not produced on the region as the landscape and climate of the British Isles was not suitable for olive oil trees(Carreras Monfort 1998, 161). Based on the archaeological records, this absence of olive oil changed with the arrival of a large amount of Dressel 20 amphorae to *Britannia* from the first century A.D (Peacock & Williams 1991, Carreras Monfort & Funari 1998). At this moment, we detect an increase of the olive oil exportation concurring with the displacement of legions during the military campaigns (Carreras Monfort 1998, 161).

The increase of the exportation of Dressel 20 amphorae created an important commercial network for exchanges. The demand for olive oil after the Roman conquest required of a new trade route due to the lack of local olive oil production; *Baetica* was chosen as its main supply.

This fact will have a particular intensity within sites close to the Hadrian Wall's garrisons. Olive oil production in *Baetica* would cross the Atlantic until they reached the province and redistribute throughout the area from a series of strategic locations (Carreras & Morais 2012).

The presence of Dressel 20 stamps in military camps in *Britannia* has been widely studied in Roman archaeology (Williams & Peacock 1983, Funari 1996, Carreras Monfort & Funari 1998, 2003).

This intense consumption of olive oil also indicates a possible provincial structure designed to organise the supply of olive oil to military camps.

There are no written records explaining how this redistribution of essential goods was organised in *Britannia*, but the archaeological evidence suggests that cities may have been the central nodes of this local trade network (Funari 2005, 45).

The consumption of olive oil would experience a progressive slowdown from the third century A.D. onwards. This date matches a change in market strategy in the Empire. This gradual decrease on *Baetican* olive oil exports can be observed as a decrease in the amount of Dressel 20 found in excavated sites

1 as this typology is replaced by other types of amphorae from other places
2 (Remesal 1991, Berni 1998).
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4.2 Germania

8 Roman studies exploring the presence of Dressel 20 amphorae in the provinces
9 Inferior and Superior during Roman Empire have not had the same impact as
10 the rest of the provinces (Remesal 2002a, 293).

11 The massive importation of Dressel 20 in both *Germania* provinces could
12 be explained due to the archaeological sources found mostly in German *limes*.
13 By contrast, it is still unknown if trade agents participated in the distribution
14 of Baetican olive oil in *Germania* or the supply was exclusively focused on the
15 Roman army garrisons (Remesal 2010, 156).
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18 *Germania* presents a similar introduction pattern of olive oil than the one
19 discussed for *Britannia*. There is no archaeological evidence for olive oil con-
20 sumption before the arrival of the Roman army to the region while a majority
21 of recovered Dressel 20 amphorae are located in the military sites that formed
22 the German *limes* (Remesal 2002b).
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25 The presence of the Roman army encouraged the exchange in the province
26 as shown by the arrival of this product both civil settlement and military sites
27 with a major concentration at the German *limes*.
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30 It seems that some Baetican centres could have been assigned to a specific
31 province for the olive oil supply to military garrisons (Remesal 2011, 125).
32 However, this hypothesis is hard to assess given the current lack of written
33 evidence related to the meaning of the amphoric stamps.
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36 Previous studies suggested that the supply to the German limes was mainly
37 based on riverine transport, but recent works suggest that the maritime route
38 through the Atlantic Ocean could have been more important than expected
39 (both for *Germania* and *Britannia*) (Remesal 2010, Rubio-Campillo et al.
40 2018).
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5 Material and Methods

45 The goal of this study is exploring the effect of the production patterns between
46 different centres. We are especially interested in identifying links between pro-
47 duction and consumption centres by using amphoric stamps.
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50 To study the amphoric stamps, we used the data collected in the CEIPAC
51 database of amphoric epigraphy from different places (Remesal et al. 2015) (see
52 the database here <http://romanopendata.eu>). The CEIPAC dataset contains
53 over 50.000 epigraphy records found on different types of amphorae, mostly
54 from Monte Testaccio.
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1 5.1 Production centres: Baetica province
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The database allowed us to retrieve 3798 stamps found in Dressel 20 amphorae recovered from workshops within *Baetica* province. Each of these stamps have detailed records on the site where it was found, the inscribed code as well as its spatial coordinates. The stamps with incomplete information were discarded, thus finishing with a sample of 987 stamps from 81 sites and displaying 130 different codes.

Our dataset also contained a new categorical variable defining the *conventus* of each site. The *conventus* were administrative centres for territorial organisation under the Roman Empire (Ozcáriz Gil 2013, 58). The creation of the *conventus* in some Roman provinces was a form of control with the purpose of organising the administration in the provinces (Albertini 1923).

The production area for Dressel 20 amphorae extended across three different *conventus*: *Hispalensis* (currently Seville, hereafter *Hispalis*), *Cordubensis* (currently Córdoba, hereafter *Corduba*) and *Astigi* (currently Écija, Sevilla, hereafter *Astigi*) (Remesal 1977-1978, Chic 2001, Berni 2008) .

It is important to mention that some workshops exhibited the same geographical coordinates while they were catalogued differently as workshops. For instance, two nearby amphora workshops such as Tesorillo de Doña Mencia and Doña Mencia were catalogued as a different name in spite of having the same geographical coordinates. Our work considered this particularity in the archaeological dataset but some biases can occur in the analysis.

The first step was to compute the frequency distribution of stamp codes and analyse it using Exploratory Data Analysis (EDA). This would allow us to study the distribution of the stamps across centres as can be seen in Figure 4. Most workshops concentrated few stamps while few workshops contained more than 100 stamps. For instance, one workshop (La Catria) concentrated a large percentage of the amphoric stamps with a total number of 228 stamps.

The type of distribution is also frequent in amphora production where we observed a major concentration of the number of stamps in few workshops (Rubio-Campillo et al. 2017, Coto-Sarmiento et al. 2018).

The distribution of code stamps for each *conventus* can be seen in Figure 5. The majority of stamps are concentrated in *Hispalis* (574 code stamps) while *Corduba* and *Astigi* have roughly half this sample size (267 and 146 code stamps). The workshops of the three *conventus* show a similar pattern on the stamp frequency distribution with the exceptions of 2 large workshops in *Hispalis* (La Catria and Arva). On these two workshops a comparatively large amount of code stamps were found (29 different code stamps on each of them).

According to previous studies, those workshops became the most important centres of amphora production in the region (Remesal 1977-1978, Remesal et al. 1997).

It is worth mentioning that a majority of these stamps were collected during field surveys with no excavation, so this difference in sample size could be biased due to differences in intensity across the different sites (Remesal et al. 1997).

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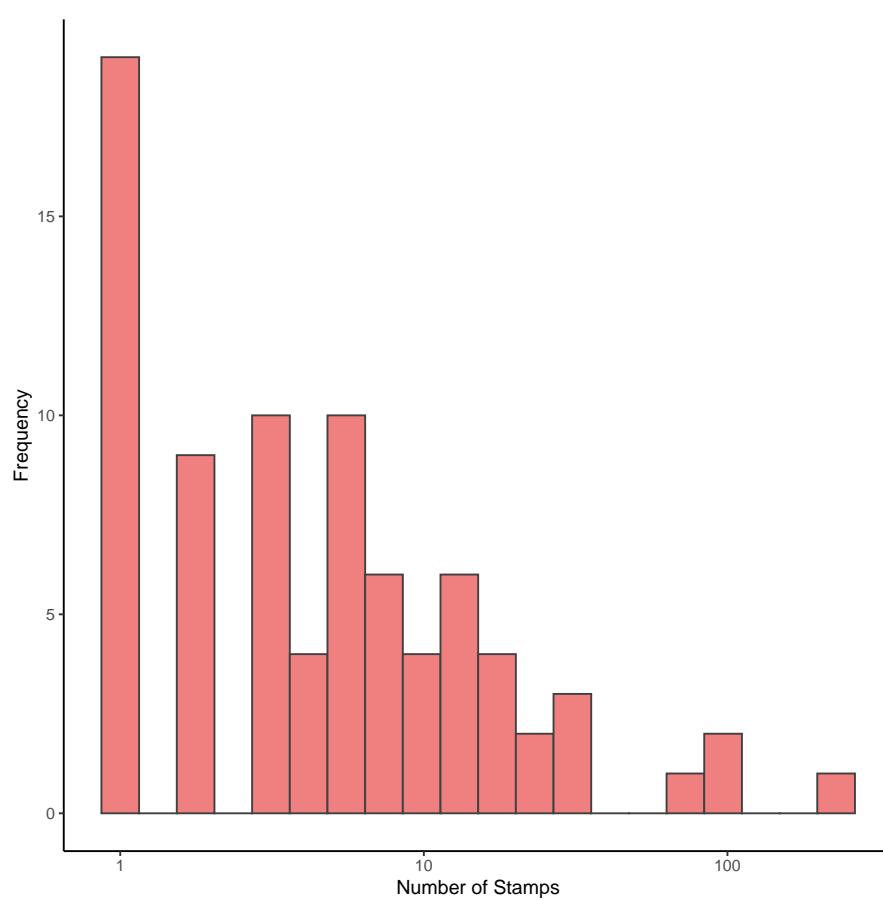


Fig. 4 Histogram on a log scale with base 10. X axis is represented by the number of stamps and Y axis is the frequency of workshop. The distribution is widely diverse with most workshops having only one stamp

5.2 Consumption centres: Britannia and Germania

The analysis of stamps in consumption areas also used the CEIPAC database and filtered in the same way than the previous dataset. However, in this case, we selected the centres with more or equal than five stamps in order to maximise the analysis with more stamps in the dataset.

The output was a dataset of 4271 stamps found in sites belonging to *Britannia* (total: 2219 stamps, analysed: 1765 stamps) and *Germania* (total: 2052 stamps, analysed: 1621 stamps). Some stamps from *Britannia* and *Germania* were discarded for the analysis for incomplete information.

Both *Germania* and *Britannia* were analysed as borders and not as Roman provinces. This means that we included in the sample some centres that are actually located beyond the administrative boundaries but were considered

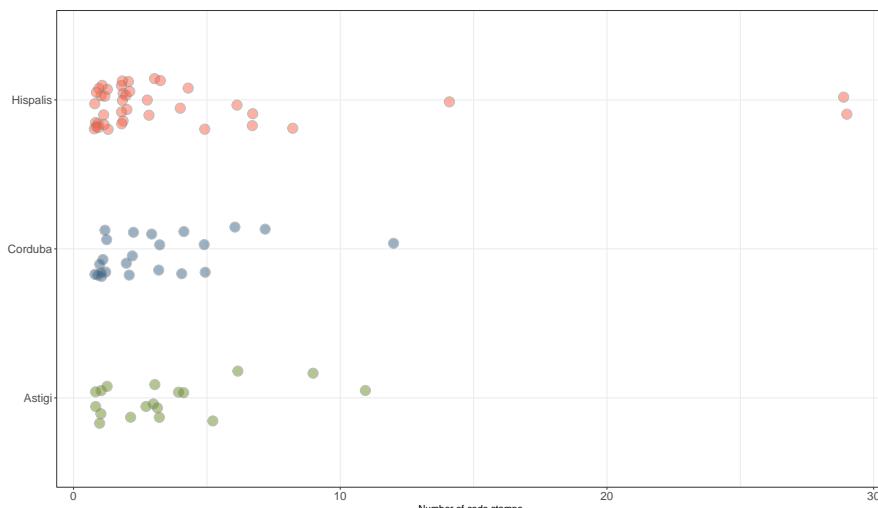


Fig. 5 Distribution of the number of different code stamps (X axis) for each *conventus* (Y axis). Each dot corresponds to a workshop sorted by different areas. Colours are represented by areas divided into *Hispalis* (red), *Astigi* (green) and *Corduba* (blue)

part of the same border. Specifically, for the German *limes* we included sites from the two provinces (Superior and Inferior) while the analysis of *Britannia* extended to *Caledonia*.

In *Britannia*, we studied a total sample of 1765 stamps from 46 sites displaying 968 unique codes. The centres located in *Britannia* can be seen in Figure 6.

In *Germania*, we collected a total of 1621 stamps from 46 sites displaying 850 different stamp codes (see Figure 7).

5.3 Measuring the dissimilarity

The approach proposed here aimed at exploring links between production and consumption centres through the identification of common amphorae codes found in different sites. For this reason we measured the similarity between amphora workshops and/or consumption sites by quantifying a pairwise distance or dissimilarity index between places (i.e. to what extent the stamp codes found on these sites were different). The chosen dissimilarity measure was the Morisita-Horn index (Morisita 1959, Horn 1966). This method was applied to measure the dissimilarity between different samples of sets. Generally, it describes the dissimilarity between the system of two communities based on the idea of inverse correlation between diversity and species (Magurran 1988). In our case, stamps from different sites will be used as a proxy to measure their dissimilarity by analysing their code.

The formula can be described as follows (Magurran 2004):

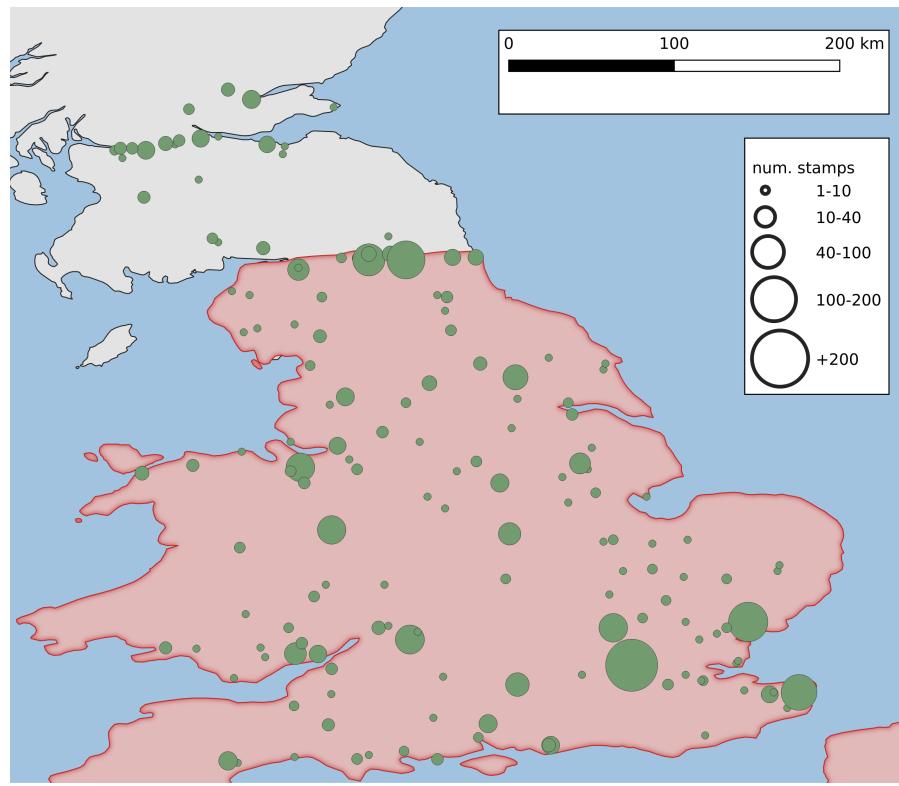


Fig. 6 Sites in *Britannia* where Dressel 20 amphoric stamps have been found. Each dot is a site while its size shows the sample size of stamps found on the site. A majority of stamps have been found in garrisons related to Hadrian's and Antonine walls

$$D(MH) = 1 - \frac{2 \sum (a_i \cdot b_i)}{(d_a + d_b) \cdot (N_a \cdot N_b)} \quad (1)$$

d_a and d_b are given by the following equation:

$$d_a = \frac{\sum a_i^2}{N_a^2} \quad (2)$$

where N_a is the total number of stamps in workshop A; N_b is the total number of stamps in workshop B; a_i is the number of different stamps for workshop A and b_i is the number of different stamps for workshop B.

Considering our dataset as a non-uniform sample, this method provides a useful tool to handle large samples with different sizes and diversity (Wolda 1981). Morisita-Horn index gives a value between 0 (sites have exact stamp codes and frequency distribution) and 1 (complete difference between stamp

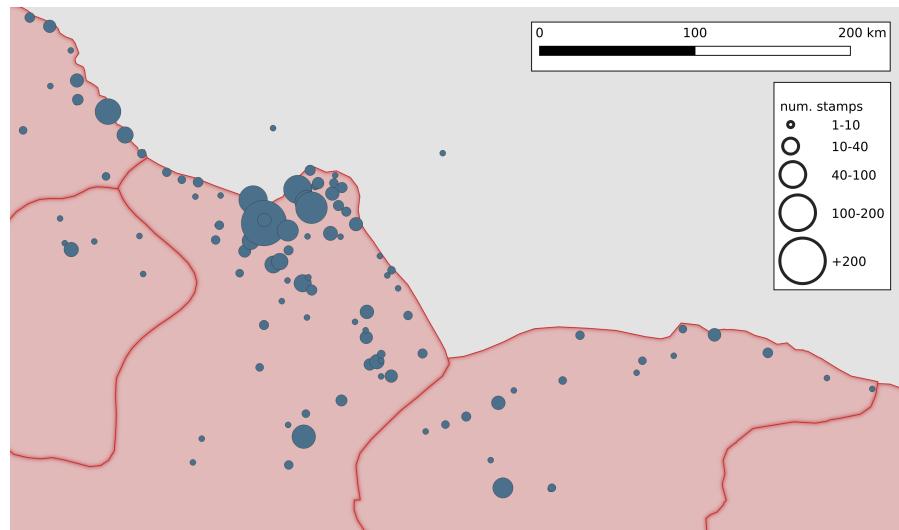


Fig. 7 Sites in Germania where Dressel 20 amphoric stamps have been found. Each dot is a site while its size shows the sample size of stamps found on the site. Most sites are located along the German *limes*

codes). To apply Morisita-Horn index, we first calculated the number of times that each stamp code appeared in an amphora workshop. This method allowed us to bear in mind the number of frequency of stamps for each workshop.

If two workshops had similar stamp code distribution then the distance index would be close to 0 whereas sites with completely unrelated stamp codes would give a distance close to 1.

5.4 Hierarchical clustering

The Morisita-Horn index was used to generate a dissimilarity matrix containing the distance value between each pairwise site based on their code stamps. Hierarchical clustering was applied to this matrix in order to group sites with similar stamps codes distributions. The algorithm was selected to cluster similar groups in order to analyse the relationship between groups of sites and the distribution of similar stamp codes. The results were visualised using a dendrogram to detect groups of sites sharing similar stamp codes.

6 Results

6.1 Production centres: Baetica Province

The hierarchical clustering of the Morisita-Horn pairwise distance matrix can be seen as a dendrogram in Figure 8. This visualisation suggests that each

1 amphora workshop often used unique stamps in their production system that
2 have not been found on any other site. In fact, the similarity values are always
3 low and a majority of stamp codes found on multiple sites are only present in
4 two or three workshops.
5

6 Nearby workshops display a higher similarity than distant workshops and
7 the varying degrees of similarity between sites which could be correlated to
8 their spatial distance; additionally, the workshops with higher similarity values
9 belong to the same *conventus* area, such as Picachos, Cerro de los Pesebres
10 and El Castillejo.
11

12 6.2 Consumption centres: Britannia and Germania 13

14 Results for the consumption regions display similar patterns than the ones
15 found for the production area of *Baetica*. The most important difference is
16 that the similarity values are lower as can be seen in Figure 9.
17

18 The lower similarity of stamp codes in *Britannia* compared to *Baetica*
19 could be explained by the spatial correlation as the area under study is much
20 bigger and the sites are more distant between them. This can be observed more
21 clearly on military sites as the ones with higher similarity are geographically
22 closer. Two patterns can be observed on the dendrogram: 1) nearby sites tend
23 to share more similar stamps and 2) a majority of stamp codes are only found
24 in one site.
25

26 The similarity of sites based on Dressel 20 stamp codes is also low in
27 *Germania* as can be seen in Figure 10.
28

29 The results for *Germania* follow a similar pattern than *Britannia* but with
30 a minor correlation as we can observe in the dendrogram.
31

32 A higher concentration of sites sharing similar stamps was found in areas
33 eminently militarised and close to German *limes*, although most sites mostly
34 showed different stamps.
35

36 7 Discussion 37

38 This work has explored to what extent the distribution of amphoric stamps can
39 provide insights into the organisation of olive oil Roman markets both at the
40 production and consumption areas. For this reason, an index of dissimilarity
41 was used to detect differences between the distribution of the amphoric stamps
42 and the spatial distance of producers and consumption centres.
43

44 7.1 Production centres 45

46 The analysis of the amphora workshops in *Baetica* province suggests that a
47 majority of stamp codes were only used on a single workshop. Beyond this
48 clear pattern, it seems that the similarity of stamp codes is correlated with
49 spatial distance and the amphoric production of spatially close sites shared
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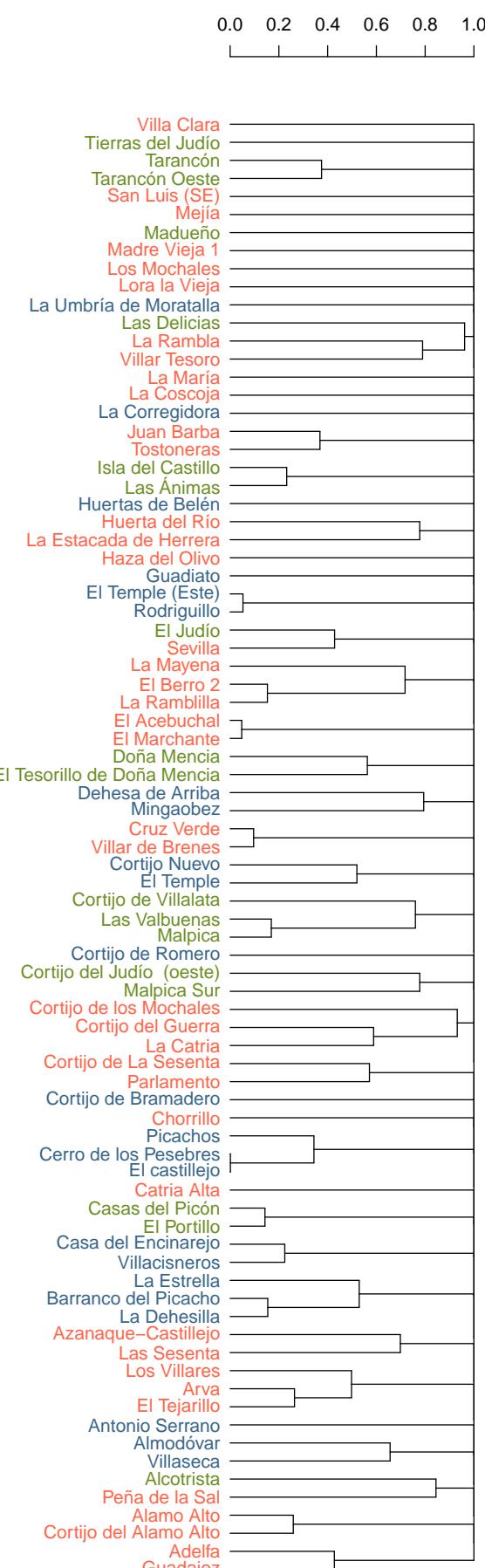


Fig. 8 Dendrogram displaying the results of hierarchical clustering based on Morisita-Horn metrics for Dressel 20 workshops located in the *Baetica* area. Site names are colour-coded by *conventus*: *Hispalis* (red), *Astigi* (green) and *Corduba* (blue)

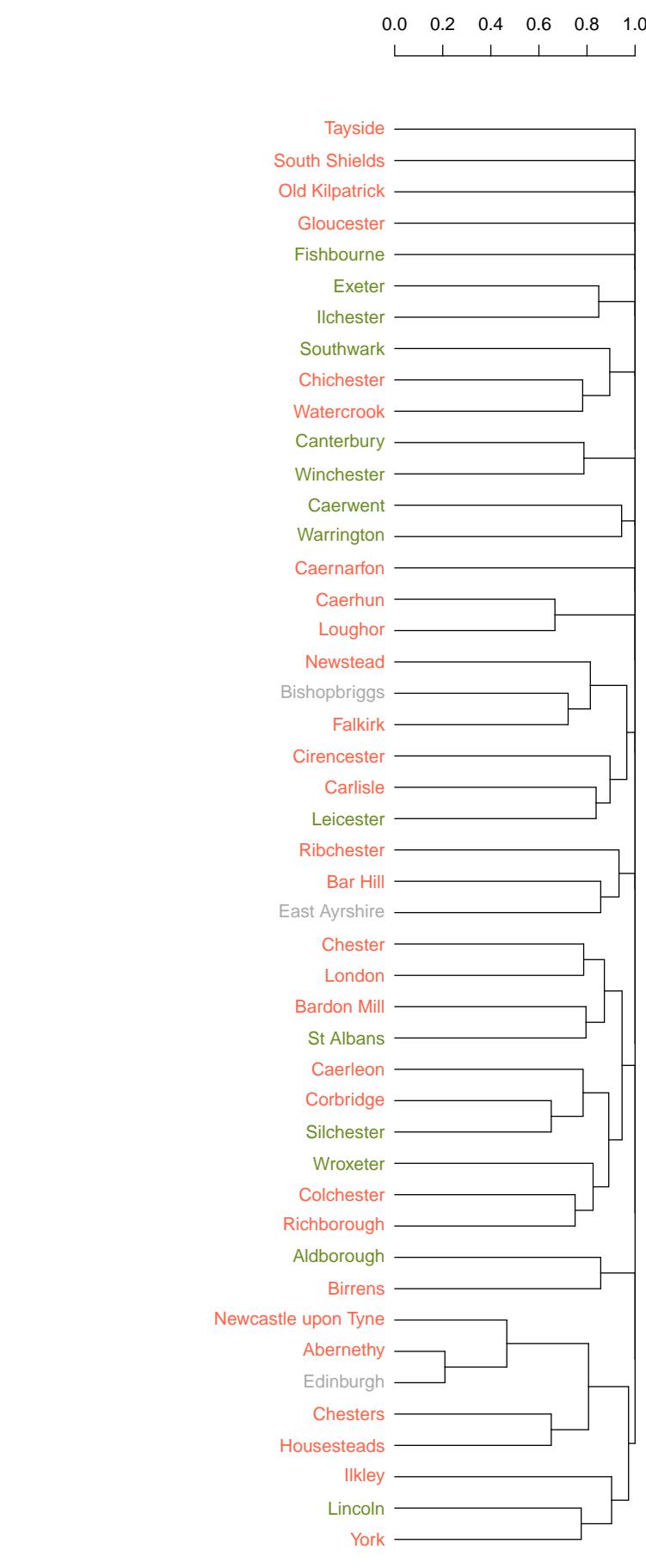


Fig. 9 Dendrogram displaying the results of hierarchical clustering based on Morisita-Horn metrics for sites in *Britannia*. Site names are colour-coded by typology: military sites (red), civilian sites (green) and unspecified (grey)

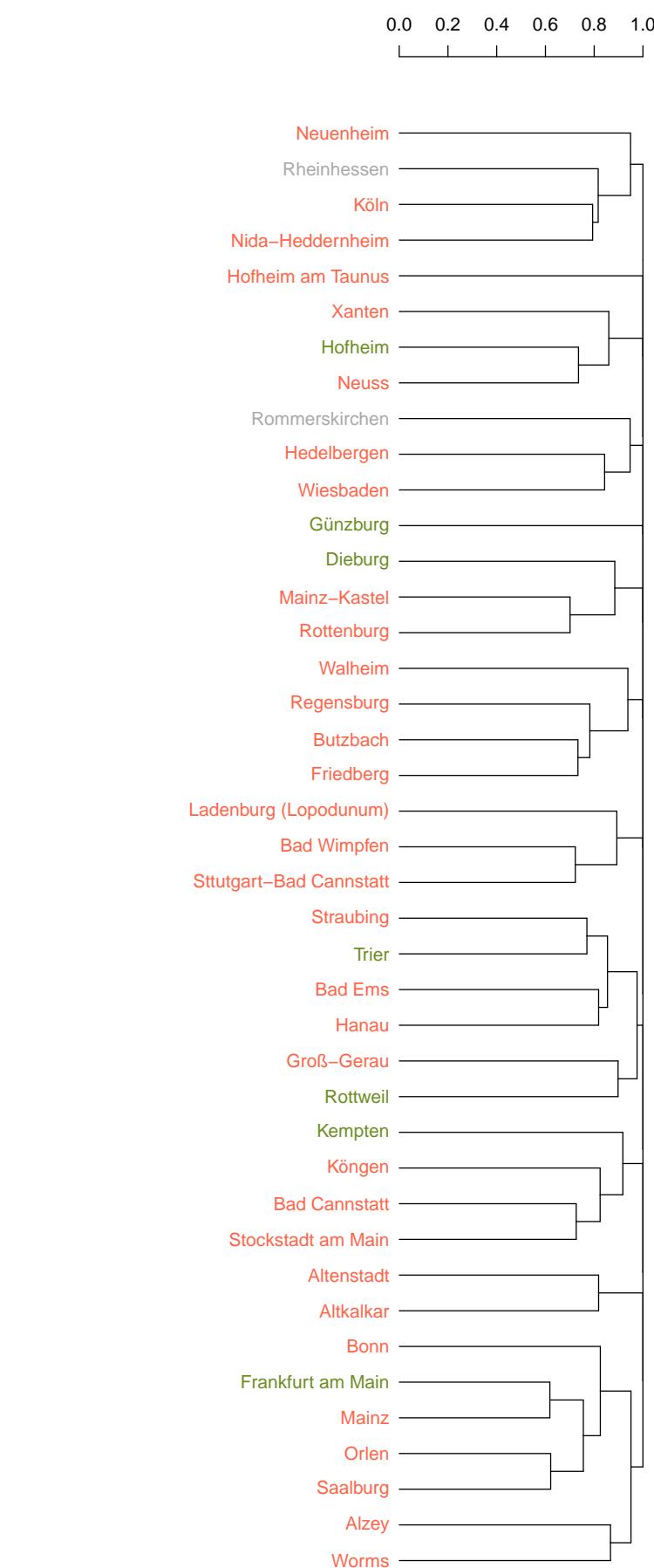


Fig. 10 Dendrogram displaying the results of hierarchical clustering based on Morisita-Horn metrics for sites in *Germania*. Site names are colour-coded by typology: military sites (red), civilian sites (green) and unspecified (grey)

some stamp codes. Particularly relevant here is the fact that our results show how similar stamp codes were found on sites belonging to the same *conventus* area. This result could indicate that the workshops of the different *conventus* used different stamp codes that were not shared between them. Despite these stamps tend to share the same area of production, we do not identify groups of any more than three workshops sharing the same amphoric stamps as the dendrogram showed.

Our results do not support previous working hypotheses suggesting that groups of workshops used specific groups of stamp codes; while there is higher stamp similarity for nearby workshops this result does not suggest any kind of organisation beyond the simple fact that nearby workshops had a higher degree of interaction. In fact; the opposite seems true: each workshop used different stamp codes and only shared some of them with the closest ones.

This unique link between workshop and stamp code can be interpreted in different ways. First, it is possible that each workshop operated independently and did not normally collaborate with other workshops. Second, stamp similarity in closer workshops could be linked to a spatial pattern. It is more probable than closer workshops tend to share more traits than distant workshops. While the role of the river was significant for the distribution of amphorae, river connectivity amongst workshops does not seem to show relevancy for the distribution or concentration of stamps in a specific river area.

Alternatively, the presence of different stamps in the same workshop could imply some kind of organisation from within the workshop only affecting nearby centres (Moros 2018). The stamped amphorae could have allowed potters to organise the different production batches for posterior commercialisation.

This could be explained such as batch systematic organisation between potters (Moros 2018). This work method could have allowed potters to identify batches by stamping amphorae for posterior commercialisation. High production of amphorae had to maintain a specialise system organisation to control this production (Moros 2018, 104).

It is worth mentioning that the performed analysis could be limited by a diversity of biases. Some workshops have been identified with different names despite the fact that they probably are sections of the same workshop; on the other hand, the amount of stamps collected on different sites is affected by different intensities for field surveys a lack of excavation. As a consequence, further fieldwork could provide a clearer picture of the links between workshops if the sample size of stamp codes is increased.

7.2 Consumption centres

Both consumption areas showed a correlation between the spatial distance of sites and their similarity of amphoric stamps. In the case of *Britannia*, the correlation was higher than *Germania*. In *Britannia* the majority of similarity stamps were mainly found in military centres.

A combined exploration of the map and the dendrogram also suggests an interesting pattern: centres with higher similarity values are closer to the coast (North Sea and Celtic Sea). This may indicate that the Atlantic route could have played an essential role in transporting olive oil to the area of *Britannia*, since in the places where there is greater similarity they are found in different strategic points near the sea.

This trend is aligned with recent works that have suggested that the Atlantic trade routes were mostly used for military supply (Remesal 1986, 2008, Carreras & Morais 2012, Morillo et al. 2016). Therefore, a majority of centres with higher similarity are related to military activities and near the coasts, thus suggesting that Dressel 20 containing olive oil were shipped to military areas and then redistributed to the civilian population using land-based transportation systems (Carreras Monfort & Funari 1998, Ayllón-Martín et al. 2018).

The areas mostly militarised share similar stamps than civil areas. However, we do not detect a concrete pattern regarding the distribution of the stamps in the German limes (Remesal 2018). This could be also interpreted by an intensity bias where military centres have been mostly excavated than civil centres.

Finally, the results suggest that there is no clear organisational pattern linking production centres and/or consumption centres beyond the spatial distance. As a consequence, our analysis does not indicate the presence of a specific workshop from *Baetica* supplying to some specific province.

This evidence means that it is unknown whether some production centres went to one province or another or, at least, that they can be clearly reflected in the data with a greater similarity in the amphoric stamps. Thus, production centres could have distributed randomly olive oil to both *Britannia* and *Germania*. Neither we do not detect production centres dedicated to the distribution of olive oil in a certain province.

8 Concluding remarks

This work has used quantitative analysis to explore long-range trade of olive oil using the stamps found in Dressel 20 vessels. The most interesting result is linked to the meaning of these inscriptions. The use of specific codes seems to be almost exclusively decided by each workshop, so it could be used to identify amphorae found in consumption centres (i.e. an amphora with a given stamp was probably made on a specific workshop). This idea could explain why the similarity of stamps between workshops is generally very low. On the other hand, some code stamps have been identified in nearby workshops so this pattern suggests that the clustered workshops were somehow connected (e.g. they belonged to the same owner).

A large number of Dressel 20 were not marked with any stamps, so some researchers suggest that potters marked the amphorae to prepare and distribute the product in order to be shipped (Berni 2008). This method would be used as an identifier to count the number of amphorae of a batch (Moros 2018).

1 Unique stamp codes could have also served to identify different groups of
2 potters working in the same amphora workshop. Potters could have marked
3 the amphorae to distinguish different groups working at the same time in
4 different orders (Li et al. 2014). This hypothesis could explain why we detect
5 different stamps in the same workshop. In any case, at present we do not have
6 enough archaeological evidence to validate which of these interpretations is
7 more plausible in our case study.

8 To conclude, the method presented here provides a useful framework to
9 improve our understanding of the organisation and processes that allowed
10 the Roman Empire to manage a massive and highly specialised production of
11 essential goods. This work has identified similarities between amphoric stamps
12 and spatial distribution in the case of the amphoric production within the
13 Roman Empire.

14 The growing amount of archaeological data requires of large-scale quantitative
15 methods such as the one presented here to identify and explore complex
16 patterns, thus allowing us to infer dynamics and improve our interpretation of
17 complex economic processes of past societies.

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28 licenses from https://github.com/Mcotsar/Baetica_stamps.

29 Conflict of interest

30 The authors declare that they have no conflict of interest.

31 References

- 32
33
34
35
36 Aguilera, A. (2007), Evolución de los tituli picti de las ánforas Dressel 20
37 entre mediados del siglo I y mediados del siglo III, in ‘Acta XII Congressus
38 Internationalis Epigraphiae Graecae et Latinae’, Monografies de la Secció
39 Històrico-Arqueològica, Barcelona, pp. 15–22.
40
41 Albertini, E. (1923), *Les divisions administratives de l’Espagne romaine*, Boc-
42 card, Paris.
43 Ayllón-Martín, R., Pérez González, J. & Remesal Rodríguez, J. (2018), ‘Olive
44 Oil at the Border of the Roman Empire. Stamps on Baetican Dressel 20
45 Found on the Tyne-Solway Isthmus’, *Münstersche Beiträge zur Antiken
46 Handelsgeschichte* 36, 167–217.
47 Berni, P. (1996), ‘Amphora Epigraphy: proposals for the study of stamp con-
48 tents’, established by: Mauro Cristofani and Riccardo Francovich pp. 751–
49 770.
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

- 1 Berni, P. (1998), *Las ánforas de aceite de la Bética y su presencia en la*
2 *Cataluña romana*, Vol. 4, Col .lecció Instrumenta. Universitat de Barcelona.
- 3 Berni, P. (2008), *Epigrafía anfórica de la Bética. Nuevas formas de análisis*,
- 4 Vol. 29, Col .lecció Instrumenta. Universitat de Barcelona.
- 5 Berni, P. & García Vargas, E. (2016), ‘Dressel 20 (Guadalquivir Valley)’.
- 6 **URL:** <http://amphorae.icac.cat/amphora/dressel-20-guadalquivir-valley>
- 7 Bevan, A. (2014), ‘Mediterranean Containerization’, *Current Anthropology*
8 **55**(4), 387–418.
- 9 **URL:** <http://www.jstor.org/stable/info/10.1086/677034>
- 10 Blázquez, J. M. (1980), La exportación del aceite hispano en el Imperio ro-
11 mano: estado de la cuestión, in ‘Producción y comercio del aceite en la
12 antigüedad. Primer Congreso Internacional’, Universidad Complutense de
13 Madrid, pp. 19–46.
- 14 Blázquez Martínez, J. & Remesal Rodríguez, J., eds (1999), *Estudios del*
15 *Monte Testaccio (Roma) I*, Vol. 6, Col .lecció Instrumenta. Universitat de
16 Barcelona.
- 17 Bowman, A. & Wilson, A. (2009), *Quantifying the Roman economy: methods*
18 *and problems*, Vol. 1, Oxford University Press.
- 19 Brughmans, T. & Poblome, J. (2016), ‘Roman bazaar or market economy?
20 Explaining tableware distributions through computational modelling’, *An-*
21 *tiquity* **90**(350), 393–408.
- 22 Carreras, C. & Morais, R. (2012), ‘The Atlantic Roman trade during the Prin-
23 cipate: new evidence from the western façade’, *Oxford Journal of Archaeol-*
24 *ogy* **31**(4), 419–441.
- 25 Carreras Monfort, C. (1998), ‘Britannia and the imports of Baetican and Lusi-
26 tanian amphorae’, *Journal of Iberian Archaeology* **1**, 159–172.
- 27 Carreras Monfort, C. & Funari, P. P. A. (1998), *Britannia y el Mediterráneo:*
28 *estudios sobre el abastecimiento de aceite bético y africano en Britannia*,
29 Vol. 5, Col .lecció Instrumenta. Universitat de Barcelona, Barcelona.
- 30 Carreras Monfort, C. & Funari, P. P. A. (2003), ‘El abastecimiento militar
31 romano en Britannia: una perspectiva arqueológica’, *ArqueoWeb* **5**.
- 32 Chic, G. (1985), *Epigrafía anfórica de la Bética I: Las marcas impresas en el*
33 *barro sobre ánforas olearias (Dressel 19, 20 y 23)*, Vol. 1, Universidad de
34 Sevilla.
- 35 Chic, G. (1997), *Historia económica de la Bética en la época de Augusto*, Serie
36 Historia, Padilla Libros, Sevilla.
- 37 Chic, G. (2001), *Datos para un estudio socioeconómico de la Bética: marcas*
38 *de alfar sobre ánforas olearias*, Vol. 1-2, Gráficas Sol.
- 39 Chic, G. (2005), ‘El comercio de la Bética altoimperial’, *Habis* **36**, 313–332.
- 40 Coto-Sarmiento, M., Rubio-Campillo, X. & Remesal, J. (2018), ‘Identifying
41 social learning between Roman amphorae workshops through morphometric
42 similarity’, *Journal of Archaeological Science* **96**, 117–123.
- 43 Dressel, H. (1878), ‘Ricerche sul Monte Testaccio’, *Annali dell’Instituto di*
44 *Corrispondenza Archeologica* **50**, 118–192.
- 45 Duncan-Jones, R. (1982), *Economy of the Roman Empire*, CUP Archive.
- 46
- 47
- 48
- 49
- 50
- 51
- 52
- 53
- 54
- 55
- 56
- 57
- 58
- 59
- 60
- 61
- 62
- 63
- 64
- 65

- 1 Funari, P. (2005), 'The Economic history of Roman Britain: olive oil contribution to the debate', *História e economia* **1**, 29–46.
- 2 Funari, P. P. A. (1996), *Dressel 20 inscriptions from Britain and the consumption of Spanish olive oil*, Vol. 250, BAR.
- 3 García Vargas, E. (2010), Formal Romanisation and the Atlantic Projection of Amphorae from the Guadalquivir Valley, in 'The Western Roman Atlantic Façade: A study of the economy and trade in the Mar Exterior from the Republic to the Principate', archaeopress edn, Vol. 2162, BAR International Series, Oxford, England, pp. 55–66.
- 4 Horn, H. S. (1966), 'Measurement of "overlap" in comparative ecological studies', *The American Naturalist* **100**(914), 419–424.
- 5 Isaksen, L. (2006), Network analysis of transport vectors in Roman Baetica, in 'Digital discovery: exploring new frontiers in human heritage. Proceedings of the 34th CAA Conference, Fargo', pp. 76–87.
- 6 Li, X. J., Bevan, A., Martinón-Torres, M., Rehren, T., Cao, W., Xia, Y. & Zhao, K. (2014), 'Crossbows and imperial craft organisation: the bronze triggers of China's Terracotta Army', *Antiquity* **88**(339), 126–140.
- 7 Magurran, A. E. (1988), Why diversity?, in 'Ecological diversity and its measurement', Springer, pp. 1–5.
- 8 Magurran, A. E. (2004), *Measuring biological diversity*, Blackwell Science Ltd.
- 9 Mattingly, D. J. (1988), 'Oil for export? A comparison of Libyan, Spanish and Tunisian olive oil production in the Roman Empire', *Journal of Roman Archaeology* **1**, 33–56.
- 10 Morillo, Á., Fernández Ochoa, C. & Salido Domínguez, J. (2016), 'Hispania and the Atlantic Route in Roman Times: new Approaches to Ports and Trade: Hispania and the atlantic route in roman times', *Oxford Journal of Archaeology* **35**(3), 267–284.
- 11 **URL:** <http://doi.wiley.com/10.1111/ojoa.12089>
- 12 Morisita, M. (1959), 'Measuring of the dispersion of individuals and analysis of the distribution patterns', *Memoirs of the Faculty of Science, Kyushu University, ser. E (Biology)* **2**, 215–235.
- 13 Moros, J. (2018), Análisis epigráfico de los sellos olearios béticos hallados en centros de producción: el caso de la zona productora de Scalensia, PhD thesis, Universitat de Barcelona.
- 14 Oksanen, J., Kindt, R., Legendre, P., O'Hara, B., Stevens, M. H. H., Oksanen, M. J. & Suggs, M. (2007), 'The vegan package', *Community ecology package* **10**, 631–637.
- 15 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.
- 16 **URL:** <http://linkinghub.elsevier.com/retrieve/pii/S0305440315003192>
- 17 Ozcáriz Gil, P. (2013), *La administración de la provincia Hispania Citerior durante el Alto Imperio Romano. Organización territorial, cargos administrativos y fiscalidad*, Vol. 44, Col. lecció Instrumenta. Universitat de Barcelona, Barcelona.

- 1 Peacock, D. & Williams, D. F. (1991), *Amphorae and the Roman economy: an*
2 *introductory guide*, Longman, London.
- 3 Remesal, J. (1977-1978), ‘La economía oleícola bética: nuevas formas de
- 4 análisis’, *Archivo Español de Arqueología* 50(135), 87–144.
- 5 Remesal, J. (1986), *La annonae militaris y la exportación de aceite bético a*
6 *Germania*, Editorial Complutense.
- 7 Remesal, J. (1990), ‘El sistema ammonario como base de la evolución económica
- 8 del Imperio romano’, *PACT* 27, 355–367.
- 9 Remesal, J. (1991), ‘El aceite bético durante el Bajo Imperio’, *Antigüedad y*
10 *Cristianismo* 8, 355–361.
- 11 Remesal, J. (1998), ‘Baetican olive oil and the Roman economy’, *Journal of*
12 *Roman Archaeology - Suppl. series* 29, 183–200.
- 13 Remesal, J. (2002a), Baetica and Germania. Notes on the concept of provincial
14 interdependence in the Roman Empire, in ‘The Roman Army and the
- 15 Economy’, J. C. Gieben, Amsterdam, pp. 293–308. in: Paul Erdkamp (ed.).
16 **URL:** <http://ceipac.ub.edu/biblio/Data/A/0325.pdf>
- 17 Remesal, J. (2002b), Baetica and Germania. Notes on the concept of “provincial
18 interdependence” in the Roman Empire, in ‘The Roman Army and the
- 19 Economy’, J. J.C. C. Gieben, Amsterdam, pp. 293–308.
- 20 Remesal, J. (2004), ‘Las ánforas Dressel 20 y su sistema epigráfico’, *J. Reme-*
21 *sal Rodríguez* (éd.), *Epigrafía anfórica. Proyecto Amphorae, Instrumenta*
22 *17*, 127–148.
- 23 Remesal, J. (2008), Provincial interdependence in the Roman Empire: an ex-
24 planatory model of Roman economy., in ‘New Perspectives on the Ancient
- 25 World. Modern perceptions, ancient representations’, BAR International Se-
26 ries 1782, Archaeopress, Oxford, England, pp. 155–159.
27 **URL:** <http://ceipac.gh.ub.es/biblio/Data/A/0524.pdf>
- 28 Remesal, J. (2010), De Baetica a Germania, consideraciones sobre la ruta
29 y el comercio atlántico en el Imperio Romano, in ‘Viajeros, peregrinos y
- 30 aventureros en el mundo antiguo’, Universitat de Barcelona, pp. 147–160.
- 31 Remesal, J. (2011), *La Bética en el concierto del Imperio Romano*, Real
32 Academia de la Historia, Madrid.
- 33 Remesal, J. (2016), ‘Sellari, ¿para qué? El sistema de comunicación en los sellos
- 34 de las ánforas Dressel 20’, *Antichità AltoAdriatiche* 83, 73–90.
- 35 Remesal, J., Aguilera, A., García Sánchez, M., Martín-Arroyo, D., Pérez
36 González, J. & Revilla, V. (2015), ‘Centro para el Estudio de la Interdepen-
37 dencia Provincial en la Antigüedad Clásica (CEIPAC)’, *Pyrenae* pp. 245–
38 275.
- 39 Remesal, J., ed. (2018), *Colonia Ulpia Traiana (Xanten) y el Mediterráneo.*
40 *El comercio de alimentos*, Vol. 63, Col .lecció Instrumenta. Universitat de
41 Barcelona, Barcelona.
- 42 Remesal, J., Revilla, V., Berni, P. & Carreras Monfort, C. (1997), ‘Arva:
43 prospecciones en un centro productor de ánforas Dressel 20 (Alcolea del
44 Río, Sevilla)’, *Pyrenae* 28(28), 151–178.
- 45 Rovira Guardiola, R. (2007), Gráfitos ante coctvram sobre ánforas Dressel :
46 una propuesta de evolución cronológica, in ‘Acta XII Congressus Interna-
47
- 48
- 49
- 50
- 51
- 52
- 53
- 54
- 55
- 56
- 57
- 58
- 59
- 60
- 61
- 62
- 63
- 64
- 65

- 1 tionalis Epigraphiae Graecae et Latinae', Monografies de la Secció Històrico-
2 Arqueològica, Barcelona, pp. 1255–1262.
- 3 Rubio-Campillo, X., Coto-Sarmiento, M., Remesal, J. & Pérez González, J.
4 (2017), 'Bayesian analysis and free market trade within the Roman Empire',
5 *Antiquity* **91**(359), 1241–1252.
- 6 Rubio-Campillo, X., Montanier, J.-M., Rull, G., Bermúdez, J. M., Díaz, J. M.,
7 Pérez-González, J. & Remesal, J. (2018), 'The ecology of Roman trade.
8 Reconstructing provincial connectivity with similarity measures', *Journal
9 of Archaeological Science* **92**, 37–47.
- 10 Temin, P. (2001), 'A market economy in the early Roman Empire', *Journal of
11 Roman studies* **91**, 169–181.
- 12 Temin, P. (2006), 'The economy of the early Roman Empire', *The Journal of
13 Economic Perspectives* **20**(1), 133–151.
- 14 **URL:** <http://www.jstor.org/stable/30033637>
- 15 Wickham, H., Chang, W. & others (2016), 'ggplot2: create elegant data visu-
16 alisations using the grammar of graphics', *R package version 2*(1).
- 17 Williams, D. & Peacock, D. (1983), 'The importation of olive oil into Iron
18 Age and Roman Britain', *Producción y comercio del aceite en la antigüedad*
19 pp. 263–280.
- 20 Wolda, H. (1981), 'Similarity indices, sample size and diversity', *Oecologia*
21 **50**(3), 296–302.
- 22
- 23
- 24
- 25
- 26
- 27
- 28
- 29
- 30
- 31
- 32
- 33
- 34
- 35
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