

The markings of the trade: exploring the patterns of olive oil production in Roman Baetica

Maria Coto-Sarmiento^{b,*}, Xavier Rubio-Campillo^a

^a*School of History, Classic & Archaeology, Room OOM.33, William Robertson Wing, Old Medical School, Teviot Place, University of Edinburgh, UK*

^b*CEIPAC, Department of Prehistory and Archaeology, Montalegre, 6-8, 08001, University of Barcelona, Barcelona, Spain*

Abstract

The aim of this study is to explore economics dynamics in the production and distribution of olive oil trade. Our case of study has been focused on the production processes located in *Baetica* province (currently Andalusia) from 1st to 3rd AD. In particular, we want to detect patterns of olive oil production that link amphora workshops and amphoric stamps. *Baetica* became important production and distribution centre during the Roman Empire. However, it remains under debate how this province was organised and whether it could be possible to identify patterns in the olive oil market. Amphoric stamps are used to identify the presence of different groups that might share similar stamps. To achieve this goal, we analyse a set of stamps from two centres: 1) producer centres by analysing different workshops in *Baetica* province and 2) two Roman provinces such as *Germania* and *Britannia* as a receptor centres. They will be used to detect a relation between the distribution of amphoric stamps and the economic structure in both centres. Here we use methods borrowed from Ecology that allow us to identify if amphora workshops share similar amphoric stamps depending on the spatial distance.

The analysis explores how quantitative approach provides a useful tool for the interpretation of the economic processes. Finally, results pretend to high-

*Corresponding author

Email address: mcotsar@gmail.com (Maria Coto-Sarmiento)

light the organisation of Baetican olive oil production in the Roman Empire linked to the differences observed in the archaeological evidence.

Keywords: Roman Empire; amphora workshops; Dressel 20; social learning; cultural evolution

1. Introduction

Material culture is one of the most frequent indicator of trade in the archaeological record. In archaeology, they allow us to highlight a part of mechanism of production and distribution of goods along the Mediterranean (Bevan, 2014). Particularly, the spread of these factors had an important impact during the Roman Age, when the progressive exploitation of communication networks allowed a major interaction between communities (Orengo and Livarda, 2016). Given this fact, an important mechanism of production control under Roman government was created spreading by different areas attending to the richness of different places. Roman provinces such as *Baetica* (currently Andalusia, south Spain) became important production centres of olive oil during the Roman Empire. Olive oil was considered as the liquid gold since it was used in different aspect of the daily life as cooking, hygiene or lighting (Mattingly, 1988). As a consequence, this product was distributed in a large number of amphorae along the province, mostly to supply the Roman Army and Italy (Blázquez, 1980).

Despite this issue has been widely discussed over many decades, the understanding about the production processes is still under debate, mostly due to the lack of written records. The application of different quantitative approaches combined with the archaeological evidence has allowed us partly to deal with the complexity of understanding the Roman production (Orengo and Livarda, 2016; Brughmans and Poblome, 2016; Coto-Sarmiento et al., 2018; Rubio-Campillo et al., 2017).

This paper aims to understand the production dynamics in connection with a different areas within Roman Empire. Specifically, our work pretends to detect microeconomic processes focused on a commercial product from a specific

province (Isaksen, 2006). We want to understand the pattern of olive oil production that link 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. To do this, an Ecology approach has been used to analyse the dispersion of stamps between amphora workshops (Rubio-Campillo et al., 2018). 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 then workshops worked independently.

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The paper is structured 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.

1.1. *The Amphoric production in Baetica province*

The high demand of Roman provinces stimulated by the good condition of the *Baetica* lands allowed to develop a massive infrastructure of olive oil production. The production and distribution of olive oil were growing exponentially during almost three centuries (Remesal, 2011). As a result, hundreds of amphora workshops were made to support this high demand of Roman Empire. These workshops were located along the rivers Guadalquivir and Genil, supplying from the riverine connectivity to the Mediterranean and Atlantic routes (García Vargas, 2010).

The majority of olive oil amphorae produced in this province and shipped through the provinces belong to Dressel 20 type (Dressel, 1878; Berni, 1998). This amphora is commonly associated with the transportation of Baetican olive oil during the Roman Empire (Berni, 2008). Most Dressel 20 were marked in stamps, inked in *tituli picti* and incise in *graffiti* with different information still unknown. Indeed most of the inscriptions on the amphora have not enough

analysed due to the fragmentation of the material or the shortage of samples (Aguilera, 2007; Rovira Guardiola, 2007).

1.2. A potential indicator of Roman economy: Dressel 20 stamps

Stamps are the most studied in this type of amphorae. The fascination aroused by stamps has caused it to be one of the inscriptions with the most publications about its origin and meaning. Its endure in time become it an essential element that were used to mark amphorae during almost three centuries (Remesal, 2016) (Fig.1).

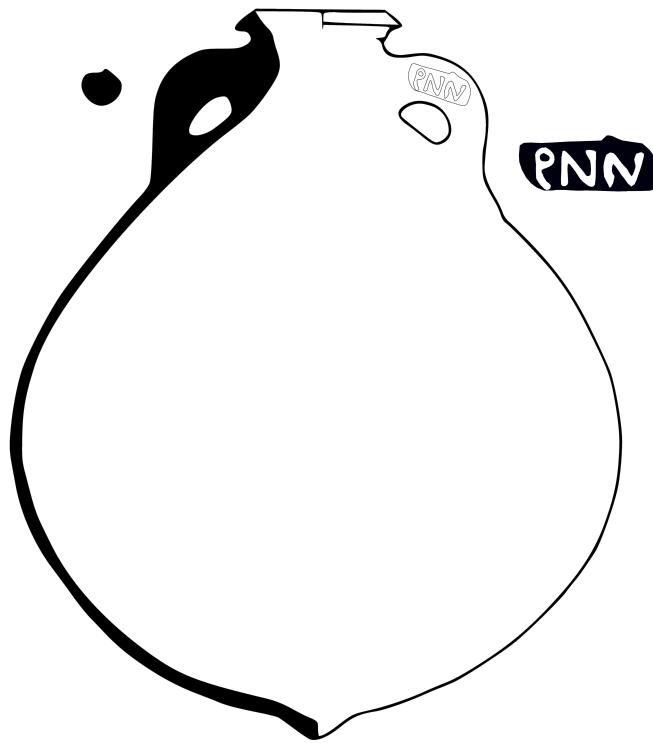


Figure 1: Dressel 20 were mostly marked with stamps of three letters called *tria nomina*

Frequently, they were marked mainly in handles but seldom in rims and body (Berni, 1998). The information of the stamps is shown in different forms and letter content and it seems that there was not a unique criterion. Stamps are

mostly formed by a code of three letters and they can appear in a abbreviated form or complete and they are known as *Tria Nomina* (Berni, 1996). Despite researchers identify stamps as a identity marks, there is not a general consensu about the meaning of the stamps (Remesal, 1998). Alike most Dressel 20 containers were not stamped being difficult to determinate.

They could be identified based on three premises: content (olive oil), context (amphora workshop) and subject (individuals involved). On the one hand, it seems that stamps could have been identified as the land owner of the olive groves (Remesal, 1977-1978). On the other, they could belong to the owner of the making amphorae workshops or even a group of amphora workers (Berni, 2008). In any case, the use of these stamps became in a good proxy to define somehow the system of working in the workshops.

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? Neither written records have been found that it could explain the economic role of *Baetica* province in the Roman organisation. Indeed, archaeological evidence shows a highly specialised production with a long activity in a this specific area with apparently few changes (Remesal, 2004).

The assumption of this study is analysing the effect of the production patterns between different centres. We are specially interested in identifying links between producers and consumption centres using amphoric stamps. To do that, we use the CEIPAC database to collect the stamps from different places. The CEIPAC dataset contains over 50.000 of epigraphy records found in amphorae, mostly from *Monte Testaccio*.

Three case study have been studied in order to analyse the relation between production centres (*Baetica*) and consumption centres (*Britannia* and *Germania*). 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 a area or if some groups have an important

role for the exportation of olive oil in those provinces. This economic connection could affect due to different aspects: a) correlation between spatial distance and centres based on the idea that closer workshops concentrate similar amphoric stamp in a specific area than the distant workshops and b) groups of similar stamps were concentrated in a specific Roman province.

Therefore, this study proposes an evolutionary baseline to explore the distribution of Baetican olive oil production by computing spatial correlation between stamps. A way to analyse is by using a quantitative framework to measure the similarity. Here we use a ecological approach based on three steps: a) to detect similarities between stamp codes, b) to explore a potential spatial correlation and c) to establish a correlation between similarity of stamp and spatial distance.

2. Material and methods

2.1. Production centres: *Baetica* province

Our case study examines the relation between the distribution of amphoric stamps and the workshops. In particular, we study the distribution of amphoric stamp with the aim of identifying a correlation between geographical distance and amphoric stamps. Based on this assumption, we proposed three hypotheses: a) it exists 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 region: stamps always stay in the same region.

The amphora workshops were situated in different locations in *Baetica* province, along the river Guadalquivir and its tributary Genil in order to detect similarities between stamps from workshops and spatial distance (see Fig.2).

The chronology in the workshops is widely diverse from the first to the third centuries AD (Berni, 1998; Remesal, 1998; Chic, 2005). Some stamps show a more specific chronology while the majority of them display a large activity of production that it can be difficult for specifying an accurate chronology. This

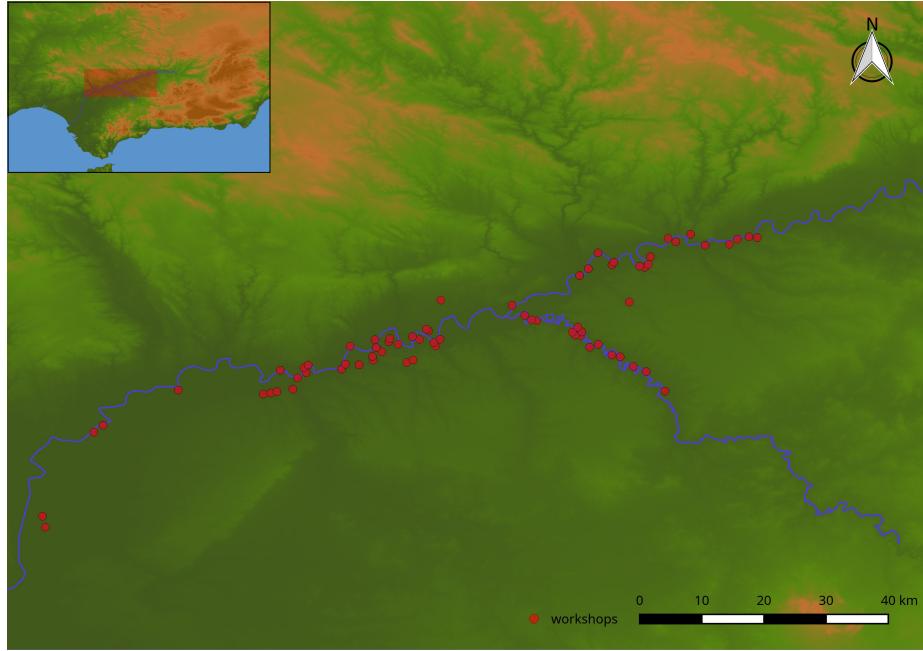


Figure 2: Distribution of the workshops

could be due to two reasons; firstly, most of the workshops were partially excavated and focused on archaeological surveys in order to collect the maximum stamps as possible; secondly, Dressel 20 was produced during almost three centuries with apparently few changes (Berni and Weiß-König, 2017).

2.1.1. Material

We studied a dataset of 3798 stamps collected from different Dressel 20 amphora workshops in *Baetica* province. The stamp database was compiled by CEIPAC database (Remesal et al., 2015) (see CEIPAC database here <http://romanopendata.eu>). However, approximately the 70 % of stamps cannot be tested due to fragmentation or incomplete information. Consequently, we discard integrate the fragmented stamps in our dataset. We finally filter a total sample of 987 stamps comprised of 130 different stamps from 81 workshops.

From the database, we collected the site where stamps were found and the stamp code. We also created a new column with the area of the stamps. These

areas, known as *conventus*, were administrative centres for territorial organization in the Roman Empire. Dressel 20 stamps were found in 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) .

2.1.2. Exploratory Analysis

We calculated the frequency of distribution in amphora stamps with the aims to carry out a exploratory analysis (EDA) to know the distribution and the number of stamps per each centre.

The frequency of stamps per workshop can be seen in Fig. 3. Most stamps are distributed in only one workshop whereas few workshops concentrate a high frequency of different amphoric stamps. The type of distribution is also frequent in Roman economy where we observed a self-organized complex system patterns typical of a free market (Rubio-Campillo et al., 2017).

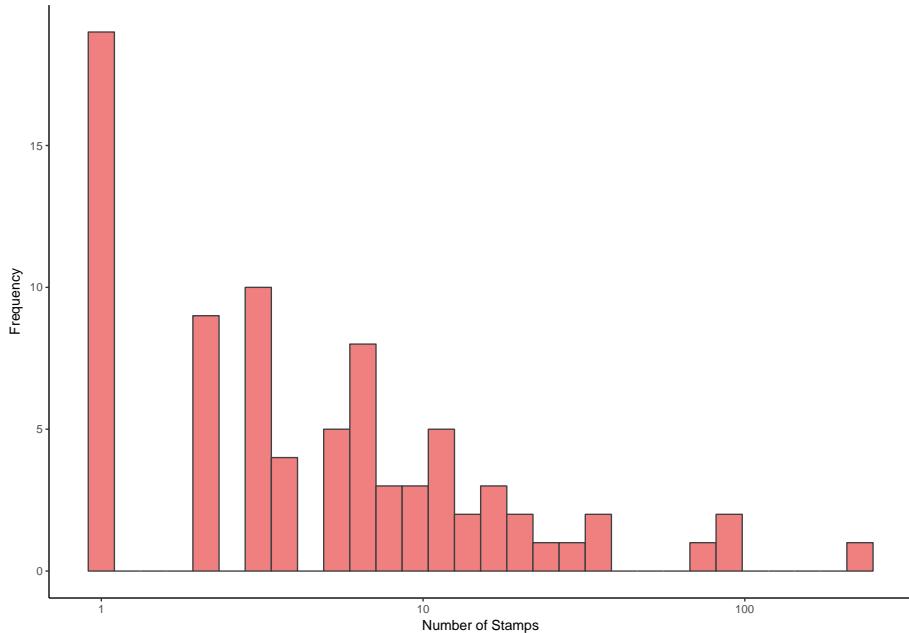


Figure 3: Distribution of the number of stamps

The distribution of amphora stamps in different *conventus* can be seen in Fig. 4. The majority of stamps found are concentrated in *Hispalis* with 574 stamps while *Corduba* and *Astigi* with 267 and 146 stamps, respectively. Mostly, workshops show a homogeneity on the frequency of stamps except both La Catria and Arva that show a big amount of stamps with 29 different stamps. According to previous studies, those workshops became in most important centres of amphora production although they could have been more intensely prospected than others. (Remesal et al., 1997).

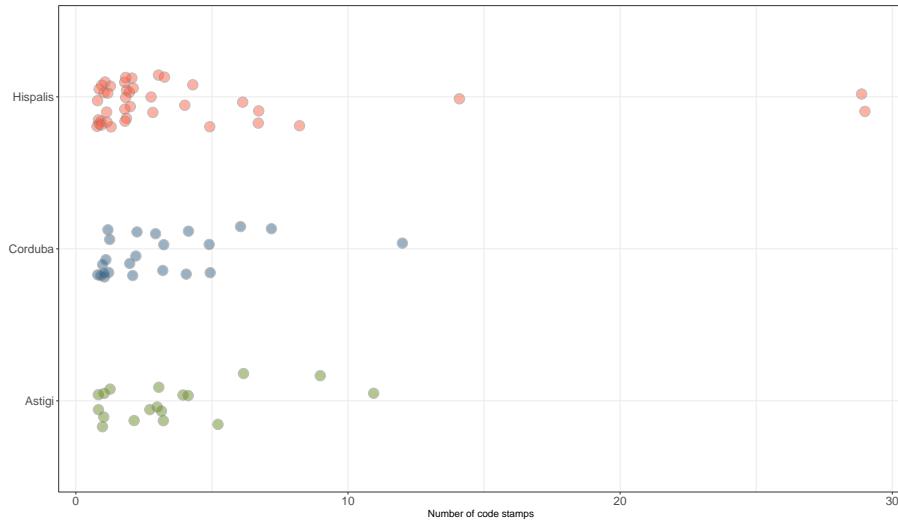


Figure 4: Distribution of the number of different code stamps for each area. Colors are represented by areas divided into Hispalis (red), Astigi (green) and Corduba (blue).

2.2. Consumption centres: Britannia and Germania

The conquest of new provinces allowed to the Roman Empire the arrival of new resources. This lead to a progressive change in the economic and social structure. As a result, Augusto's administration created the figure of the *praefectura annonae* for the supply of wheat. The role of the *praefectura annonae* was mainly to provide through *frumentationes* a quantity per month of wheat to Roman citizens (Remesal, 1986, 2011).

2.2.1. Britannia

The consumption of olive oil in *Britannia* was residual until starting the Roman conquest (Funari, 1996; Carreras Monfort and Funari, 2003).

It is well known that this product was not frequently consumed by autonomous population. The absence of olive oil importation before the conquest can be reflected by the shortage of this product until the arrival of high percentage of Dressel 20 amphorae to *Britannia* (Carreras Monfort and Funari, 1998, 1). Additionally, the land of *Britannia* showed inadequate for the olive oil production due to low environmental conditions. This issue was necessary for creating an important export apparatus from *Baetica* to supply Roman legions. In this moment, we detect an increase of the olive oil exportation concurring with the displacement of Roman legions during the military campaigns (Carreras Monfort, 1998, 161). This fact will be spatial incidence in sites close at Hadrian Wall. Olive oil production in *Baetica* would cross the Atlantic until they reached the province and redistribute throughout the area from a series of strategic points (Carreras and Morais, 2012). The increase of the exportation of Dressel 20 amphorae created an important commercial network for exchanges. Thus, the network was mainly focused on the support of soldiers during military campaigns.

The presence of Dressel 20 stamps in military camps in *Britannia* have been widely studied in Roman archaeology (Carreras Monfort and Funari, 1998). This fact also indicates a possible governmental organisation allocate to reforce and supply of olive oil in military camps, such as *Germania* (Remesal Rodriguez, 1986). However, it is unknown the type of economical system when managing or control the redistribution of olive oil in different sites in *Britannia* but it seems that it could have been in the main cities (Funari, 2005, 45).

Finally, The increase in olive oil exports would experience a progressive slowdown from the third century A.D., coinciding with the change in market strategy in the Empire. In that moment, a progressive decrease of Dressel 20 is documented being gradually replace for Dressel 23 amphorae.

2.2.2. Material

We analysed a dataset of 2219 stamps from different centres in *Britannia*. The stamp database was also compiled by CEIPAC database. The database contained anomalies that were eliminated using the same criteria cited above. We finally selected the centres with more or equal than 5 stamps. As a result, we studied a total of 1765 stamps comprised of 968 different stamps from 46 centres. The centres located in *Britannia* can be seen in Fig.5.

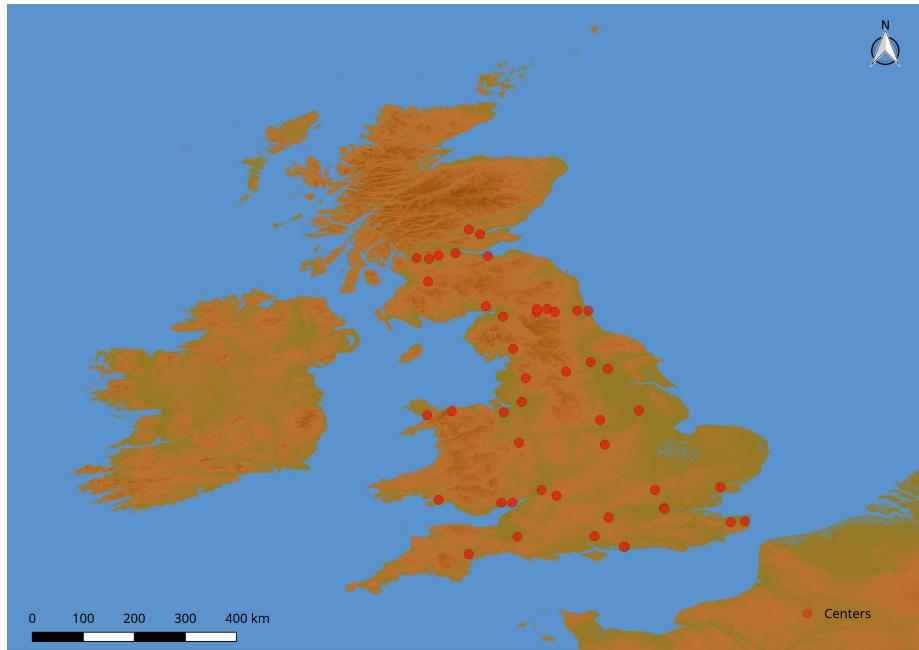


Figure 5: Distribution of centres in *Britannia*

2.2.3. Germania

The Roman conquest in *Germania* dates from the end of the 1st century BC, during Caesar campaign and subsequently continued by Augusto. The advance of the Roman legions toward *Gallia* opened a way though the Atlantic Ocean to *Germania* (Remesal, 1986, 2002).

It is thought that this route would have been initiated previously through terrestrial transport, although recent studies question this position giving an

important role to the Atlantic route for both the conquests of *Germania* and those of *Britannia* (Remesal, 2010; Rubio-Campillo et al., 2018).

As the case of Britain, the consumption of olive oil in *Germania* was not detected before the conquest.

The need to supply roman legions created a logistic network to supply to the army. In this moment, we detect the arrival of olive oil amphorae to *Germania* evidenced by the presence of Dressel 20 amphora in different sites close to limes.

The roman studies about the presence of Dressel 20 amphorae has not been the same repercussion than the rest of the province. This can be explained due to the lack of data (González Cesteros, 2010).

As a consequence, we do not the role that commerce agents in the participation of the distribution and exportation of olive oil in *Germania* or, on the contrary, the Roman army was the responsible to supply the product in the own province (Remesal, 2010, 156).

The presence of Roman army encouraged the exchange in the province showed by the arrival of this product both civil settlement and military sites with a mayor concentration at german limes. It seems that some baetican centres would be assigned to the support of olive oil. However, this hypothesis can not be proven by the lack of archaeological sources (Remesal, 2011, 125).

2.2.4. Material

We analysed a dataset of 2052 stamps placed in *Germania*. All the data was also compiled by CEIPAC database. We finally selected a total of 1621 stamps consist of 850 different stamps from 46 sites (see Fig. 6). As previously before, the centres were selected with more or equal than 5 stamps.

2.3. Measuring the dissimilarity in stamps

The approach proposed here is based on the idea of measuring the similarity between amphora workshops by quantifying similar stamps. A measure of dissimilarity has been chosen to analyse the dataset. We use the statistical technique Morisita-Horn index (Morisita, 1959; Horn, 1966). This method

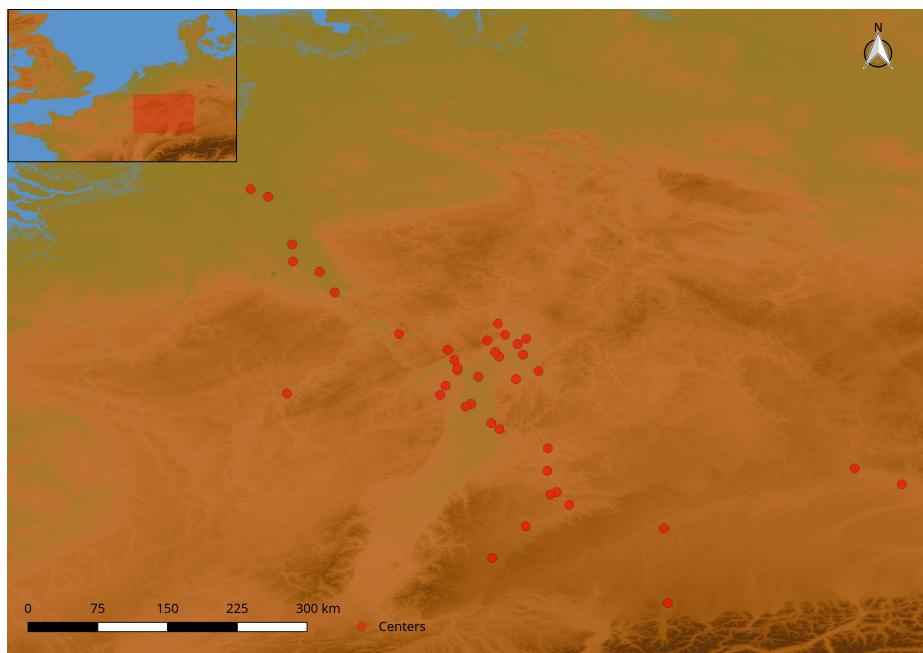


Figure 6: Distribution of the sites in *Germania*. Most sites were located in limes during the Roman Empire

was performed 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).

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

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

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 can be expressed considering 0 as total presence of similarity of stamps and 1 a totally dissimilarity between stamps. In our case, it will be calculated the number of times that one stamp appears in an amphora workshop. This method allows to bear in mind the similar number of times for each repeated stamp per workshop. If two workshops have similar stamp codes then the probability would be 0 whereas stamps codes are totally different when the results would be 1.

3. Results

3.1. Production centres: Baetica Province

The analysis shows that amphoric stamps could be correlated with the spatial distance. The correlation coefficients range from a minimum to a maximum. The dendrogram shown in Fig. 7 was obtained with Morisita-Horn index. The dendrogram suggests that amphora workshops used different stamps for their production system. Nearby workshops show a similarity on the stamps while most of them seem to display different stamps roles. Additionally, groups of workshops sharing similar stamps were not found in the cluster: the majority of stamp grouping was composed by no more than three workshops. Indeed workshops that shared more similar amphoric stamps belonged to the same *conventus* area, such as Picachos, Cerro de los Pesebres and El Castillejo.

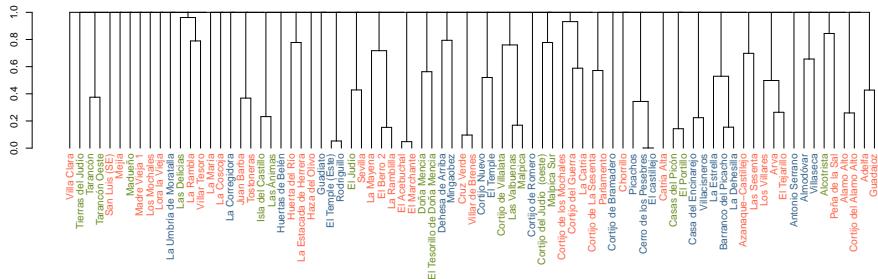


Figure 7: Dendrogram obtained by Morisita-Horn algorithm of different amphora workshops in *Baetica* area. Colours are represented by areas divided into *Hispalis* (red), *Astigi* (green) and *Corduba* (blue)

3.2. Reception centres: Britannia and Germania

3.2.1. Britannia

The results show a correlation similar to the obtained in *Baetica* province. However, the similarity is less pronounced as we observed in the dendrogram in Fig. 8

A minor correlation can be explained by the fact that *Britannia* spatial area is much wider than *Baetica* where the centres were more concentrated.

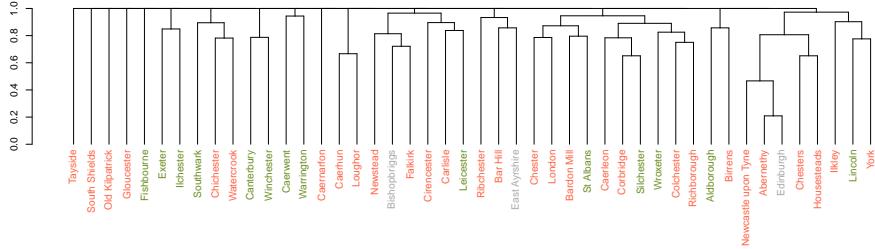


Figure 8: Dendrogram obtained by Morisita-Horn algorithm of different sites in *Britannia*. Colours are represented by type of sites divided into military sites (red), civil sites (green) and no specific (grey)

Most military sites that showed greater similarity in the results were geographically close. We identified two factors in the results: 1) nearby sites tend to share similar stamps and 2) most sites have different stamps. By contrast, most sites did not show a strong similarity in stamp correlation. Neither we found a grouping of similar stamps in a specific place. In general, we did not observe any production pattern that indicates a clear organisation between production centres and reception centres. In other words, our results did not indicate the presence of a specific production center from *Baetica* in *Britannia* province. Rather it seems that olive oil production was distributed by non specific production centres.

3.3. Germania

The similarity of stamps shows a results less significant than *Britannia* province as it can be seen in the dendrogram (Fig. 9).

The sites with more similarity in stamps were closely located in limes. In this case, most sites have different stamps which means that we did not detect any pattern. On the other hand, there seems to be a greater concentration of the seals in areas eminently militarised and close to the German limes. However, It is still no possible to determine with the data that the existence of a defined pattern that reflects in more detail the route of this production in the area of

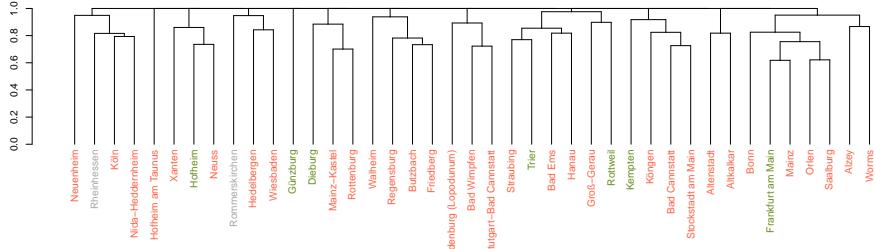


Figure 9: Dendrogram obtained by Morisita-Horn algorithm of different sites in *Germania*. Colours are represented by types of sites divided into military sites (red), civil sites (green) and no specific (grey)

the German limes.

4. Discussion and Conclusion

In this work, we aimed to analyse whether amphoric stamps could play an important role in the organisation of the workshops along rivers. For this reason, dissimilarity index was used to detect differences among workshops and stamps.

In our analysis, no strong relation between stamps and spatial distance have been detected in amphora workshops. The analysis suggests that there is not connection between stamps and the same amphora workshops, excluding certain exceptions when nearby workshops share the same amphoric stamp. Consequently, the majority of stamps are located in different amphora workshops and only similar stamps between closer amphora workshops were found. In any case, our results show that most similar stamps were detected in the same *conventus* area. These stamps tend to share the same area of production but there is not a general relation between groups of amphora workshops and area.

The hypothesis about groups of amphora workshops sharing the same stamps seems do not match with the results of the analysis even though there are similar stamps in closer workshops. Rather, it seems that each workshop were organised independently with different stamps. Those stamps detected in closer workshops do not move from other distant workshops. In other words, the stamps tend

to keep in the same area and different stamps were located in a same amphora workshops.

This could be defined by several factors. First, each workshop had a different organisation involved to the use of stamps and they were not used in 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 river was significant for the distribution of amphorae in consumption places, river connection amongst workshops does not seem show a relevancy for the distribution of stamps. Finally, the distribution of stamps could have shown some research bias. In some cases, workshops have been catalogued with different names in spite of belonging to the same workshops or being closer between each other. Additionally, most of the workshops were not widely excavated.

The results of the case study could be interpreted by several reasons. On the one hand, the use of these amorphic stamps could have been exclusively running by the owner or owners of the workshop to distinguish the amphora workshop. This hypothesis would explain the fact that we do not find similar stamps in different workshops; however, we found different amphora stamps in the same workshops that they would be barely difficult to assign different owners. On the other hand, it could be interpreted somehow a batch systematic organisation. Considering that Dressel 20 was not marked in most cases, some authors point out that potters marked amphorae to prepare and distribute the commodity to be shipped (Berni, 2008). This method would be used as an identifier to count the number of amphorae of a branch (Moros, 2018). This method could also have served to identify different groups of potter workers working in the same amphora workshop. Potters could have marked the amphorae to distinguish different groups working in parallel (Li et al., 2014). This it would explain wherefore why we detect different stamps in a same workshop. In any case, we do not have enough archaeological evidence that can validate the interpretations presented here and our results are certainly valid only with the context of our case study.

As summary, this method presented here provides a potential tool to understand mechanisms of production based on the similarity of artefacts. This method have identified differences in the case of the amphoric production within Roman Empire. Accordingly, the results have highlighted for the interpretation of the complex economic processes connected with the archaeological evidence.

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6. References

- Aguilera, A., 2007. Evolución de los tituli picti de las ánforas Dressel 20 entre mediados del siglo I y mediados del siglo III, in: Acta XII Congressus Internationalis Epigraphiae Graecae et Latinae, Monografies de la Secció Històrico-Arqueològica, Barcelona. pp. 15–22.
- Berni, P., 1996. Amphora Epigraphy: proposals for the study of stamp contents. established by: Mauro Cristofani and Riccardo Francovich , 751–770.
- Berni, P., 1998. Las ánforas de aceite de la Bética y su presencia en la Cataluña romana. volume 4. Col .lecció Instrumenta. Universitat de Barcelona.
- Berni, P., 2008. Epigrafía anfórica de la Bética. Nuevas formas de análisis. volume 29. Col .lecció Instrumenta. Universitat de Barcelona.
- Berni, P., Weiß-König, S., 2017. Amphorae-Epigraphy: Stamps, Graffiti and Tituli Picti from Roman Nijmegen, in: Amphorae from the Kops Plateau (Nijmegen): trade and supply to the Lower-Rhineland from the Augustan

period to AD 69/70. Archaeopress Archaeology, Oxford. volume 20 of *Archaeopress Roman Archaeology*, pp. 185–282, 289–343.

Bevan, A., 2014. Mediterranean Containerization. Current Anthropology 55, 387–418. URL: <http://www.jstor.org/stable/info/10.1086/677034>, doi:10.1086/677034.

Blázquez, J.M., 1980. La exportación del aceite hispano en el Imperio romano: estado de la cuestión, in: Producción y comercio del aceite en la antigüedad. Primer Congreso Internacional. Universidad Complutense de Madrid, pp. 19–46.

Brughmans, T., Poblome, J., 2016. Roman bazaar or market economy? Explaining tableware distributions through computational modelling. Antiquity 90, 393–408.

Callender, M., 1965. Roman Amphorae, with Index of Stamps. Oxford University Press.

Carreras, C., Morais, R., 2012. The Atlantic Roman trade during the Principate: new evidence from the western façade. Oxford Journal of Archaeology 31, 419–441. doi:10.1111/j.1468-0092.2012.00396.x.

Carreras Monfort, C., 1998. Britannia and the imports of Baetican and Lusitanian amphorae. Journal of Iberian Archaeology 1, 159–172.

Carreras Monfort, C., Funari, P.P.A., 1998. Britannia y el Mediterráneo: estudios sobre el abastecimiento de aceite bético y africano en Britannia. volume 5. Col .lecció Instrumenta. Universitat de Barcelona, Barcelona.

Carreras Monfort, C., Funari, P.P.A., 2003. El abastecimiento militar romano en Britannia: una perspectiva arqueológica. ArqueoWeb 5.

Chic, G., 2001. Datos para un estudio socioeconómico de la Bética: marcas de alfar sobre ánforas olearias. volume 1-2. Gráficas Sol.

Chic, G., 2005. El comercio de la Bética altoimperial. Habis 36, 313–332.

- Coto-Sarmiento, M., Rubio-Campillo, X., Remesal, J., 2018. Identifying social learning between Roman amphorae workshops through morphometric similarity. *Journal of Archaeological Science* 96, 117–123.
- Dressel, H., 1878. Ricerche sul Monte Testaccio. *Annali dell’Instituto di Correspondenza Archeologica* 50, 118–192.
- Funari, P., 2005. The Economic history of Roman Britain: olive oil contribution to the debate. *História e economia* 1, 29–46.
- Funari, P.P.A., 1996. Dressel 20 inscriptions from Britain and the consumption of Spanish olive oil. volume 250. BAR.
- 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 ed.. BAR International Series, Oxford, England. volume 2162, pp. 55–66.
- González Cesteros, H., 2010. La llegada de Ánforas Hispanas a Germania durante los últimos siglos de la dominación romana. Una cuestión para el futuro. CuPAUAM 36, 107–129.
- Horn, H.S., 1966. Measurement of "overlap" in comparative ecological studies. *The American Naturalist* 100, 419–424.
- 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.
- 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, 126–140.
- Magurran, A.E., 1988. Why diversity?, in: Ecological diversity and its measurement. Springer, pp. 1–5.

- Magurran, A.E., 2004. Measuring biological diversity. Blackwell Science Ltd.
- 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.
- 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.
- Moros, J., 2018. Análisis epigráfico de los sellos olearios béticos hallados en centros de producción: el caso de la zona productora de Scalensia. Ph.D. thesis. Universitat de Barcelona.
- Oksanen, J., Kindt, R., Legendre, P., O'Hara, B., Stevens, M.H.H., Oksanen, M.J., Suggests, M., 2007. The vegan package. *Community ecology package* 10, 631–637.
- 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. URL: <http://linkinghub.elsevier.com/retrieve/pii/S0305440315003192>, doi:10.1016/j.jas.2015.12.003.
- Remesal, J., 1977-1978. La economía oleícola bética: nuevas formas de análisis. *Archivo Español de Arqueología* 50, 87–144.
- Remesal, J., 1986. La annonaria militaris y la exportación de aceite bético a Germania. Editorial Complutense.
- Remesal, J., 1998. Baetican olive oil and the Roman economy. *Journal of Roman Archaeology - Suppl. series* 29, 183–200.
- Remesal, J., 2002. Baetica and Germania. Notes on the concept of provincial interdependence in the Roman Empire, in: The Roman Army and the Economy. Amsterdam, pp. 293–308. URL: <http://ceipac.ub.edu/biblio/Data/A/0325.pdf>. in: Paul Erdkamp (ed.).

- Remesal, J., 2004. Las ánforas Dressel 20 y su sistema epigráfico. J. Remesal Rodríguez (éd.), *Epigrafía anfórica. Proyecto Amphorae, Instrumenta* 17, 127–148.
- Remesal, J., 2010. De Baetica a Germania, consideraciones sobre la ruta y el comercio atlántico en el Imperio Romano, in: *Viajeros, peregrinos y aventureros en el mundo antiguo*. Universitat de Barcelona, pp. 147–160.
- Remesal, J., 2011. La Bética en el concierto del Imperio Romano. Real Academia de la Historia, Madrid.
- Remesal, J., 2016. Sellar, ¿para qué? El sistema de comunicación en los sellos de las ánforas Dressel 20. *Antichità AltoAdriatiche* 83, 73–90.
- Remesal, J., Aguilera, A., García Sánchez, M., Martín-Arroyo, D., Pérez González, J., Revilla, V., 2015. Centro para el Estudio de la Interdependencia Provincial en la Antigüedad Clásica (CEIPAC). *Pyrenae*, 245–275.
- Remesal, J., Revilla, V., Berni, P., Carreras Monfort, C., 1997. Arva: prospecciones en un centro productor de ánforas Dressel 20 (Alcolea del Río, Sevilla). *Pyrenae* 28, 151–178.
- Rovira Guardiola, R., 2007. Gráfitos ante coctvram sobre ánforas Dressel : una propuesta de evolución cronológica, in: *Acta XII Congressus Internationalis Epigraphiae Graecae et Latinae, Monografies de la Secció Històrico-Arqueològica*, Barcelona. pp. 1255–1262.
- Rubio-Campillo, X., Coto-Sarmiento, M., Remesal, J., Pérez González, J., 2017. Bayesian analysis and free market trade within the Roman Empire. *Antiquity* 91, 1241–1252.
- Rubio-Campillo, X., Montanier, J.M., Rull, G., Bermúdez Lorenzo, J.M., Moros Díaz, J., Pérez González, J., Remesal Rodríguez, J., 2018. The ecology of Roman trade. Reconstructing provincial connectivity with similarity measures. *Journal of Archaeological Science* 92, 37–47.

Wickham, H., Chang, W., others, 2016. *ggplot2: create elegant data visualisations using the grammar of graphics.* R package version 2.

Wolda, H., 1981. Similarity indices, sample size and diversity. *Oecologia* 50, 296–302.