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

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Abstract

XRC: reescribir abstract, demasiado general y entonces demasiado específico

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 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. 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) production centres by analysing different workshops in *Baetica* province and 2) two Roman provinces such as *Germania* and *Britannia* as consumption centres. They will be used to detect a connection 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 the quantitative approach provides a useful tool

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for the interpretation of the economic processes. Finally, results pretend to highlight the organisation of Baetican olive oil production in the Roman Empire linked to the differences observed in the archaeological evidence.

1. Introduction

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

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

The structure and processes associated to this massive olive oil production has been extensively discussed over the last decades(Remesal, 1977-1978; Chic, 1997; Berni, 1998). Our knowledge of this economic activity has benefited from new findings and data sources, but despite all these advances several questions remain open: XRC: no entiendo esta pregunta

 what patterns were followed for the distribution of olive oil to the different

provinces? XRC: no es esta pregunta idéntica a la anterior?

Did each province follow a different pattern for its distribution? XRC: esta frase no tiene sentido aquí; o la pones antes o en otro párrafo, pero es raro acabar un set de 2 preguntas con una frase que no sea otra pregunta

Nor the lack of written records has made possible to detect any indication of patterns in the olive oil market.

XRC: las preguntas no van sobre patrones; los patrones son las trazas en la evidencia que te ayudan a responder a las preguntas

Advances in the research of the Roman studies have currently led an environment with various interpretations on commercial dynamics (Duncan-Jones, 1982; Temin, 2006; Bowman and Wilson, 2009). The application of different quantitative approaches has allowed us to improve our interpretation of the growing amount of archaeological evidence and reveal the dynamics of the Roman production (Brughmans and Poblome, 2016; Orengo and Livarda, 2016; Rubio-Campillo et al., 2017; Coto-Sarmiento et al., 2018; Rubio-Campillo et al., 2018b).

XRC: me parece que aquí falta más chicha, porque saltas de una cosa super general (complejidad, economía, grandes dinámicas) a unos casos muy específicos. Deberías aquí explicar algo más sobre tu estudio y lo que quieres entender, por ejemplo qué preguntas específicas quieres responder? Como se enlazan con lo que has explicado hasta ahora? Cómo es que ahora saltas a casos de estudio regionales? Las preguntas específicas de los 3 casos de estudio deberían entrelazarse en una pregunta general del paper, que esté vinculada a lo que has explicado hasta ahora

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.
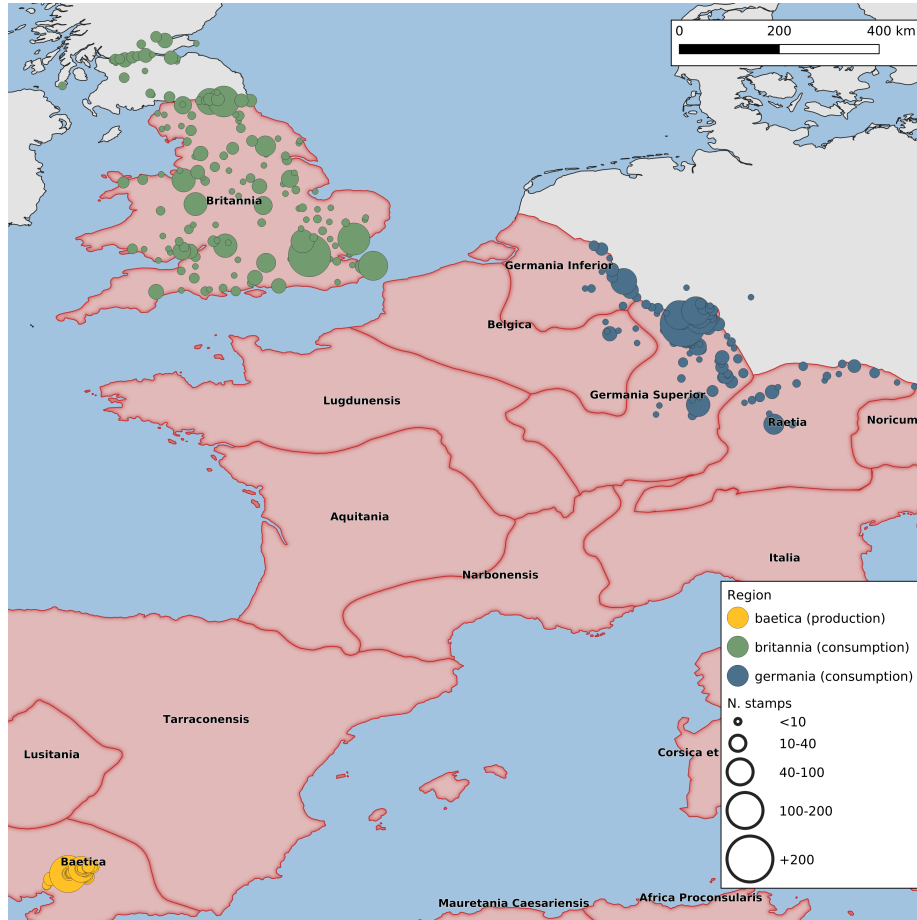

Figure 1: Overview of the sites analyzed in this paper. The color defines the three different regions under study (Baetica as producer; Germania and Britannia as consumers) while the size of each dot highlights the number of Dressel-20 amphoric stamps found on each of these sites

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 centres 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.

To do this, a population approach has been used to analyse the dispersion of stamps between amphora workshops (Rubio-Campillo et al., 2018b). 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.

2. The Amphoric production of Baetica

The landscape of the *Baetican* province was one of the best regions to face the increase in demand of 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 build 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).
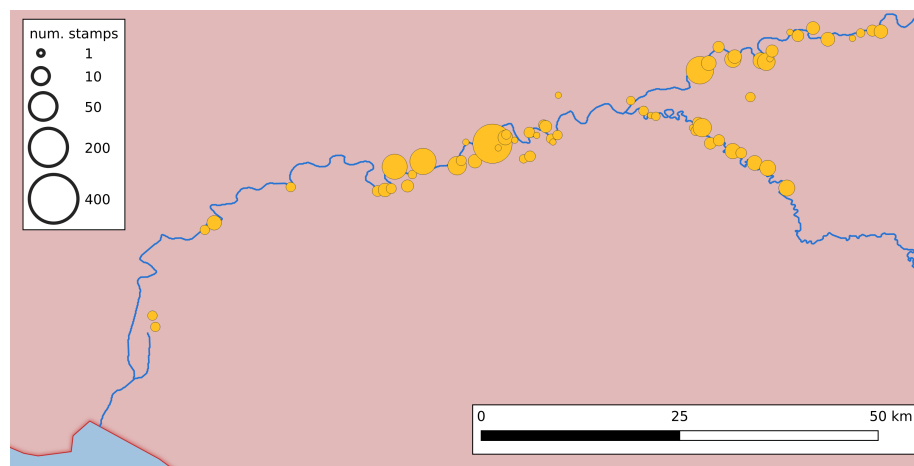
Figure 2: Distribution of stamps found in Dressel-20 workshops along the Guadalquivir riverbank. The size of each point depends on the number of stamps found on each site

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 with apparently few changesXRC: deberías desarrollar esto un poco más; qué tipo de evidencia demuestra esto? pocos cambios en qué? los talleres? las tipologías anfóricas?
(Remesal, 2004).

A large majority of this Baetican amphorae production is composed by Dressel 20 types(Dressel, 1878; Berni, 1998). Dressel 20 amphorae were shipped and distributed from *Baetica* throughout western EuropeXRC: esto ya lo has mencionado; quizás podrías explicar en 2 líneas la capacidad y forma de la dressel 20

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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).

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

Dressel 20 was the amphora most stamped during the Roman Empire (Berni, 1998, 18). The usage period is associated with a large amphora production for almost three centuriesXRC: esto está repetido no?

.

The large sample size of recovered Dressel 20 stamps is distributed across all the western provinces of the Roman Empire. For this reason there are several publications of this type of evidence discussing its origin, its meaning, its long period of use and its spatial distribution (Remesal, 2016) (Fig.3).XRC: si dices que es muy popular debería haber aquí más citas aparte de Remesal

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Most stamp codes display a large activity of production that can be difficult to date using an accurate chronology. They have been frequently dated with the consular dating by studying *tituli picti* found in *Monte Testaccio* (Blázquez Martínez and Remesal Rodríguez, 1999; Berni, 2008). However, the chronology of stamps could be also biased in other sites taking into account that amphorae were deposited after being produced and consumedXRC: esto necesita un poco de desarrollo. quieres decir que el código se encuentra en contextos de cronologías diferentes no? Y lo del Testaccio, pos eso, que hay pocos y todos de un yacimioento, lo que añade un bias

.

These stamps are typically found on handles but they were also imprinted
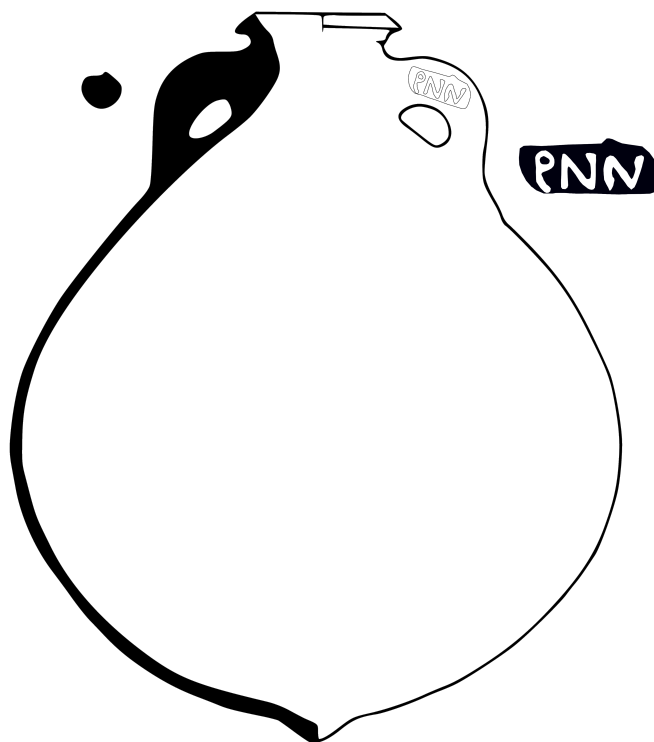
Figure 3: Dressel 20 were mostly marked with stamps of three letters called *tria nomina*

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 can appear in abbreviated form or complete and they are known as *Tria Nomina* (Berni, 1996).XRC: que quieres decir con abbreviated o complete? Como abrevias un código de 3 letras?

Scholars agree that stamps are some type of identification mark, but there is no consensus on the meaning of these marks(Remesal, 1998). Additionally, a large percentage of Dressel 20 containers were not stamped thus complicating the interpretation XRC: esta última frase aquí es un poco random no?
. The stamp codes are interpreted based on three main ideas: content (olive oil), context (amphora workshop) and subject (individuals involved on 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 were the amphorae was made or even to a group of amphora workers (Berni, 2008). In any case, the use of these stamps is a good proxy to explore the system of olive oil production and trade developed in Baetica.

Nevertheless, some challengesXRC: acabas de decir que tampoco se sabe qué es el sello, así que esta frase queda rara
 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 the use of written records have allowed providing enough information that can explain the economic role of *Baetica* province in the Roman organisation.XRC: esta frase esta fuera de contexto. Si la pones entonces deberías expandir la idea de frase a párrafo, y poner referencias
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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)XRC: pero estabas hablando del ejército no? Has hecho un salto aquí a los ciudadanos
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Some authors argue elsewhere that this same *Annona* could also have organized the supply of additional goods such as olive oil to the Roman legions (Remesal, 1986, 1990)XRC: pero no hay evidencia? Las fuentes escritas no lo mencionan?
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The importance of this olive oil trade is revealed by the massive amount of Dressel 20 amphorae found across the Roman provinces. This amphora has been commonly associated with the transportation of Baetican olive oil for supplying military camps and civil settlements (Berni, 2008).XRC: me parece repetitivo, porque unos párrafos antes ya hablabas de lo mismo. Quizás unificar texto aquí o allá?

The military consumption of olive oil in Roman provinces may be related to two aspects: a) cultural consumption whose product is consumed by cultural reasons such as to identity or habit and b) economical reasons where olive oil distribution is based on the transport costs, unlike other products (Carreras Monfort and Funari, 1998, 69-70)XRC: no pillo esta frase
..

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 good from military sites to civil settlements(Remesal, 1986; Carreras Monfort and Funari, 1998)XRC: lo que quieres decir es que tienes muchas ánforas en sitios civiles cerca de militares? no queda claro

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XRC: faltaría un enlace a la siguiente sección, queda muy abrupto

4.1. Britannia

The evidence for olive oil consumption in *Britannia* is scarce before the Roman conquest (Funari, 1996; Carreras Monfort and Funari, 2003). 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 record this absence of olive oil changed with the arrival of a large amount of Dressel 20 amphorae to *Britannia* (Carreras Monfort and Funari, 1998, 1)XRC: en qué siglo?

. The demand of 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.

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)XRC: repetitivo? fusionar párrafos

. 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 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 campaignsXRC: estas 2 frases repiten cosas ya explicadas
.

The presence of Dressel 20 stamps in military camps in *Britannia* has been widely studied in Roman archaeology (Carreras Monfort and Funari, 1998).XRC: si dices widely studied no puedes referencias solo 1 autor
.

This intense consumption of olive oil also indicates a possible provincial structure designed to organize the supply of olive oil to military camps, such as *Germania* (Remesal Rodrıguez, 1986)XRC: por qué such as Germania? Aún no has explicado qué hacen en Germania
. 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 a gradual decrease on *Baetican* olive oil exports can be observed as a decrease in the amount of Dressel 20 found in excavated sites as this typology is replaced by Dressel 23 amphorae (Remesal, 1991; Berni, 1998).XRC: pero entonces la dressel 23 de donde viene? Cuidao que estás diciendo que se acaban las dressel 20, pero esto implica que hay menos aceite de oliva o que viene de otras partes o que va en recipientes distintos a la dressel 20?

4.2. Germania

Julius Caesar's campaigns in *Gallia* during 1st BC opened the door to the invasion of *Germania* during Augustus rule (Remesal, 1986, 2002)XRC: no hay un resumen de la conquista similar para Britannia, queda raro
. Previous studies suggested that the supply to the German limes was mainly based on riverine transport, but recent works suggest that the maritime route through the Atlantic Ocean could have been more important than expected

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(both for Germania and Britannia). (Remesal, 2010; Rubio-Campillo et al., 2018b).XRC: lo del océano atlántico está un poco descontextualizado; no sería mejor ponerlo al final de esta sección?

Roman studies exploring the presence of Dressel 20 amphorae in *Germania* has not had the same impact as the rest of the provinceXRC: no entiendo esta frase. Que qué provincia? Germania son 2 provincias no?
. This could be explained due to the lack of archaeological sources (González Cesteros, 2010). As a consequence, it is still unknown if trade agents participated on the distribution of Baetican olive oil in *Germania* or the supply was exclusively focused on the Roman army garrisons(Remesal, 2010, 156)XRC: quieres decir que aquí sólo encontramos dressel 20 en yacimientos militares porque no se han excavado muchos civiles?
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Germania presents a similar introduction pattern of olive oil than the one discussed for *Britannia*. There is no archaeological evidence for olive oil consumption before the arrival of the Roman army to the region while a majority of recovered Dressel 20 amphorae are located in the military sites that formed the German *limes*XRC: cita?
.

The presence of the Roman army encouraged the exchange in the province as shown by the arrival of this product both civil settlement and military sites with a mayor concentration at the German *limes*XRC: pero justo antes decías que no había en civiles no?
. It seems that some Baetican centres would be assigned to the support of olive oilXRC: the support of olive oil no se entiende. Además, falta alguna cita y desarrollar esta idea
. However, this hypothesis is hard to assess given the current lack of archaeological evidence XRC: related to BLABLABLA. Habría que detallar un poco porque hay un montón de evidencia arqueológica del limes, así que qué es exactamente lo que falta?

(Remesal, 2011, 125).

5. Material and Methods

The goal of this study is exploring the effect of the production patterns between different centres. We are especially interested in identifying links between production and consumption centres by using amphoric stamps. To do that, we use the CEIPAC database to collect stamps from different places. The CEIPAC dataset contains over 50.000 of epigraphy records found in amphorae, mostly from *Monte Testaccio*. This study proposes a robust baseline to explore the distribution of Baetican olive oil production by computing the spatial correlation between stamps. 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 potential spatial correlation and c) to establish a correlation between similarity of stamps and spatial distance. XRC: estos 2 párrafos explican objetivos, que deberían ir en la intro y no aquí, donde deberías empezar a hablar directamente de la BBDD

5.1. Production centres: Baetica province

To study the stamps found in the Baetican workshops we used the data collected in the CEIPAC database of amphoric epigraphy (Remesal et al., 2015) (see the database here `http://romanopendata.eu`). This database contains over 50.000 epigraphy records found on different types of amphoraeXRC: podrías mover esta parte a los 2 párrafos anteriores y explicar la bbdd brevemente antes de empezar a hablar de la Bética (porque es info que también aplica a los otros 2 casos de estudio no?

.

There databased allowed us to retrieve 3798 stamps found in Dressel 20 amphorae recovered from workshops within *Baetica* province. Each of these

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stamps ha 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 code.

Our dataset also contained a new categorical variable defining the *conventus* of each site. The *conventus* were administrative centres for territorial organisation in the Roman Empire (Ozcáriz Gil, 2013, 58)XRC: estaría bien ampliar un poco esto; qué organizaban exactamente?
. 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 coordinates but they were catalogued as different workshops in Roman Studies (i.e. Tesorillo de Doña Mencia and Doña Mencia). The analysis took into account this particularity but some biases can occur due to the archaeological datasetXRC: No se entiende; deberías explicarlo un poco mejor y citar algo si dices eso. Piensa que la mayoría de lectores no sabrán quién es Doña Mencia
.

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 contained only one stamp XRC: el gráfico es dificil de entender...yo leo que hay unos 20 workshops con 1 solo stamp, por lo que entiendo que no es cierto que la mayoría solo tengan 1 sello (hay como 50 workshops con entre 2 y 30 sellos no?)
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 self-organised complex system pattern with a major concentration of the number of stamps in a few workshops (Rubio-Campillo et al., 2017; Coto-Sarmiento et al., 2018)XRC: no
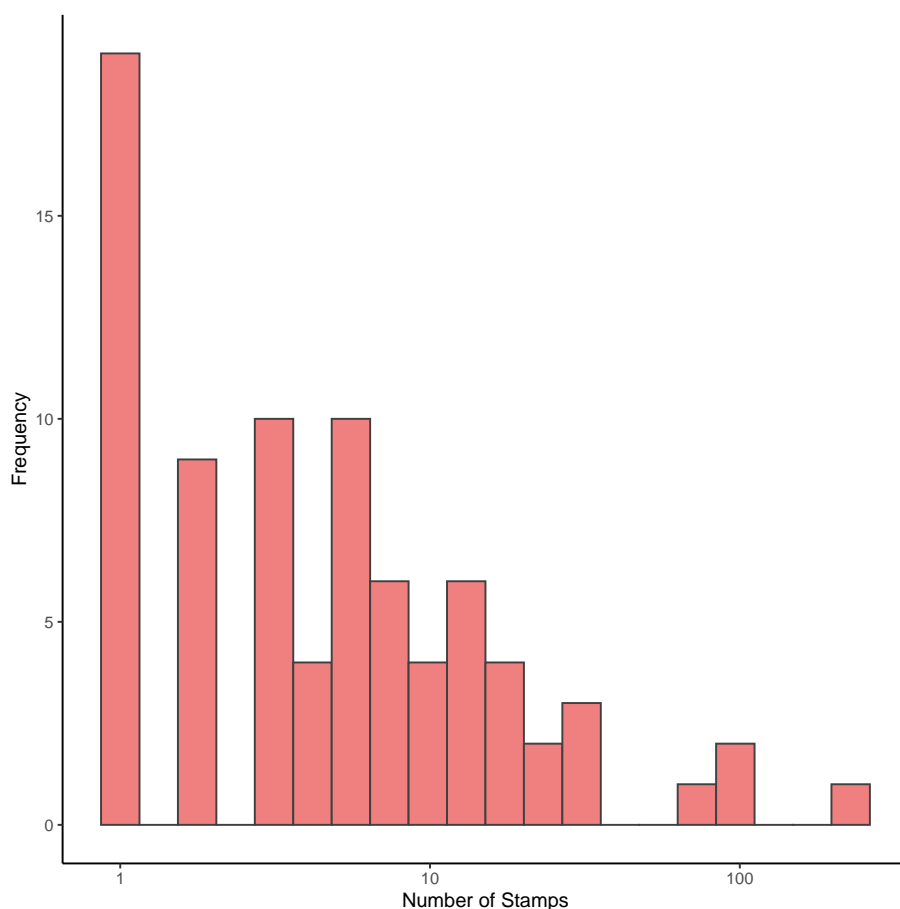
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Figure 4: Histogram on a log scale with base 10. X axis is represented by the number of stamps and Y axis is the frequency of workshop. The distribution is widely diverse with most workshops having only one stamp

The distribution of amphora stamps for each *conventus* can be seen in Figure 5. The majority of stamps are concentrated in *Hispalis* (574 stamps) while *Corduba* and *Astigi* have roughly half this sample size (267 and 146 stamps). The workshops of the three conventus show a similar pattern on the stamp fre-

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quency distribution with the exceptions of 2 large workshops in *Hispalis* (La Catria and Arva). On these two workshops a comparatively large amount of stamps were found (29 different code stamps on each of them)XRC: una cosa, aquí has pasado de sellos a códigos, y los valores son distintos que en el gráfico anterior. Deberías clarificarlo antes de empezar a hablar de la figura

. According to previous studies those workshops became the most important centres of amphora production in the regionXRC: cita de estos estudios

. It is worth mentioning that a majority of these stamps were collected during ield 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).
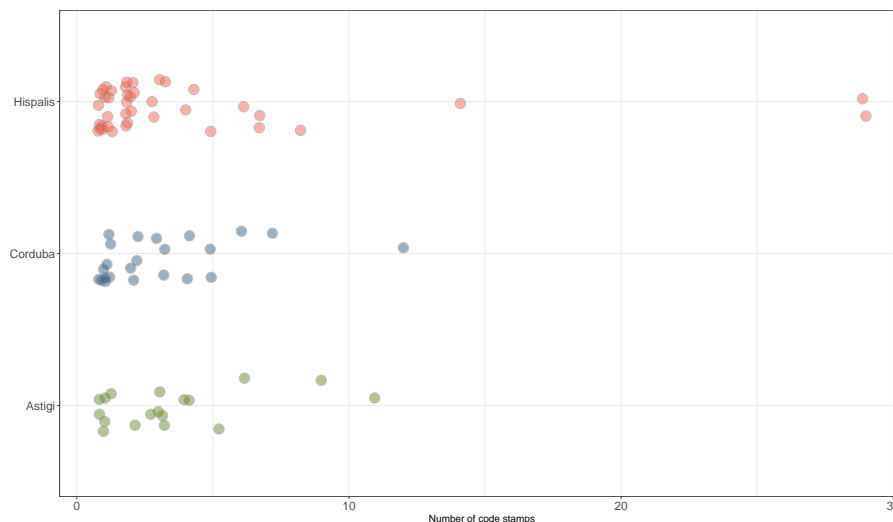

Figure 5: Distribution of the number of different code stamps (X axis) for each *conventus* (Y axis). Each dot corresponds to a workshop sorted by different areas. Colours are represented by areas divided into Hispalis (red), Astigi (green) and Corduba (blue)

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. We selected the centres with more or equal than five stampsXRC: pero esto no se hizo en el de Baetica

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The output was a dataset of 4271 stamps found in sites belonging to *Britannia* (2219 stamps) and *Germania* (2052 stamps). 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 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 centers 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)

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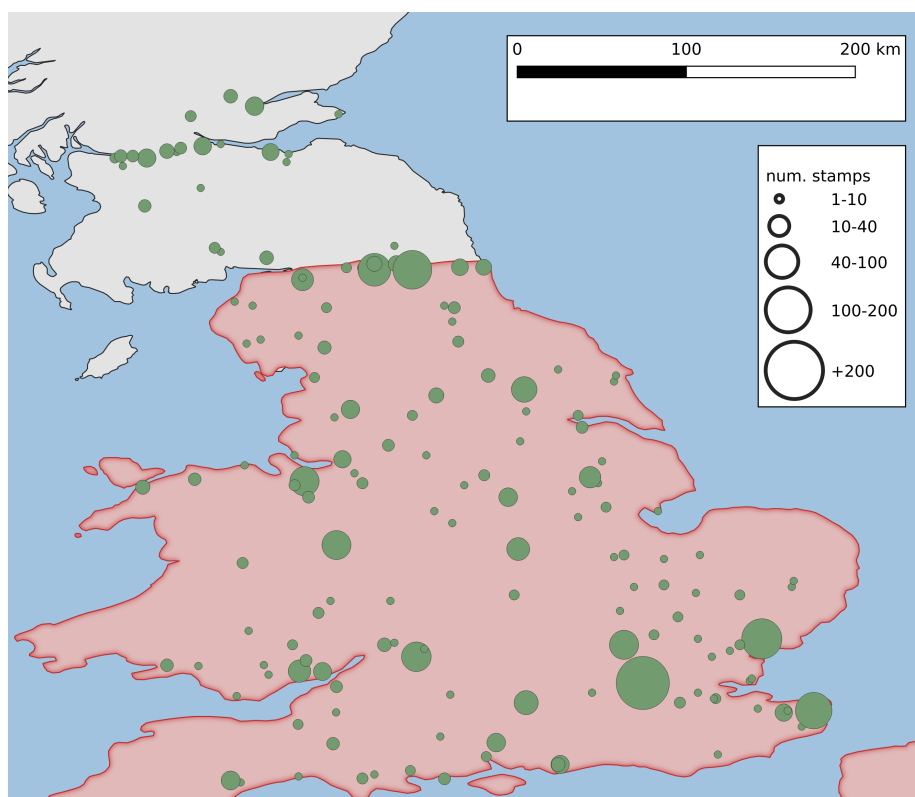The formula can be described as follows (Magurran, 2004):

Figure 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 in the site. A majority of stamps have been found in garrisons related to Hadrian's and Antonine walls
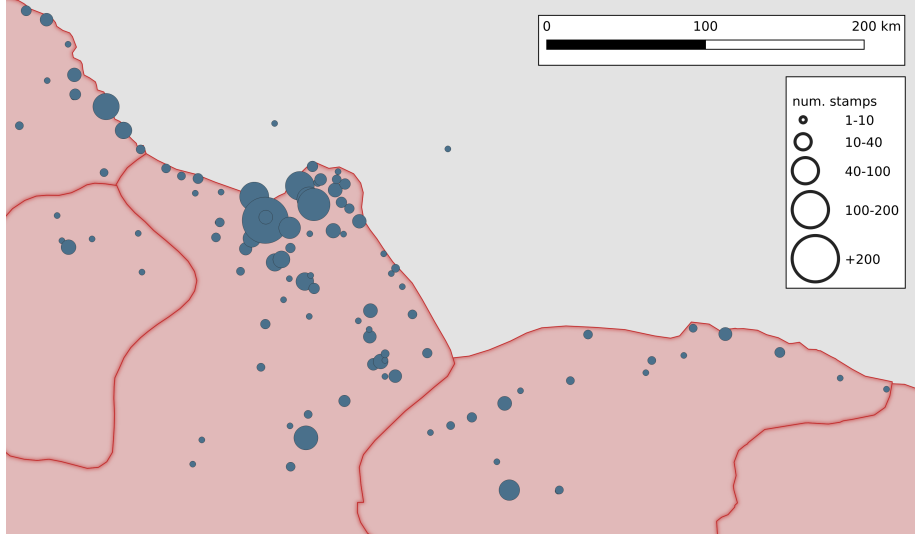
Figure 7: Sites in Germania where Dressel-20 amphoric stamps have been found. Each dot is a site while its size shows the sample size of stamps found in the site. Most sites are located along the German *limes*

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

d_a and d_b are given by the following equation:

$$d_a = \frac{\sum a_i^2}{N_a^2} \tag{2}$$

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 an exact stamp

codes and frequency distribution) and 1 (complete difference between stamp codes). To apply Morisita-Horn we firstly calculated the number of times that each stamp code appeared in an amphora workshop. This method allowed us to bear in mind a similar number of times for each repeated stamp per workshopXRC: no entiendo esta frase

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

Nearby workshops display a higher similarity than distant workshops and the varying degrees of similarity between sites which could be correlated to their spatial distance; additionally, the workshops with higher similarity values belong to the same *conventus* area, such as Picachos, Cerro de los Pesebres and El Castillejo.
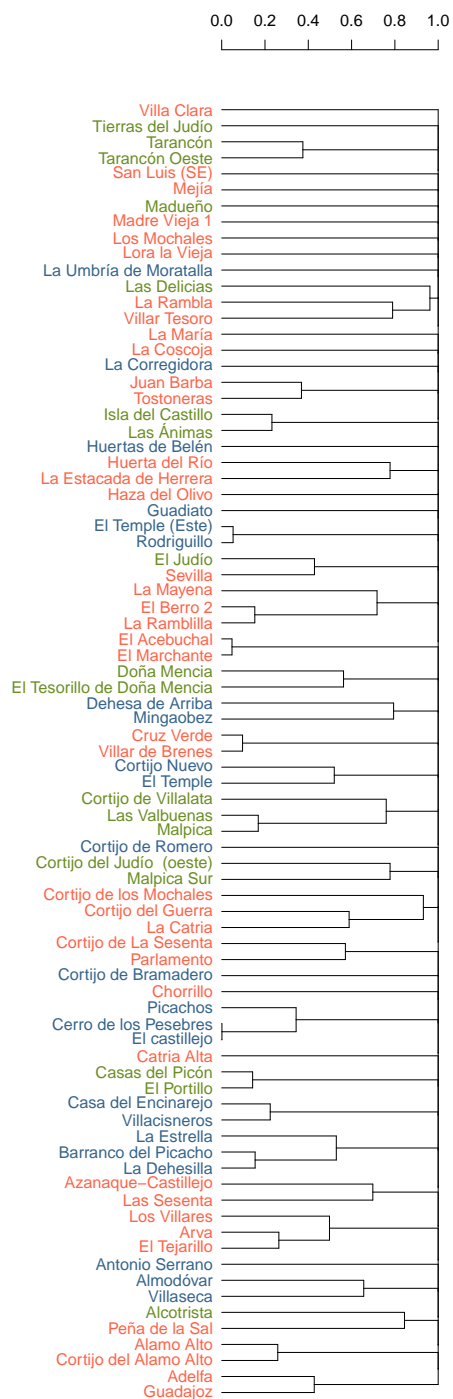
Figure 8: Dendrogram displaying the results of hierarchical clustering based on Morisita-Horn metrics for Dressel 20 workshops located in the *Baetica* area. Site names are color-coded by conventus: *Hispalis* (red), *Astigi* (green) and *Corduba* (blue)

6.2. Consumption centres: Britannia and Germania

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

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

By contrast, most sites did not show a strong similarity in stamp correlationXRC: qué quieres decir? porque lo de que hay una similaridad baja ya lo has repetido arriba

. We also did not find any groups of similar stamps in a specific placeXRC: tampoc entiendo esto. que no hay sellos similares en un solo sitio...?

.

These results suggest that there is no clear organizational pattern linking production centres and/or consumption centres beyond spatial distance. As a consequence, our analysis does not indicate the presence of a specific production centre from *Baetica* to *Britannia* province. Rather, it would imply that olive oil production was distributed by non-specific production centresXRC: esto no iría en la discusión? Por otra parte, no entiendo qué quieres decir exactamente, igual hay que desarrollarlo

.

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

A higher concentration of sites sharing similar stamps were found in areas eminently militarised and close to German *limes*, even if most sites mostly showed different stamps XRC: quieres decir que los sitios más cercanos al limes
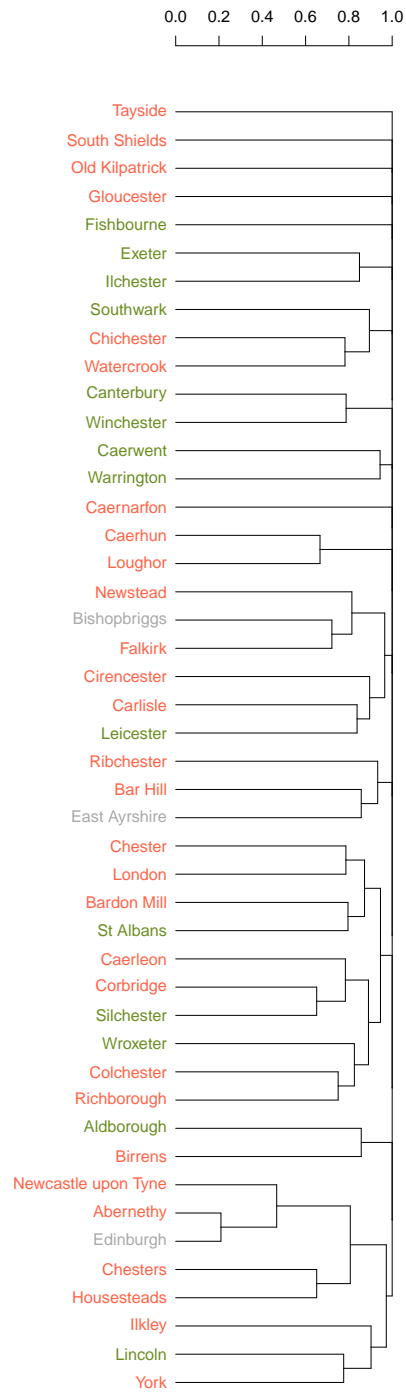
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Figure 9: Dendrogram displaying the results of hierarchical clustering based on Morisita-Horn metrics for sites in *Britannia*. Site names are color-coded by typology: military sites (red), civilian sites (green) and unspecified (grey)
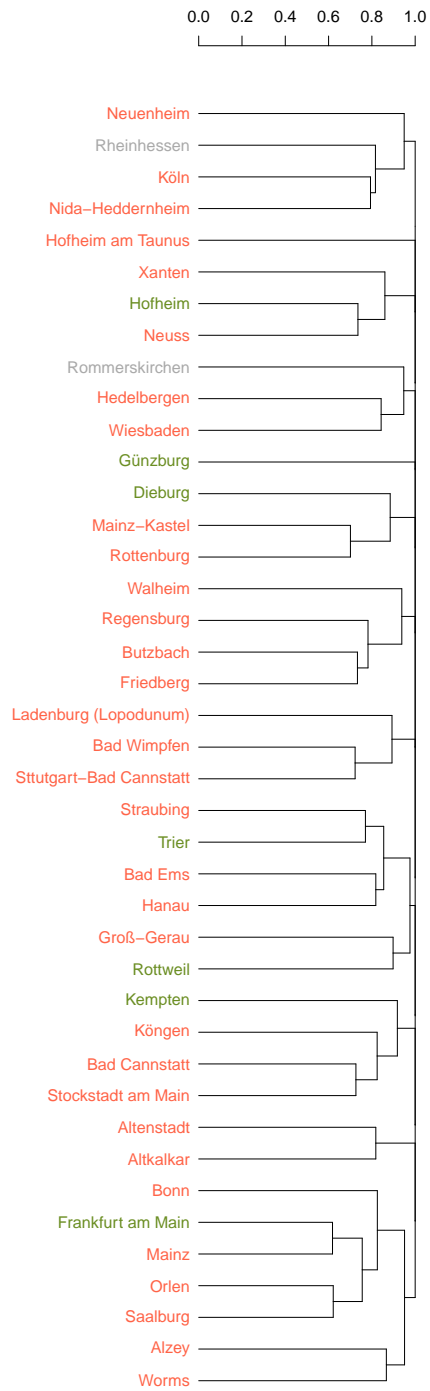
Figure 10: Dendrogram displaying the results of hierarchical clustering based on Morisita-Horn metrics for sites in *Germania*. Site names are color-coded by typology: military sites (red), civilian sites (green) and unspecified (grey)

son más similares? no queda claro y hay que detallarlo un poco más

.

7. Discussion

This work has explored to what extent the distribution of amphoric stamps can provide insights on the organisation of olive oil Roman markets both at the production and consumption areas. For this reason, an index of dissimilarity was used to detect differences between the distribution of the amphoric stamps and the spatial distance of producers and consumption centres. The general purpose was to explore if such differences found in the stamp codes could play an important role in the Roman marketXRC: este párrafo es un poco reiterativo no?

.

7.1. Production centres

The analysis of the amphora workshops in *Baetica* province suggests that a majority of stamp codes were only used on a single workshop. Beyond this clear pattern it seems that the similarity of stamp codes is correlated with spatial distance and the amphoric production of spatially close sites shared 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. In general, the majority of stamps were located in different amphora workshopsXRC: estas 2 frases repiten cosas dichas antes

.

Our results do not support previous working hypotheses suggesting that groups of workshopes used specific groups of stamp codes; while there is higher

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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. These stamp codes detected in closer workshops do not move from other distant workshops. In other words, the stamps tend to remain in the same area and different stamps were located in a same amphora workshopXRC: de nuevo estas 2 frases repiten cosas de antes

.

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 of stampsXRC: qué quieres decir con esto? que los diferentes ríos no muestran ningún patrón?

.

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 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

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stamps were mainly found in military centres. This could be also interpreted by an intensity bias where military centres have been mostly excavated than civil centresXRC: pero no decías que el aceite llegaba por las legione? Entonces por qué es un bias? En todo caso ponlo al final de la sección y no al inicio

.

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 seaXRC: por qué más conectividad implica más similaridad? no será porque encuentras más ánforas?

.

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 and Morais, 2012; Morillo et al., 2016; Rubio-Campillo et al., 2018a). 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 and Funari, 1998; Ayllón-Martín et al., 2018).

The results for *Germania* follow a similar pattern than *Britannia* but with a minor correlation as we can observe in the dendrogramXRC: esta frase está repetida de los resultados. quizá quitarla de ahí y dejarla aquí?
. 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).

It is worth mentioning that it was not detected a robust model of organisation in both cases with regard to the distribution of stamps in consumption centresXRC: de nuevo esto es redundante no?
. 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 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 centers (i.e. an amphorae 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).

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 commercialisationXRC: estos 2 párrafos igual deberían ir a la discusión no? La conclusión debería ser algo más general y aquí estás aún interpretando resultados

.

This could be explained such as batch systematic organisation between potters (Moros, 2018). This method allowed to potters organises the production with the batch stamping for the posterior commercialisationXRC: y esto para qué serviría? debería explicarse un poco más

.

A large number of Dressel 20 were not marked with any stamps, so some

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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).

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

To conclude, the method presented here provides a useful framework to improve our understanding of the organisation and processes that allowed the Roman Empire to manage a massive and highly specialized production of essential goods. This work has identified differences in the case of the amphoric production within the Roman EmpireXRC: qué diferencias?
. The growing amount of archaeological data requires of large-scale quantitative methods such as the one presented here to identify and explore complex patterns, thus allowing us to infer dynamics and improve our interpretation of complex economic processes of past societies.

9. Acknowledgements

10. 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.

Ayllón-Martín, R., Pérez González, J., Remesal Rodríguez, J., 2018. Olive Oil at the Border of the Roman Empire. Stamps on Baetican Dressel 20 Found on the Tyne-Solway Isthmus. Münstersche Beiträge zur Antiken Handelsgeschichte 36, 167–217.

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.

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.

Blázquez Martínez, J., Remesal Rodríguez, J. (Eds.), 1999. Estudios del Monte Testaccio (Roma) I. volume 6. Col .lecció Instrumenta. Universitat de Barcelona.

Bowman, A., Wilson, A., 2009. Quantifying the Roman economy: methods and problems. volume 1. Oxford University Press.

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

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., 1997. Historia económica de la Bética en la época de Augusto. Serie Historia, Padilla Libros, Sevilla.

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 Corrispondenza Archeologica 50, 118–192.

Duncan-Jones, R., 1982. Economy of the Roman Empire. CUP Archive.

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.

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, 267–284. URL: `http://doi.wiley.com/10.1111/ojoa.12089`, doi:`10.1111/ojoa.12089`.

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`.

Ozcáriz Gil, P., 2013. La administración de la provincia Hispania Citerior durante el Alto Imperio Romano. Organización territorial, cargos administrativos y fiscalidad. volume 44. Col .lecció Instrumenta. Universitat de Barcelona, Barcelona.

Remesal, J., 1977-1978. La economía oleícola bética: nuevas formas de análisis. Archivo Español de Arqueología 50, 87–144.

Remesal, J., 1986. La annona militaris y la exportación de aceite bético a Germania. Editorial Complutense.

Remesal, J., 1990. El sistema annonario como base de la evolución económica del Imperio romano. PACT 27, 355–367.

Remesal, J., 1991. El aceite bético durante el Bajo Imperio. Antigüedad y Cristianismo , 355–361.

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 intedependence 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., 2008. Provincial interdependence in the Roman Empire: an explanatory model of Roman economy., in: New Perspectives on the Ancient World. Modern perceptions, ancient representations. Archaeopress, Oxford, England. BAR International Series 1782, pp. 155–159. URL: `http://ceipac.gh.ub.es/biblio/Data/A/0524.pdf`.

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. (Ed.), 2018. Colonia Ulpia Traiana (Xanten) y el Mediterráneo. El comercio de alimentos. volume 63. Col .lecció Instrumenta. Universitat de Barcelona, Barcelona.

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., Bermúdez, J., Montanier, J., Moros Diaz, J., Pérez-González, J., Remesal, J., 2018a. Provincias, sellos e hipótesis nulas: la identificación de rutas de comercio a través de medidas de distancia cultural, in: Cuantificar las economías antiguas. Problemas metodológicos. Instrumenta. Universitat de Barcelona, Barcelona, pp. 237–249.

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., 2018b. The ecology of Roman trade. Reconstructing provincial connectivity with similarity measures. Journal of Archaeological Science 92, 37–47.

Temin, P., 2001. A market economy in the early Roman Empire. Journal of Roman studies 91, 169–181.

Temin, P., 2006. The economy of the early Roman Empire. The Journal of Economic Perspectives 20, 133–151. URL: http://www.jstor.org/stable/30033637.

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.