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Preliminary Approaches for the Identification and Classification of Mediterranean Murex Dye Production Sites

Introduction

Murex snails were used as early as the Bronze Age in the Mediterranean to produce an expensive, reddish-purple dye. By the Roman period, murex-dyed fabrics were well-established symbols of high status, power, and wealth (Jensen 1963). Because the product was used by the Phoenicians, Minoans, Greeks and Romans, Mediterranean history is littered with textual and archaeological evidence of the dye and textile making process. Influenced by the available data, current research leans toward recreating the recipe: determining how many murex snails were needed, the application and utility of additives, and the type of facilities or equipment used. While significant progress has been made in this regard (Koren 1999; Cardon *et al.* 2004; Koren 2005; Ruscillo 2005; Ruscillo 2006; Koren 2007; Cooksey 2009; Hoffman *et al.* 2010; Cardon *et al.* 2011; Cooksey 2013; Karapanagiotis *et al.* 2013; Margariti *et al.* 2013), inaccurate presentations and problematic methodologies of the evidence still exist when attempting to identify the actual locations of dye production.

The first step towards recognising the variations in the archaeological record is to realise that all available data must be considered equally. While Pliny is arguably the ancient authority on dye production, if we only relied on his descriptions to verify archaeological remains, our results would be biased – experimental studies clarify the intricacies in ingredients and processes, and the areas where his descriptions (and

those of other authors) are lacking. On the other hand, the ancient authors' knowledge should not be disregarded, particularly when they mention specific locations in which production occurred. In other words, all available datasets must be utilised and questioned.

Because extensive textual, scientific and archaeological remains are available for the Roman period, this paper will focus on Mediterranean dye manufacture evidence between the 1st century BCE and the 5th century CE. Strengths and weaknesses are presented for textual, scientific and archaeological data in order to qualify the unique evidence each can reveal and to clarify how textual and scientific data can enhance our ability to recognise archaeological remains. Based on this methodological analysis, a catalogue of Roman-period sites which are 'definitively' or 'probably' linked to murex dye production are presented.

Some scholars might argue that earlier production should be considered as well. While there is extensive scientific and archaeological scholarship available on Bronze Age dye production sites, contemporary textual references are not readily available. Our understanding of Bronze Age dyeing is affected by later evidence – there was a (perhaps intentional) lack of record keeping prior to the Roman period, especially with regard to the exact ingredients, recipes and techniques used (Ziderman 1987, 51). Roman authors, on the other hand, recorded detailed accounts of snail harvesting and manufacturing processes



(Stieglitz 1994; Ruscillo 2005; Schneider 2012). I do not intend to argue that there is no plausible relationship between Bronze Age and later-period manufacturing techniques. Because of the amount of skewed evidence and misidentification, however, I am intentionally limiting this case study in order to link the appropriate textual evidence to whatever material evidence is available.

Ultimately, this paper proposes a 'clean up' of the evidence, which could lead to informed decisions when handling the archaeological evidence. By systematically addressing the diversity of the existing evidence, it will become much easier to identify the material evidence. Future research could lead to site-type classification schemes and the ability to compare production facilities on a regional level. By clarifying what exactly constitutes evidence for a murex dye production site, we will be able to understand why variations in the record might be present and how the methodologies for dye manufacture would have varied over time and space.

The past and present of murex dye studies

Thanks to the detailed descriptions made by the ancient sources, the social significance of murex dye is well attested. Social positions were displayed in the ability to wear the dye in various Mediterranean cultures and periods, the Roman period included (Jensen 1963, 115). Roman literature is littered with references to powerful and privileged individuals possessing the cloth. Romulus' mantle, for example, was described as being adorned with purple stripes. Subsequently, togas representing various social and political positions were dyed in purple as well (Pliny, *Hist. Nat.* 9.71 ff.). The *toga praetexta*, *toga picta*, *paludamentum* and *tunica palmata*, for example, were regulated garments adorned with varying amounts of purple (Elliot 2008, 181; Livy, *Ab urbe con.* 10.7 ff.).

In later periods, purple was restricted to specific state officials, regardless of whether one was wealthy enough to purchase the product. Julius Caesar (Suetonius, *Caes.* 43) restricted purple-dyed fabrics to certain individuals and events. Nero actually employed police to close wholesalers and strip individuals of their purple-dyed clothing if seen in public (Suetonius, *Nero* 32.4). Scholars have linked these restrictions with efforts to preserve imperial power (Reinhold 1970). Indeed, in the midst of imperial struggle, Diocletian restricted the finest-quality dyes to the imperial household and court. Various qualities of cloth were under scrutiny, and in the *Edict on Maximum Prices*, Diocletian set the price of purple wool at 50,000 *denarii* a pound and purple silk at 150,000 *denarii* a pound, while high-quality, undyed wool was only 175 *denarii*

a pound (Reinhold 1970, 58-59). Despite the arguable care that ancient authors, Pliny primarily, took to record the actual dye production process, it is at this point that the literature becomes complicated.

Intrigued by these descriptions, scholars have been eager to identify the ingredients used, the ways they were collected and the methods by which the dye was processed and the cloth dipped. Unfortunately, our understanding of these processes is hindered not only by the archaeological record, but also by the limited application of interdisciplinary study and comparative datasets. All too often, mention of murex dye production is found in excavation site reports (e.g. Reese 1980, 2007, 2010; Wilson 1999, 2001, 2002, 2004; Alfaro Giner and Costas Ribas 2008), meaning the location is presented as an isolated entity. Detail of the dye production facilities is often limited – middens are often unmeasured, vats and pits are described as 'large' or 'small'. Particular sources of evidence that could indicate dye manufacture, such as crushing tools, residue or ash, are often not mentioned, leaving scholars to wonder if sites were not used for dye production, or if excavation techniques need to improve in dye-related contexts.

One exception is Alberti (2008, 75), who carefully considers the variable forms of evidence (heating sources, vats, residue, and murex shells) and classifies sites into three categories: 'direct', 'indirect' by means of waste material, and 'indirect' by means of recycled debris. While this study is invaluable for its attempt to categorise forms of evidence, many points are left unaddressed. There is little mention of the textual sources or experimental projects which could aid our understanding of production methodologies, and in turn, the identification of archaeological remains. Furthermore, the typology is applied to sites ranging from the Bronze Age through to the Roman periods, with no discernible pattern of available evidence per period or per location (Alberti 2008, 82). With such a long-standing interdependent relationship through space, time and with other modes of production, limiting studies to a smaller span of time or a specified geography could provide a greater understanding of the dye production process and, ultimately, regional variability.

A proposal for interdisciplinary, multi-data analyses

In the following I will put forth an alternative methodology: to analyse the separate datasets available within a specific period of time, identify the various forms of evidence they can each yield, and therefore realise the strengths and weaknesses of each dataset before actualising them as a larger unit of information. Dye production evidence will be discussed according



to dataset type: textual data, experimental/scientific data and evidence yielded from excavations. Within these dataset types, the various forms of evidence which can be found are discussed, and are identified as follows:

Necessary: Evidence without which a dye production site could not be definitively identified.

Corroborating: Evidence which can assist in the identification of dye activities, but cannot easily be used to identify the location of a dye production site.

Dataset types are first discussed in isolation, in order to highlight the specific forms of evidence that can be extracted, and how they will manifest themselves individually. Connections are mentioned in order to highlight the benefits of a multidisciplinary and multi-data approach to murex dye production studies, and can also be observed by comparing Tables 1-3. This methodology importantly highlights our ability to understand which dataset is most appropriately going to provide evidence for various aspects of the industry. Some data cannot be feasibly retrieved from the archaeological record; textual sources mentioning particular methods or ingredients and experiments attempting to recreate dye according to these

descriptions can help us fill in the gaps. Alternatively, textual and experimental data can clarify which types of ingredients or equipment were needed, but cannot always offer an accurate picture of the retrievable archaeological remains.

While datasets may generally reveal the same form of evidence, the ways in which this evidence manifests itself can vary significantly, and in turn the identification of a production site can be problematic. These variations should be expected, even at sites where a 'definitive' label is applied. This dye was vastly popular across time and space, and variations in methodology are inevitable. Like the 'necessary' and 'corroborating' evidence categories, variations in evidence can best be understood only when all forms of data are considered.

Literary references

Necessary textual evidence for dye production

Roman textual descriptions refer to murex dye in any number of circumstances; the most useful for the purposes of identifying dye production sites are descriptions of snail collection, dye production, and variations in recipe and final product. This section will describe the snail collection process, how the dye was produced, and the relationship between snail species,

| Necessary Evidence for Dye Production | Textual Data | Experimental/Scientific Studies | Archaeological Evidence |
|--|--------------|---------------------------------|-------------------------|
| <i>Snails</i> | | | |
| Large amounts of shells in a midden/concentrated context | | | x |
| Confirmation of <i>Murex</i> snail species | x | x | x |
| <i>Dye Production Process</i> | | | |
| Vein extraction | x | x | |
| Dye mixing | x | x | |
| Heating | x | x | x |
| Specific production location (reference to location or particular environment) | x | x | x |
| Evidence of residue | x | x | F |
| <i>Dye Production Equipment</i> | | | |
| Pits, vats, and channels | x | x | x |
| Extraction tools | x | x | F |
| Light and oxygen controls | x | x | x |

Table 1. This table summarises the necessary evidence for dye production facilities, and which of the three datasets can yield evidence for these categories. Tools and residue are marked as 'F', meaning they are forms of evidence which could be argued as necessary proof for a dye production facility, but are not always feasible to recover during excavation, or while revisiting previously excavated materials. Extraction tools are misunderstood due to a misinterpretation of dye production facilities; in the case of residue, excavation and preservation methods can often prevent retrieval. Arguably, even if there is a lack of evidence for either of these features, but the other six forms of archaeological evidence are present, a dye production site can feasibly be identified.



| Corroborating Evidence for Dye Production | Textual Data | Experimental/Scientific Studies | Archaeological Evidence |
|---|--------------|---------------------------------|-------------------------|
| <i>Snails</i> | | | |
| Catching Snails | x | x | |
| Shells in a non-dye related context | | | x |
| Shell treatment (crushed, holes) | x | x | x |
| <i>Dye Production Equipment</i> | | | |
| Metal vessel | x | x | |
| Clay vessels/pottery | x | x | x |

Table 2. This table summarises corroborating evidence for dye production. In this analysis, sites which possess primarily corroborating forms of evidence are identified as ‘possible’ dye production sites until further investigations can be made.

| Variable (“Problematic”) Evidence for Dye Production | Textual Data | Experimental/Scientific Studies | Archaeological Evidence |
|--|--------------|---------------------------------|-------------------------|
| <i>Snails</i> | | | |
| Variations in species | x | x | x |
| Variations in final product colour | x | x | |
| <i>Dye Production Equipment</i> | | | |
| Evidence of non-mollusk ingredients | x | | x |

Table 3. This table summarises problematic evidence for identifying dye production. This evidence is considered problematic because it highlights the enormous degree of variation that can be found in various texts, in experiments or at sites – problematic evidence should not be interpreted as a reason for disregarding the possibility that dye production occurred at any given location. In the case of “variations of final product colour,” this form of evidence is confirmed in both textual and experimental studies. Archaeologically, this evidence is difficult to find, with the exception of textiles. These artefacts, however, have not been included in the catalogue because their find spots are more likely linked to consumption of goods, not production.

colour and region – arguably the most complex piece of textual evidence.

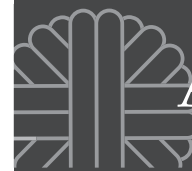
According to Pliny (*Hist. Nat.* 9.61 ff.), the carnivorous snails were caught in baited baskets. Because the dye would dry out when the snail died, dye extraction needed to occur within a 50-day period, during which the snails could stay alive using their own saliva. No descriptions of storage facilities are offered, however. The hypobranchial vein was then removed from the snail. No clarification is given by Pliny as to whether the snail was pulled from the shell or the shell was crushed. Vitruvius (17.3.2) suggests that the snails were crushed with iron (*ferramentis*) tools. We do not know how it was extracted, but the vein was then soaked in salted water for three days at the most. Alkaline-based boiling proceeded in lead¹ vessels over a moderate heat: “[the dye] is heated by means of moderate heat and brought to a separate kiln via a pipe” (Pliny, *Hist. Nat.* 9.70).²

After a maximum of ten days (or until the colour of the dye had reached a satisfactory shade), cloth (for the Romans, most likely wool) was dipped into the dye. The cloth had to be soaked for five days at least, the length of time dependent on the type of mixtures used with the murex.³ The dyed cloth would then be exposed to sunlight to trigger the dyeing colour (Pliny, *Hist. Nat.* 9.70; Vitruvius 17.3.2 ff.).

Corroborating and problematic textual evidence for dye production

From the ancient sources we have an excellent understanding of how intricate the dyeing process was. Changes to the recipe could result in any number of variations of colour; these intricacies are simultaneously the value and the quandary of this particular dataset.

Interpreting murex dye production evidence is inevitably linked to an understanding of the dye’s



social value – the social value was linked to its colour. According to Vitruvius (17.3.2 ff.), the various shades of dye produced were a result of regional variations in sun exposure. Eastern and western regions of the Mediterranean would have blueish hues, while the south would have had a reddish tint. The northern regions like Pontis and Gallia would be *atrum*, or black. Because Tyrian purple was the most valued type, we infer it was recognisable by its shade – this was actually a deep blood-red colour (Pliny, *Hist. Nat.* 9.62.38), and not our modern idea of purple.

Variations in colour could be a result of sun exposure, but snail species were a major factor as well. Pliny refers to *Purpura*, *Buccinum* and *Pelagia* snails being used throughout his text (Pliny, *Hist. Nat.* 9.68). If *Buccinum* was the only dyeing agent employed, the fabric would be an inferior quality because it is not colourfast. In order to resolve this issue, he claims that the ideal mixture was 50 pounds of wool, 200 pounds of *Buccinum* juice, and 111 pounds of *Pelagio*. By adding the *Pelagio*, the dye became colourfast, and it added a crimson-like hue. The coveted Tyrian colour was also made with these ingredients, but it was double-dipped – the wool was first soaked in the *Pelagio* and then the *Buccinum* (Pliny, *Hist. Nat.* 9.70 ff.).

Link these snail types to modern species is problematic, in part because of inconsistencies in Pliny's text, in addition to a lack of detail by other ancient authors (Bostock and Riley 1855, 9.70 note 1). The variable relationships between colour and the snail species used will be discussed more thoroughly in the next section, which presents contemporary experimental attempts to recreate the dye.

Experimental and scientific evidence

Necessary experimental/scientific evidence for dye production

Scholars who have attempted to recreate the dye have made great strides in demonstrating which portions of the ancient sources are accurate or inaccurate, and have made clarifications of the dye manufacturing environment. This can help to clarify the physical evidence that archaeologists have identified. As a result, it is more effective to discuss experimental recreations of dye prior to describing presently-known archaeological remains of the industry.

Ruscillo (2006, 811-815) tested several methods of snail collection and dye creation in order to verify and better understand the recipes mentioned in textual accounts. As a result of these studies, valuable data is available describing the number of snails needed to make the dye. Baited baskets were left in shallow water, and managed to both trap snails and attract others for hand collection. Without baited baskets,

hand collection reduces the collection rate of 100 snails per hour by 70 %. Dropping baskets off a boat was also less efficient, yielding about 30-50 snails, though the length of time this took was not specified.

A 125 cm² piece of wool textile was tested using dye made from the snail collection. In order to achieve a full coverage of dye, 200 murex snails were needed; it was estimated that 5000 snails would be needed to dye a single cloak. Koren (2005, 138-143) recorded similar data, determining that one gram of unwoven wool could be dyed with only three snails, though it was commented that the colour was quite light, and was not a reflection of the dye qualities mentioned by Pliny.

Gland extraction was also tested during these experiments because textual descriptions are limited. Koren (2005, 140) intentionally crushed the snails with a hammer in order to puncture the gland, and placed the snail and shell in a jar to collect the dye. Ruscillo (2006, 813) used a brass pointed tool and a hard stone to break open the shells. When a hammer and the pointed tool were used to make a hole in the shell beforehand, the process was much easier, and also enabled a controlled break to be made and prevent the gland from being broken.

Environmental regulations were necessary during the process. Ruscillo (2005, 104-105) tested several heating methods, and found that boiling actually damaged the dye. She tested several forms of water (salt, fresh, mixed with various additives, *etc.*) and found that maintaining an eight-degree Celsius temperature for three days helped to steep the dye and made sieving much easier.

Modern experiments have demonstrated how sensitive the mixture was to light exposure and oxidation; too much light or oxygen during the dyeing process could severely alter the final shade. When cloth is initially dipped into murex dye, it turns green; not until intentional and regulated exposure to light and oxygen does the dyed cloth turn from green to purple. Cooksey (2009, 176-177) showed that overexposure of the dye mixture *prior* to the cloth being dipped creates a purple hue that is very different from the blood-red goal described. Modern Tekhelet cloth, for example, is very different from the 'Tyrian ideal' indicated in texts; this murex-based dye is blue-purple. The difference in colouration is a result of intentional exposure to light and oxygen for a lengthy period of time (Hoffman *et al.* 2010, 89) (Fig. 1).

Corroborating and problematic experimental/scientific evidence for dye production

While the textual and experimental data confirm the importance of heating the mixture, it is difficult to



determine whether metal or clay vessels were used. One of the most popular translations of Pliny's "*fevere in plumbo*" refers to being "boiled in lead" (Bostock and Riley 1855, 9.70). Experimental studies focused on recreating the dye have attempted to decipher what 'lead' actually refers to, and whether the material was a necessary chemical component. Doumet (1980, 47) explained that Pliny might have been referring to 'white lead' or Roman tin.

Koren (2005, 139-142) recognised the necessity for an alkaline reaction, but questioned whether the alkaline needed to be supplied by the vessel itself. His experiments proved that the addition of sodium carbonate, plant/wood ash or lime into a clay pot achieved the same reduction process as would a metal vessel. Many sites listed in the following catalogue indicate evidence for pottery, but confirming whether this pottery was used specifically for dye production would necessitate residue analysis. As for the lack of metal vessels, it is entirely possible these were melted and reused. While these experiments are able to confirm whether the recipes were accurately recorded, they also highlight the huge range of possible shades, and in turn, how difficult these variations can be to identify in the archaeological record.

As mentioned, Pliny references a variety of snail species (murex included), which could produce a purple hue. According to the texts, we can confirm that murex species, specifically *Hexaplex trunculus* L., *Bolinus brandaris* L. and *Stramonita haemastoma* L. were used to create a dye which could be considered real 'Tyrian Purple' (Koren 2005, 137). Kenrick (1855, 239) argues that *Pelagia* is *Murex trunculus*, and *Buccinum* is likely *Nucella lapillus* or 'Dog Whelk' (called *Buccinum lapillus* by Linnaeus). *Pelagia* could also be referring to *Murex brandaris* or *Murex tribulus* (Struck 2009). According to Ziderman (2008, 40), *Pelagia* could be a general reference for murex species that bore purple. Rawlinson (1889, 46) argues that Pliny's *Buccinum* could be referring to any number of snails: *Murex trunculus*, *Murex/Bolinus brandaris* or *Helix ianthina*. The *trunculus* and *brandaris* species are closely related; the *brandaris* is more common on the Phoenician coast. Despite its commonality, he argues that "it is unlikely that the ancients regarded it as a different shell from *Murex trunculus*."

Alternative, non-murex species should also be mentioned. These snails could produce similar shades, but were not colourfast, and therefore made an inferior product. *Helix ianthina* L. is an example. It produced violet dye and is believed to have been used in the eastern Mediterranean. Evidence of its usage has been found at Beirut and Tyre (Jensen 1963, 105). Chemical analysis, particularly High Performance

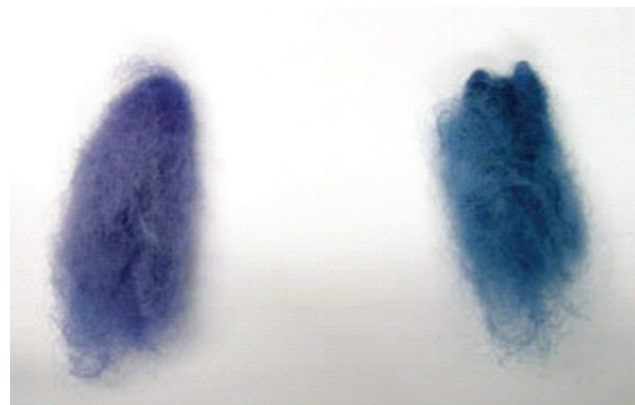


Fig. 1. Wool dyed with *Murex trunculus*, demonstrating that lengthened exposure to light will result in a bluer shade (After: Hoffman *et al.* 2010, 893).

Liquid Chromatography (HPLC), performed on the dye and paint pigments found can help to identify the ingredients used. Realising the variation that could occur, Koren (2007) analysed the pigment secretions from several *Hexaplex trunculus* L. snails from Israel, Spain and Italy. Isolating the different chemical signatures of these snails demonstrated that variation in composition as well as hue was possible across the same species; they ranged from reddish purple to violet. These variations are due to differing amounts of red or blue colourants in the pigment itself; these observations were made prior to any dye process being implemented (Koren 2007, 388).

Bolinus brandaris L. and *Stramonita haemastoma* L. are nearly indistinguishable from one another via HPLC analysis. The 6,6' -dibromoindigotin levels of both species will peak at about 60%, and unlike *Hexaplex trunculus* L., both have high levels of 6-bromoisatin (Koren 2007, 388-389). Another study (Karapanagiotis *et al.* 2013, 78) describes similar results, but was unable to distinguish *Bolinus brandaris* L. and *Stramonita haemastoma* L. from one another using both Principal Component Analysis and HPLC. In other words, though we have textual references to types of snail species used to create the dye, and though it is possible to isolate species types via residue analysis, there is still a huge lack of understanding about exactly which snail types would have been used, in what amounts, and in what regions.

Additives could be incorporated to alter the colour of the dye, including urine and a variety of plants and berries (Jensen 1963, 108-111). Kermes was also popular for its red-coloured shade, though thousands of these insects were needed, and they were nearly as expensive as murex (Cardon *et al.* 2011, 202-203).



Currently, the incorporation of these additives is a popular topic of debate in studies that chemically analyse ancient dyes, with questions as to how the additives may have reduced or increased the value of the product, as well as possible other snail species that could have been used. While analyses of residues and textiles are contributing to our understanding of how the dye was made, they simultaneously complicate our understanding by highlighting the intricacies and possible variety (Koren 1999, 2005; Cardon *et al.* 2011).

Archaeological evidence

Necessary archaeological evidence for dye production

Textual evidence highlights the types of equipment, materials and environments necessary to create purple dye; the experimental evidence confirms these features' utility. These datasets also demonstrate the variations possible, which can therefore lead to misunderstandings of the archaeological record. In this section, the archaeological evidence which is confirmed as 'necessary' will be discussed, in addition to corroborating and problematic evidence.

Murex dye facilities were often constructed away from residential areas because of the noted unpleasant smell, confirmed by contemporary experimental projects as well as nearly every ancient text mentioning dye manufacture (Cooksey 2013, 178). Facility features include vats, water sources and cisterns in open courtyards, in addition to associated burned contexts. Aforementioned sensitivities to oxygen and light exposure mean that the Roman period dyeing facilities and equipment would have needed mechanisms to protect against overexposure. Excavations have been able to confirm equipment similar to what Pliny describes, specifically sites with vats of varying sizes at the mouth, connected with channels and holes. According to Sagona (1999, 39), "while the channels obviously imply the flow of fluids into the vat, the smaller holes to the side might be to vent gases from the vat without allowing too much light or air into the chamber." She also argues that more awareness should be given to the possibility for overhead roofing systems and walls, which could have helped to monitor the oxygen exposure.

Corroborating and problematic archaeological evidence for dye production

While these features are *necessary* for murex dye production, they should be considered cautiously and in conjunction with all other available evidence. Cuicul (present day Wilaya, Algeria) demonstrates the difficulty in identifying murex production in the archaeological record. At Cuicul, heating sources and vats were found, which are confirmed in this study

as 'necessary' evidence, on the basis of textual and scientific data. The archaeologists also identified a yellow liquid deposit found in context with these vats as secretions of murex snails prior to processing. Despite these features, there are many problems with identifying Cuicul as a dye production site. The residue was never chemically analysed, and the 'dyeing facilities' (found in an altered bath house) have no traces of murex shells. According to Wilson (2004, 158) the vats and heating systems could be evidence of plant-based dye manufacture.

Wilson's caution that a lack of murex shells at Cuicul means that no murex dye installation can be *definitively* identified is valid. His argument can be countered, however: could the shells have been moved? Should the site be identified as a production site using 'indirect evidence', according to the typology presented by Alberti (2008, 75), or should it be dismissed, as Wilson suggests? Some scholars have attested that shells are *required* evidence (Spanier and Karmon 1987, 171-191); or "the most important" evidence (Alberti 2008, 74). While these are reasonable assumptions, particularly on the basis of the data published by Koren (2006) and Ruscillo (2005), we should investigate all available possibilities.

Murex shells found in large numbers should be considered necessary for confirming production occurred there, but careful consideration should be given to why there may be a small cache of shells, or none at all. Smaller amounts of shells could be evidence for the variations in recipes implemented at any given location. As demonstrated by Koren (2005, 138-143), a small number of snails *could* dye a piece of wool, but the final product would be a light colour. Small amounts of shells are also possibly an indication for non-dyeing activities (Alfaro Giner and Costa Ribas 2008, 198). For example, the 17 murex snail shells found at the gardens in the Villa Livia at Rome were likely used to decorate the garden wall niches, not to dye fabric (Pinto-Guillaume 2002, 44). The snails are also edible – they are discussed in contemporary recipes (Lovell 1867, 134), in archaeological cooking contexts (Jensen 1963, 106; Marzano 2013, 148) and in ancient texts. Macrobius (3.13.12), for example, describes a dinner hosted by Caesar that included murex snails.

Thinking back to our Cuicul example, a lack of shells could be proof of recycling for lime plaster (Dix 1982, 331). The large murex middens at Meninx (Djerba), for example, were cut into, likely to harvest shells for plaster production (Wilson 2004, 161). Such a site demonstrates that the number of shells found in a context, even if related to dye production, could change. Much like the process of understanding dye



production, placing lime manufacture necessitates finding the materials and the facilities. Berenice (Libya) is an excellent example. Large murex middens are found outside of the city walls. Although poor-quality kilns and ovens were found within the city, archaeologists believe that they were used for lime production using recycled murex shells. Murex dye manufacture facilities would likely not be so close to a residential area, and would have needed better-quality equipment (Reese 1980, 89).

A lack of murex shells still means that a 'definitive' label is problematic. Without the shells physically present in conjunction with features related to dye production, the vats, pits and heating sources could be evidence for another form of production. Similarly, a large pile of murex shells found in isolation could be indirect evidence for production (Alberti 2008, 76), but we cannot apply a 'definitive' label – the shells could have been moved.

Catalogue of (possible) Roman-period dye sites

According to the above-mentioned criteria, evidence for murex dye production can be identified as 'necessary' or 'corroborating', and grouped according to what datasets most likely reveal such evidence. Archaeological studies can therefore confirm six of the ten evidence types necessary for murex dye production:

1. Large amounts of shells in a midden or concentrated context
2. Confirmation of murex snail species
3. Evidence of heating
4. A specified production area
5. Pits, vats and channels
6. Sunlight and oxygen controls

In consideration of the identified 'necessary' (Table 1) and 'corroborating' (Table 2) evidence categories, several sites previously related to murex dye production were studied. Eighteen sites are included here (Fig. 2), grouped into 'definitive' and 'possible' sites. The 'definitive' sites have examples of each of the six forms of evidence; 'possible' sites do not have all

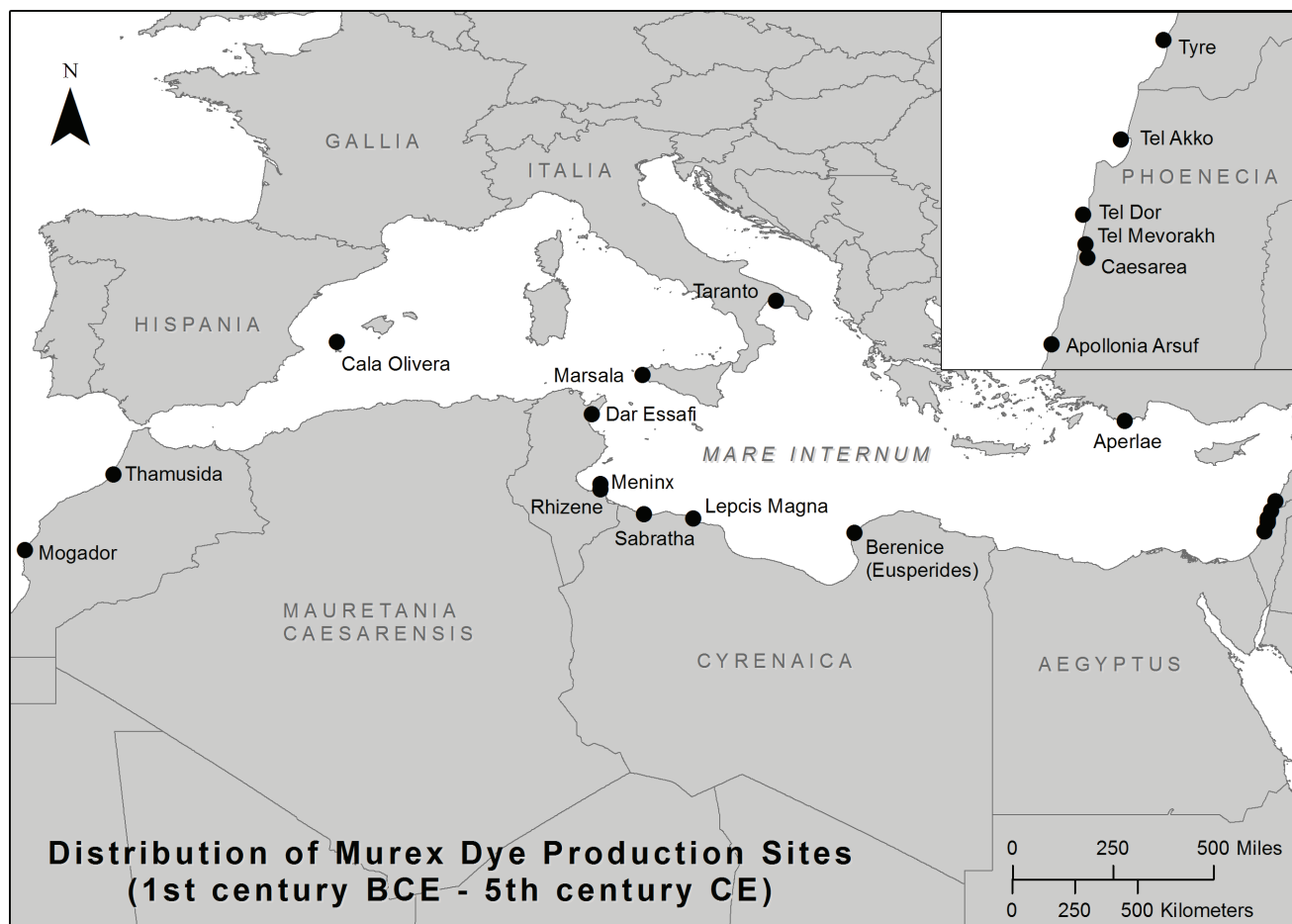


Fig. 2. Map of murex dye production sites (Map: Natalie Susmann).



evidence types, but demonstrate enough promise that further study could prove otherwise.

Using this catalogue in conjunction with the multi-data analysis proposed here, the extreme degree of variability becomes clear – while the evidence for snails, dye production processes or dye production equipment may be present, they manifest themselves in very different ways. The possible dye production sites that are presented here are limited to the constraints of my own research, the complexities of stratigraphy and the dating of materials, and the available details of published excavation reports. As more sites are identified, either via retroactive investigation or through further excavation, additions to the catalogue are to be expected.

Definitive production sites:

1.1 Apollonia Arsuf, Israel (32.17364, 34.803485)

Date: Mid 5th century BCE - late 1st century BCE
(RO⁴: mid – late 1st century BCE)

Source: Karmon 1999

Snails: Murex concentrations are found within the ancient urban city, in areas H and D, dating to the 4th century BCE - 1st century BCE. Roman occupation indicates that loci 1514, 1515, and 1517 were areas of dye manufacture.

Evidence for dye production processes and equipment: Large pits were also found near the shells in these areas. Crushed shells were found together with burnt ash and other burnt organic materials, as well as pottery sherds (Karmon 1999, 278).

1.2 Cala Olivera, Ibiza (38.988268, 1.411908)

Date: 2nd century BCE – first half of 3rd century CE

Source: Alfaro Giner and Costa Ribas 2008

Snails: There is a large shell mound measuring 8 x 4 m, protected by a now-collapsed rock shelter with roof. At least 62% of the snail species present were *Murex trunculus*. Many other uncrushed snails were found in the mound, which were hypothesised as being used for bait for fishing for the carnivorous murex (Alfaro Giner and Costa Ribas 2008, 204-205).

Evidence for Dye Production Processes and Equipment: There appears to be a retaining wall constructed for the shell dump after its initial development. Heating evidence is mixed with the sherds associated with the retaining wall. It is believed that the fire was kept consistently burning for dye production. This workshop is seen as a small-scale operation with portable containers, not permanent vats (Alfaro Giner and Costa Ribas 2008, 202-203).

1.3 Tel Dor, Israel (32.64131, 34.918620)

Date: Late 4th century BCE – mid 1st century CE
(RO: mid 1st century BCE – mid 1st century CE)

Source: Reese 2010

Snails: Murex shells were found in dye contexts, as well as in a construction fill dated to the late 1st century BCE.

Evidence for dye production processes and equipment: A pit was found in area A, completely filled with crushed murex shells. The top of the pit was lined with stones. It was connected to another pit via a 2 m long channel. This second pit was located near a third, as well as a small, square, plaster and stone-lined basin. Purple material was found in the channel, the basin, and the second pit, as was the surrounding soil. Evidence of heating was also found in the area (Reese 2010, 134-135).

Possible production sites:

2.1 Tel Akko, Israel (32.91154, 35.053753)

Date: Late 2nd century BCE – mid 1st century CE
(RO: mid 1st century BCE – mid 1st century CE)

Source: Spanier and Karmon 1987; Reese 2010

Snails: Large amounts of crushed murex were found together with waterproofed, thickened wall vessels.

Evidence for dye production processes and equipment: The vessels, dating in the period from the 13th to the early 12th century BCE, were found with only murex crushed shells and their residues, and are therefore believed to have been used to create the dye. Later occupation layers are thick, mixed with ash and shells, and as such are possibly evidence for heating dye. Roman-period murex activities are identified by large amounts of crushed shells in area H and a plastered basin (Reese 2010, 121). There is no Roman evidence for heating, therefore justifying the designation as a 'Type 2' site. Karmon and Spanier (1987, 153) comment that the lack of decorative pottery in this area could be evidence of industrial work occurring here.

2.2 Aperlae, Turkey (36.15861, 29.783611)

Date: Late 3rd/early 4th century CE – ?

Source: Hohlfelder and Vann 2000

Snails: The town has large middens of crushed murex shells covering a total area of 1600 square metres. A 'conservative estimate' of the number of shells would surpass hundreds of thousands.

Evidence for dye production processes and equipment: Possible holding tanks are also present, likely for keeping the snails alive before dye was harvested. The holding tanks are quite clearly Roman in construction, and bricks, a hydraulic mortar enclosing a ceramic tile floor, and cobblestones date to the 4th century CE (Hohlfelder and Vann 2000, 132).



2.3 Caesarea, Israel (32.48573, 34.34123)

Date: Late 3rd/early 4th century CE – ?

Source: Levine 1975

Snails: The *Targum Jonathan* references murex at Caesarea. Levine (1975, 52) translates the passage thus: “they shall take joy in the *Murex* and from its blood they will dye their fabrics a purple color.” The Caesarean Talmud and *Expositio* mention the industry in the city as well. Levine (1975, 53) claims that “special pools for the preparation process existed in Caesarea, and regulations were enforced to keep them sufficiently removed from other buildings because of their stench.”

2.4 Dar Essafi, Tunisia (36.39439, 10.621752)

Date: Mid 2nd century BCE – late 2nd century BCE

Source: Sagona 1999; Wilson 2004

Snails: Several large crushed murex middens were located near the town’s small harbour (Wilson 2004, 162).

Additional notes: There are also sites nearby which have earlier evidence of dye production, suggesting possible murex production in the so-called ‘prehistoric’ period. Tas-Silg, two kilometres away, has large middens of crushed shells (Sagona 1999, 35).

2.5 Euesperides/Berenice, Libya [Sidi Khrebish, Benghazi] (32.12485, 20.063571)

Date: Late 4th/early 3rd century BCE – mid 5th century CE (RO mid 1st century BCE – mid 5th century CE)

Source: Reese 1980; Wilson 2002, 2004

Snails: At Euesperides (Berenice’s predecessor town), large spreads and dumps of shells were found in the southern part of the city. The location of the dumps varies; some were found in a burnt state in the courtyard of a building with dye-specific architecture; others were found across the city, suggesting the shells were recycled for street surfacing (Wilson 2004, 161). About 95% of the spreads were confirmed to be murex-specific, and the presence of other types of species in the midden is arguably accidental. The shells were completely crushed, suggesting that the gland would not have been removed intact from the snail. Instead, it is likely that the crushed snail body and shell were heated together (Megías and Wilson 2008, 57-58). At Berenice, Euesperides’ Roman successor, Wilson (2004, 162) confirms there are large middens of murex shells present in unexcavated areas, so numerous that it suggests murex dye production continued to play a major economic role.

Evidence for dye production processes and equipment: Archaeologists argue that the magnetometric evidence of burning at Euesperides is an indication for furnaces and hearths (Megías and Wilson 2008,

57), which are necessary for murex dye manufacture. Yellow staining is further evidence for snails having been dumped there (Wilson 2004, 161). Archaeologists agree that murex dye production would have occurred at Berenice as a result of the clear evidence for earlier production activities at Euesperides. That being said, no production facilities have been found that can clearly be associated with the Roman period (Wilson 2002, 255). Until confirmed Roman-period architectural evidence for production is found, the site remains ‘possible.’

2.6 Lepcis Magna, Libya (32.64972, 14.264444)

Date: Late 1st/early 2nd century CE – late 3rd/early 4th century CE

Source: Wilson 2002

Snails: Crushed murex shells are mixed into the mortar of structures dating to the 2nd and 3rd centuries CE, including the foundations of the cistern and *castellum* adjoining the Chalcidicum fountain, in the external mortar of the large cisterns located behind the Hadrianic bath latrines, and in the ground near the Arch of Tiberius. It is assumed that the significant amount of crushed shells is direct evidence for a dyeing industry, one which recycled the byproducts for construction material. Architectural features or equipment relating to dye processing have yet to be found (Wilson 2002, 255).

2.7 Marsala, Italy (37.79908, 12.434233)

Date: Mid 3rd century BCE – ?

Source: Cassiodorus; Gleba 2008

Textual: The ancient site (Hydron) was referenced in Cassiodorus’ *Variae* as the Italian equivalent of Tyre for its flourishing textile and dye production: “If the Hydruntum diver had searched for the crushed conches of sea at a suitable time, that Neptunian harvest, always generating a flourishing purple harvest, mixed with copious amounts of water, would have released the flaming liquid which showers the princely robes adorning the thrones” (Cassiodorus 1.2.2).

Roman coins depicting *Muricidae* have been interpreted as evidence that the region was engaged in murex dye industries in some way, either by way of supplying the snails, or in manufacture of the dye (Gleba 2008, 81).

2.8 Meninx [Jerba], Tunisia (33.68582, 10.922214)

Date: Early 5th century BCE – late 1st/early 2nd century CE (RO: mid 2nd century BCE – late 1st/early 2nd century CE)

Source: Strabo; Wilson 2002, 2004

Snails: The large midden is 540 m long, 340 m wide



and 3 m high, with later evidence of quarrying for lime mortar. Mau wine vessels dated to the 1st/2nd centuries CE were found broken in the midden.

Evidence for dye production processes and equipment: Early mentions of purple dye manufacturing at Meninx were made by Strabo (17.3-18), who refers specifically to purple and salting factories found at Syrtis, a small city. Archaeological evidence for Roman-period dye production is indicated by the mixture of crushed murex and large ash dumps (Wilson 2004, 161). Previous research has identified cisterns near the ash dumps (Wilson 2002, 249).

Although these cisterns are large enough to accommodate murex dye production, they are identical in design to domestic rainwater cisterns found in other sectors of the site, as well as in North Africa generally. Additionally, Wilson (2004, 161) is hesitant to link the cisterns to dye production because of the lack of “durable or permanent” dye-related structures or vats. Still, it is unlikely that such a large murex dump accumulated just for lime manufacture. The location of the dye manufacture is unknown, but the byproducts are a strong indicator of dye production somewhere in the vicinity.

2.9 Tel Mevorakh, Israel (32.53381, 34.926831)

Date: Late 4th/early 3rd century BCE – ? (RO: mid 1st century BCE – ?)

Source: Stern 1978

Snails: Large middens of murex shells

Evidence for dye production processes and equipment: A 4th/3rd-century BCE vat made from a hollowed-out block of limestone is assumed to be evidence of dyeing installations. The vat has a chiseled groove running along approximately two thirds of its rim. Three holes are evenly spaced between the groove and the inner basin. This vat is similar in design to those found at other clear dye production sites: Judah and Ain Shems in Palestine, and Tell Beit Mirsim, Tell en-Nasbeh, Bethel and Gezer in Israel. However, these earlier vats are closed at the top. No evidence of heating was found (Stern 1978, 24).

2.10 Mogador [Cerne], Morocco (31.512501, 9.770005)

Date: Late 1st century BCE – early 1st century CE

Source: Euzennat 1976; Edens 1999

Snails: Many large middens have been found near Essaouira (modern Mogador) with murex shells, as well as with *Purpura haemostoma* (a species mixed with murex dye to create cheaper imitations) (Euzennat 1976). There was a mixture of crushed and whole shells. Many of the whole shells have a single puncture mark in them (Edens 1999, 83).⁵

2.11 Rhizene, Tunisia (33.874943, 10.926486)

Date: Mid 2nd century BCE – late 1st/early 1st century CE

Source: Slim *et al.* 2004

Snails: Murex shells have been found in massive quantities at the site, near the coastline (Slim *et al.* 2004, 101).

2.12 Sabratha, Libya (32.79194, 12.484722)

Date: Mid 2nd century BCE – early 4th century CE

Source: Wilson 1999, 2002

Snails: The town has several large buildings with floors covered in murex shells dating to the 2nd-3rd century CE. These buildings include the House of Leda, the House of the Swan, the floor near the Seaward Baths, and the floor north of the theatre. The shells are believed to be an indication recycling after dye production took place elsewhere. Wilson states that the dye industry ended in around 300 CE, proven by the fill in a well near Mausoleum A. A number of murex shells were found in the fill, which appeared to have artificial holes (Wilson 1999, 42-44).

Evidence for dye production processes and equipment: A series of vats have been found at the site, 1-2 m wide and 1 m deep. The smaller, circular vats at the site could have been used for dye production because they are lined with waterproof mortar (Wilson 2002, 242). Because of the cost of murex dye, it is possible that the small size of these vats is appropriate, as they could have been used for “An expensive dyestuff or color not normally used for dyeing whole garments” (Wilson 1999, 46). Larger vats at Sabratha have been disregarded as dye vats because of their size, and were likely used for fish salting. It has also been suggested that the small vats mentioned above were used for *garum* production (Wilson 2002, 242).

2.13 Taranto [Tarentum], Italy (40.46923, 17.24000)

Date: Late 3rd century BCE – early 4th century CE

Source: Silver 1997; Gleba 2008; Pliny, *Hist. Nat.*

Snails: Dye workshops are believed to have been located on the coast, as indicated by the large middens of murex shells (Gleba 2008, 197) now referred to as ‘Monte Testacea’ (Silver 1997, 254).

Additional notes: Pliny’s account of Cornelius Nepos’ youth confirms production here: “During my youth, he said, violet purple flourished, whose scale weighed 100 denarii, and not long after, the ruddy Tarentine (color). From here entered the double dyed Tyrian, which was not able to be freely purchased for 1000 denarii per pound” (Pliny, 9.63.39). Tarentine coinage designs depict shells, further emphasising the importance of the industry (Gleba 2008, 81).



2.14 Thamusida, Morocco (34.21854, -6.592132)

Date: Mid 1st century CE – mid 3rd century CE

Source: Wilson 2002, 2004

Snails: Large spreads of murex shells are present. The distance between the site and the ocean implies a substantial amount of manpower was necessary for this location to operate successfully. The snails would have been brought from the ocean and down the Oued Sebou River for processing at Thamusida (Wilson 2004, 162).

Evidence for dye production processes and equipment: Magnetometer surveys have revealed furnace/hearth areas beneath the shell spreads (Wilson 2002, 253).

2.15 Tyre, Lebanon (33.26985, 35.206942)

Date: Late 15th/early 14th century BCE – late 1st/early 2nd century CE (RO: mid 1st century BCE – late 1st/early 2nd century CE)

Source: Karmon and Spanier 1987; Reese 2007

Snails: Bronze Age dyeing occurred, demonstrated by the murex middens and round sandstone pits along the coast with crushed murex shells inside. Similar evidence has yet to be found associated with the Roman period.

Additional notes: Diocletian's Edict on Maximum Prices has direct references to the imperial manufacture at Tyre, which was a state monopoly in CE 383 (Reese 2007, 237). The edict also confirms that Tyre was exporting murex purple and imitations of the product (Karmon and Spanier 1987, 158). Other literary evidence includes the account in Strabo's *Geography* (16.2.23) that "the purple of Tyre was the best. The great number of dye works made the city smell unpleasant. Nevertheless, Tyre was rich and prosperous ..." (Hamilton *et al.* 1903).

Coins dating to the 1st century CE from Tyre have depictions of murex shells (Reese 2007, 237).

Discussion

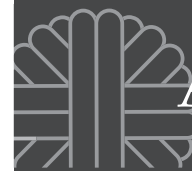
In order to decipher the production and consumption trends of murex dye, scholars need to be certain that the possible production sites should in fact be included in the sample set. In this particular catalogue, the 18 sites were identified because they possessed certain archaeological indicators for dye production: murex shells covering large concentrated areas, particular forms of equipment and evidence for heating. Via the discussions of textual and scientific data this study has clearly articulated the foremost difficulty in identifying production locations. Murex dye was a popular product used across the Mediterranean, which resulted in regional and temporal variations in ingredients used and methodologies applied. No single dataset can properly highlight these variations;

murex dye production studies should therefore be approached in an interdisciplinary manner.

It is for this reason that I have focused only on Roman-period production. Roman-period dye manufacture has associated textual and archaeological data, in addition to scientific studies attempting to recreate these environments. Despite this advantage over, for example, Bronze Age manufacture, complications are clearly present. Certain ancient authors provide specifics for certain points: Pliny makes no mention of crushing tools used, but Vitruvius does, emphasising the range of minutiae that can be considered.

For studies focusing on earlier periods where texts are not available, scholars have a greater challenge. They can only rely on the features that are manifest in the archaeological record, and the types of equipment and environment that have been confirmed to be necessary through experiments. No contemporary textual data is available, but like the Roman examples, evidence linked to dye production could also be related to other industries. At the Thessaloniki *toumba*, for example, while Bronze Age dye production evidence has been found (hearths and kilns, spindle whorls, and crushed murex shells), scholars caution this could be evidence for other activities. Specifically, it is difficult to identify production locations within the site. During the middle Bronze Age, the murex could have been used for cooking, and in later periods, dye production could have occurred in the house (Veropoulidou *et al.* 2008, 175-176). Classification of the evidence is therefore necessary and could help in discerning period- and region-specific production evidence.

Thinking about this Bronze Age example, the methodology presented here can be used as a stepping stone for future murex dye studies. The limitations imposed on the study provide immense value, in that they actualise intricacies in the process, as well as weaknesses and strengths of the dataset. By isolating the locations of production centres, future studies can focus on placing the economy in actual space: understanding regional variations in selecting snail species types and how this would affect the dye production process and product value, as well as how other production facilities, like lime factories, were linked to these locations (Alfaro Giner and Costa Ribas 2008, 198). A catalogue which organises and qualifies potential evidence of dye manufacture enables scholars to identify patterns and trends, and the locations can begin to be analysed as a collective unit, not merely as a scatter of isolated occurrences. Typological analysis of dye production, like that of any other product, will reveal the intricacies of the ancient Mediterranean economies.



Notes

1. This translation is often debated. The phrase *fevere in plumbo* (Pliny, *Hist. Nat.* 9.70) has been translated as “boiled in lead” by Bostock (1855), but *plumbo* could also be a reference to tin (Bostock and Riley 1855, 9.70; Doumet 1980, 47; Koren 2005, 139-142).
2. All Latin translations are my own.
3. The process was extremely odorous. Strabo (6.10) comments that Tyre, despite being rich as a result of its superior skill in dye production, was an extremely unpleasant city to live in.
4. Some sites have evidence of murex production prior to Roman occupation. The first date range encompasses earliest to latest activity, and the ‘RO’ indicates Roman-specific usage.
5. Whether murex shells are found whole or crushed varies, though the catalogue yields primarily crushed shells. Shells in middens are also often pierced with small holes. These holes could be evidence for an alternative vein extraction method, in which the vein was removed without crushing the shell. The holes could also be evidence of eating one another while being held in a tank prior to dyeing: by drilling a small hole into one via their radula, after which they push their proboscis through the hole to feed on flesh (Armstrong 2004, 1250). Recent excavations at Mount Zion have also revealed a large amount of murex snails associated with a mansion likely used by the elite priests. James Tabor argues that the punctures in the shells are an indication that they were strung and tied around vessel necks – this could have been a way of marking dye types or quality. Note that this site has not been included in the catalogue because Tabor believes there are too few shells to indicate production (Ngo 2013).

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