# nailos

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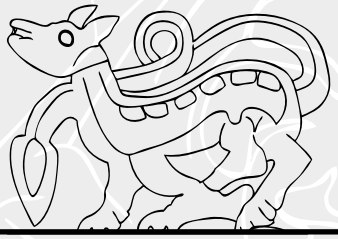




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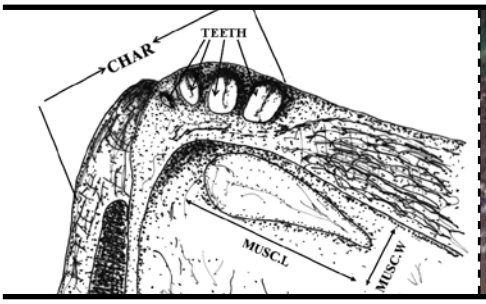
## Recensiones



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# Summary

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## Recensiones



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# Study and taxonomic identification of mussel shells found in five portuguese archaeological sites

Estudio e identificación taxonómica de las conchas de mejillón encontradas en cinco yacimientos arqueológicos portugueses

João Paulo S. Cabral y Cláudia Manso

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## Abstract

Mussel shells found in five Portuguese archaeological sites, dated from the Upper Paleolithic to the Roman period, were studied and identified at species level using a set of morphometric variables and a reference collection of modern shells. Results indicated that archaeological shells belong to *Mytilus galloprovincialis* Lamarck, 1819, the only mussel (*Mytilus*) today present in continental Portugal. It was concluded that in the Portuguese continental coast, the minimum seawater temperatures at about 11,000 BP and during the Magdalenian was probably not lower than 1.5-3.0°C in relation to today temperatures.

**Keywords:** shells; mussels; *Mytilus*; palaeoenvironment; archaeology; Portugal.

## Resumen

En este artículo se estudian las conchas de mejillón encontradas en cinco yacimientos arqueológicos portugueses, fechados desde el Paleolítico superior hasta el periodo romano. Para la identificación de la especie se ha recurrido a distintas variables morfométricas y a una colección de referencia de conchas modernas. Los resultados indican que las conchas arqueológicas pertenecen a *Mytilus galloprovincialis* Lamarck, 1819, única especie de mejillón (*Mytilus*) presente hoy en la Portugal continental. Se concluye que en la costa continental portuguesa, las temperaturas mínimas del agua del mar hace aproximadamente 11.000 años BP y durante el Magdaleniense, probablemente no fueron inferiores a 1,5-3,0°C respecto a las temperaturas actuales.

**Palabras clave:** conchas; mejillón; *Mytilus*; paleoambiente; arqueología; Portugal.

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## 1. Introduction

Due to their fragility, the presence of mussel shells in archaeological contexts is relatively scarce. When they appear, are frequently fragmented, making their morphometric study and taxonomic identification difficult. These observations apply to Portuguese archaeological sites, where mussel shells are not common, and are generally broken, very fragmented or badly preserved. To what species do they belong? The question is relevant because *Mytilus edulis* Linnaeus, 1758 and *Mytilus galloprovincialis* Lamarck, 1819, the two main mussel species presently found in European waters, have different ecological requirements and almost disjunctive distributions, the former living in cold seawaters and the latter in warmer waters. The identification of archaeological mussel shells may contribute to a reconstitution of the environment in the past.

*Mytilus* is represented in Europe by three species: *M. trossulus* Gould, 1850 is present only in Northern Europe (Väinölä and Strelkov 2011); *M. edulis* Linnaeus, 1758, a cold-temperate species, lives from the northern European waters to the French/Spanish border in the Bay of Biscay; *M. galloprovincialis* Lamarck, 1819 occurs from southern Ireland and Great Britain, and French (Atlantic) coast, to the Mediterranean (Fly *et al*. 2015; Kijewski et al. 2011). The distribution of *M. edulis* and *M. galloprovincialis* overlap in southern Britain and French Atlantic coasts, and in these areas hybridization can occur (Fly *et al*. 2015; Kijewski *et al*. 2011). Based on morphological and genetic data, Sanjuan *et al*. (1994) concluded that, at present, the only *Mytilus* species occurring in the Iberian Peninsula coasts is *M. galloprovincialis*. Recent guides and text-books on Portuguese and Spanish marine molluscs follow this assessment (Gofas *et al*. 2011; Macedo *et al*. 1998; Trigo *et al*. 2018).

*M. edulis* and *M. galloprovincialis* typical shells display different shape and color. *M. edulis* shell is narrow and of bluish tones, whereas that of *M. galloprovincialis* is broad and of dark colors (Figure 1). However, depending on local conditions, shell's shape and color can vary appreciably and the shells of the two species may be indistinguishable. This led to the search for other more consistent shell features. Work carried out by several researchers, in particular Gosling (1984), Groenenberg *et al*. (2011), McDonald *et al*. (1991), Sanjuan *et al*. (1994), Seed (1974) and Verduin (1979), which used morphological and genetic characteristics, allowed to conclude that the main morphological differences between the two species consist in the dimensions (relative to the length of the shell) of the hinge plate and of the anterior adductor muscle scar.

*Mytilus* lives on rocky substrates from the intertidal zone to infratidal levels, the animal being therefore submerged part or all of the time. Seawater temperature is the main factor that influences the global distribution of *M. edulis* and *M. galloprovincialis* in European waters, in particular the minimum (January-February) and maximum (August) seawater temperatures (Fly *et al*. 2015). *M. edulis* occurs in coastal waters with minimum and maximum seawater

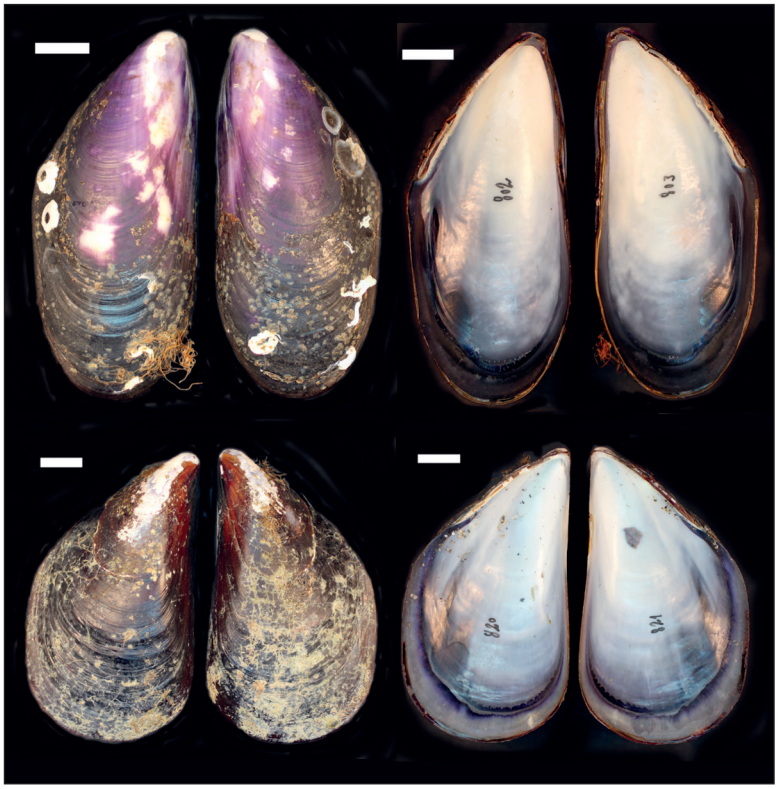

Figure 1. Typical modern *Mytilus edulis* (upper line) and *Mytilus galloprovincialis* (lower line) shells. Scale, 1 cm.

temperatures below 12°C and 22°-23°C, respectively, whereas *M. galloprovincalis* lives in areas with minimum and maximum seawater temperatures above 9°C and 15°C, respectively (Fly *et al.* 2015: figure 2).

At present, minimum and maximum seawater temperatures between Bilbao (northeast Atlantic Iberian Peninsula) and Huelva (southwest Atlantic Iberian Peninsula) are within the ranges 12.5°-15.5°C and 18°-23°C, respectively (Cabral and Simões 2007: figure 2 and 6) allowing the presence of *M. galloprovincalis* but not of *M. edulis*. In the Bay of Biscay seawater temperature in August can reach 23°C (Cabral and Simões 2007: figure 2 and 6) inhibiting the presence of *M. edulis*, but allowing the occurrence of *M. galloprovincalis*. Only in the French coast, northern to Hendaye-Biarritz, the maximum and minimum seawater temperature falls below 22.5°C and 12°C, respectively (Cabral and Simões 2007: figure 2 and 6), creating conditions for the growth and survival of *M. edulis* (Fly *et al.* 2015: figure 2). In the Portuguese continental coast, present seawater temperatures in February (minimum) are in the range 13.5°-15°C and in August (maximum) between 18.5° and 20°C (Cabral and Simões 2007: figure 2 and 6). The limiting

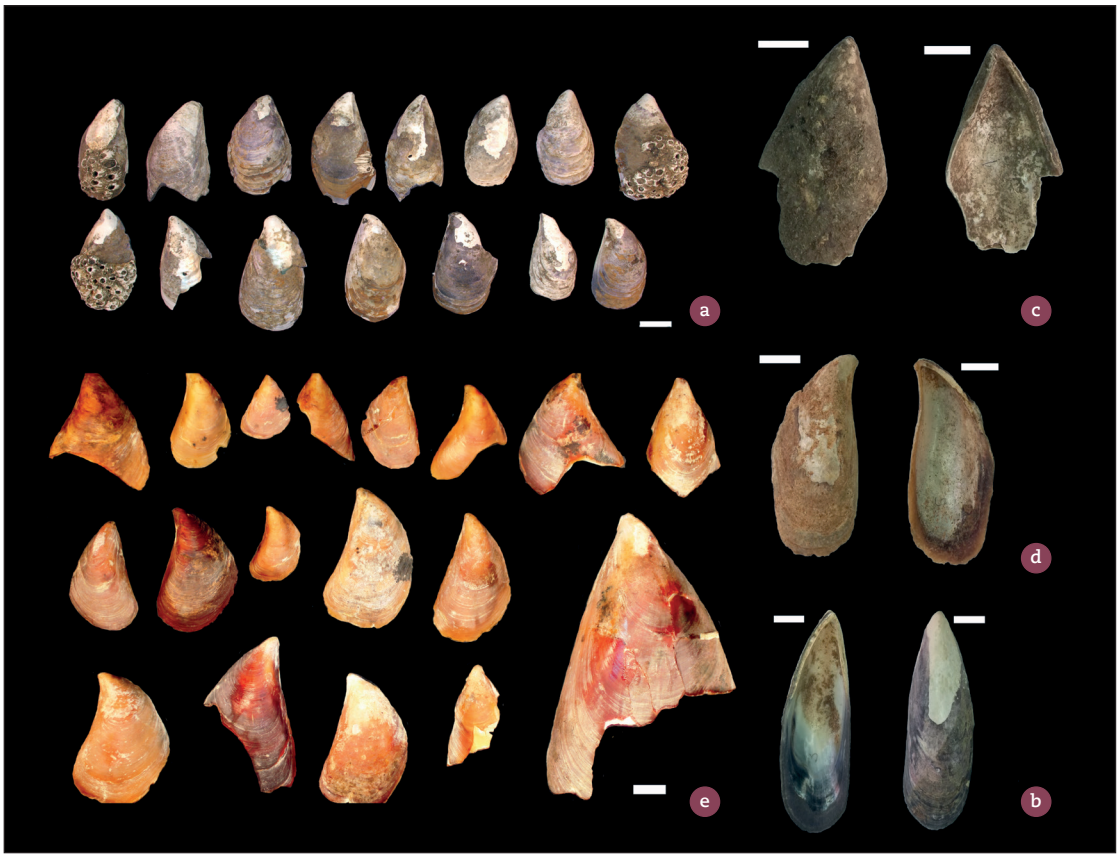


Figure 2. A selection of best-preserved archaeological *Mytilus* specimens studied in the present work. *Monumento da Bela Vista* (a), *Praia do Magoito* (b), *Tholos da Praia das Maçãs* (c), *Grutas do Poço Velho* (d) and *Lapa do Suão* (e). Scale, 1 cm.

factor for the presence of *M. edulis* in the Portuguese coast is therefore not the maximum seawater temperature, which does not exceed the maximum tolerable for this species (22°-23°C), but the minimum which does not go below 12°C, necessary for the presence of this mussel species.

## 2. Portuguese archaeological sites with *Mytilus* shells studied in the present work

We studied the mussels shells found in five archaeological sites, all located in the Portuguese Estremadura: *Monumento da Bela Vista* (BV), *Praia do Magoito*

(MAG), *Tholos da Praia das Maçãs* (PM), *Grutas do Poço Velho* (PV) and *Lapa do Suão* (LS). The location of the sites is presented in Figure 3 and indicated in the text as the *freguesia*, *concelho* and *distrito* where it belongs, as well as the CNS code according to the *Portal do Arqueólogo*[1]. All these shells are deposited in public state museums and are available for study. LS shells are in the Museu Municipal do Bombarral, and the others in the *Museu Geológico* (MG), *LNEG*, Lisbon.

| Stratigraphic insertion | Laboratory | Type of sample | Date BP | Date cal BC 2σ / Date cal BP 2σ* | Period/Phase |
|---|---|---|---|---|---|
| ***Monumento da Bela Vista*** **(BV)** | | | | | |
| - | - | - | Not available | Not available | - |
| ***Praia do Magoito*** **(MAG) (Daveau and Ramos-Pereira 1982; Soares 2003:95, table 1)** | | | | | |
| Inferior level (2) | GrN-11229 | Charcoal | 9,580±100 | Not available | Early Mesolithic |
| Inferior level (2) | ICEN-80 | *Mytilus* sp. | 9,970±70 | 9,230-8,650 BC | Early Mesolithic |
| Level III (Shell Midden) | ICEN-577 | *Mytilus* sp. | 9,880±80 | 9,210-8,550 | Early Mesolithic |
| Level A (location A) | ICEN-427 | *Mytilus* sp. | 4,690±60 | 3,100-2,700 | Late Neolithic |
| Level A (location A) | ICEN-540 | *Mytilus* sp. | 4,970±45 | 3,520-3,100 | Late Neolithic |
| ***Tholos da Praia das Maçãs*** **(PM) (Cardoso and Soares 1995:11)** | | | | | |
| Unspecified | OxA-5509 | Bone | 4,410±75 | 3,340-2,880 BC | Late Neolithic and/or Early Chalcolithic |
| Unspecified | OxA-5510 | Bone | 4,395±60 | 3,310-2,890 | Late Neolithic and/or Early Chalcolithic |
| ***Grutas do Poço Velho*** **(PV)** | | | | | |
| - | - | - | Not available | Not available | - |
| ***Lapa do Suão*** **(LS) (Bicho *et al.* 2011:8, table 1)** | | | | | |
| Level 6 | GX-27589 | Charcoal | 14,380±90 | 17,140-17,865 BP | Late Magdalenian |
| Level 7 | GX-27592 | Charcoal | 10,900±70 | 12,600-12,960 | Late Magdalenian |
| Level 7 | GX-27590 | Charcoal | 12,410±80 | 14,090-15,000 | Late Magdalenian |
| Level 8 | GX-27593 | Charcoal | 15,110±90 | 18,030-18,600 | Early and/or Middle Magdalenian |
| Level 9 | GX-27594 | Charcoal | 12,590±80 | 14,240-15,180 | Early and/or Middle Magdalenian |
| * Calibration curves are IntCal09 and Marine09 (Reimer *et al.* 2009). | | | | | |

Table 1. Radiocarbon dates and chronologies for the five archaeological sites studied in the present work.

1 https://arqueologia.patrimoniocultural.pt/index.php

## 2.1. Monumento da Bela Vista (BV)

The monument (megalithic tomb) of Bela Vista (Sintra, Sintra, Lisboa, CNS 19452) was studied in the 1950s by members of the *Serviços Geológicos de Portugal* and yielded materials corresponding to the Neo-Chalcolithic and Chalcolithic periods (Mello *et al*. 1961). Mollusc shells, including mussels studied in the present work (ref. MG, LNEG, 533.29.15.) were found in the last intervened layer (Mello *et al*. 1961). No $^{14}C$ dating of materials from this site has been published.

## 2.2. Praia do Magoito (MAG)

Magoito beach (São João das Lampas and Terrugem, Sintra, Lisboa, CNS 19467) archaeological sites were discovered and studied by H. Breuil and Georges Zbyszewski in the 1940s and 1950s. The first site contained a black deposit underneath a consolidated Wurmian dune, displaying «charcoals, ashes, stones burst into the fire» and shells of «*Mytilus galloprovincialis*, *Tapes decussata*, *Cardium edule*, *Scrobicularia plana*, *Patella coerulea*, *Littorina littorea*, *Balanus*» (Zbyszewski 1958:69). This shell deposit covered a yellowish layer that rested directly on the fossilized slope of the ancient valley (Zbyszewski 1958:69). A first radiocarbon date of charcoals was published by Daveau and Ramos-Pereira (1982) (Table 1, MAG, Inferior level (2) Charcoal). Subsequently, according to values published by Soares (2003), more radiocarbon dates for charcoals, and for *Mytilus*, *Patella* and *Cerastoderma edule* shells, would confirm that this site had an human occupation in the Early Mesolithic (Table 1, MAG, Inferior level (2) *Mytilus*, and Level III). A second site, containing «*Mytilus galloprovincialis*, *Cardium edule*, *Purpura haemastoma*, *Rumina decollata*» was found on the side of the Wurmian dune and was dated of the Neolithic or after (Zbyszewski 1958: 69). Radiocarbon dates for *Patella*, *Thais haemastoma* and *Mytilus* shells were interpreted as corresponding to two occupation periods, one more ancient, and another, more recent (Table 1, MAG, Level A), both corresponding to a Late Neolithic occupation (Soares 2003: 95, 97). In the present work we studied three mussel shells that were originally labeled (MG, LNEG): «*Praia do Magoito. Nível inferior*» (Magoito beach. Lower level) that should correspond to the black deposit of the first site.

## 2.3. Tholos da Praia das Maçãs (PM)

**This funerary monument, located at** *Praia das Maçãs* (Colares, Sintra, Lisboa, CNS 146), was firstly described by Machado (1929) who reported the presence of «shellfish shells». In 1961, a series of systematic excavations allowed the identification of a western chamber, several intermediate chambers, a *tholos* chamber and a corridor (Leisner *et al*. 1969: 16). Materials recovered by Gonçalves in 1979 led to the conclusion that the monument was erected and occupied in four cultural phases, from the Middle Neolithic to the Late Chalcolithic (Gonçalves 1982-1983). Radiocarbon dates of materials found in the western chamber


Figure 3. Location of the archaeological sites with *Mytilus* shells studied in the present work, in southwest Iberian Peninsula: *Monumento da Bela Vista* (BV), *Praia do Magoito* (MAG), *Tholos da Praia das Maçãs* (PM), *Grutas do Poço Velho* (PV) and *Lapa do Suão* (LS). Map made using Google Earth Pro.

(Table 1, PM, Unspecified levels) confirmed that this part of the monument was erected in the transition from the Late Neolithic to the Early Chalcolithic of the Portuguese Extremadura (Cardoso and Soares 1995). The construction of the *tholos* was probably carried out in the Late Neolithic or in the transition to the Early Chalcolithic (Gonçalves 1982-1983: 56). Mussel shells studied in the present work (ref. MG, LNEG, 316.388) were probably those found and described by Machado (1929). Later studies did not mention the finding of mollusc shells.

## 2.4. Grutas do Poço Velho (PV)

**The** *Poço Velho* Caves (Cascais and Estoril, Cascais, Lisboa, CNS 642) consist of a network of galleries at the base of a limestone cornice. Studied by Carlos Ribeiro in 1879, materials (including mollusc shells) were deposited in the *Museu Geológico, LNEG* and posteriorly studied by Estácio da Veiga and Afonso do Paço,

who assigned the materials to the Chalcolithic (Paço 1941; Paço *et al.* 1959). The set of mussel shells studied in the present work, originally labelled by Carlos Ribeiro («*Mytilus edulis, Linneu (exemplar incompleto). Proced: Cascais*») has no stratigraphic record. No $^{14}$C dating of materials from this site has been published.

### 2.5. Lapa do Suão (LS)

*Lapa do Suão* cave (Roliça, Bombarral, Leiria, CNS 44) is composed of a corridor (23 meters long and 2.5 meters wide) and two terminal rooms. Initially studied by Carlos Ribeiro in the 19th century, the cave was later excavated by António dos Santos Rocha and Artur Salles Henriques in the early 20th century, followed (between 1963-1968 and 1970) by a group of local amateurs guided by Georges Zbyszewski and Octávio da Veiga Ferreira of the *Serviços Geológicos de Portugal* (Cortes *et al.* 1977; Furtado *et al.* 1969) and, finally, by Jean Roche (Manso 2013). The 1963-1968 excavations yielded mollusc shells, including mussels, and diverse material assigned to the Neolithic and Chalcolithic (Furtado *et al.* 1969). In 1970, the team of local amateurs carried out two stratigraphic sections, one at the end of the corridor and another at the entrance of one of the terminal rooms. The findings included mussel shells, materials assigned to a very wide chronology - Upper Paleolithic to Iron Age, and even from the Roman period, with most belonging to the Neolithic and the Chalcolithic. It was concluded that materials were all mixed as a result of «long depredations and incipient excavations over a century» (Cortes *et al.* 1977: 232). The team led by Jean Roche started excavations in 1973 and found a stratigraphy composed of five main layers, with mussel shells present in levels 6, 7, 8 and 9, that were all assigned to the Upper Paleolithic. Radiocarbon dates for charcoals found in these four levels published by Haws and Valente (2006) and converted in Bicho *et al.* (2011) fall within the Portuguese Magdalenian (Table 1, LS, Levels 6-9). Of the 37 shells from Lapa do Suão that were studied in the present work, only four specimens (LS #2, #3, #4 and #9) have labels that indicate they were collected during Jean Roche's excavations and therefore in Magdalenian levels. The other shells could have been retrieved from Upper Paleolithic to Roman levels.

## 3. Methodology

Firstly we confirmed that shells were identifiable as either *M. edulis* or *M. galloprovincialis* because of the general shape of the shell, the number of teeth and the shape of the posterior retractor and the adductor anterior muscle scars. It should be noted, however, that in relation to shell color, archaeological shells from *Lapa do Suão* (Figure 2) had dominant shades of red on their outer face, which does not occur in these two species of mussel (nowadays). However, based on our knowledge of collections of archaeological shells from various institutions in which many mussel shells are found in archaeological context

with similar tonalities, we conclude that this coloring is possibly a result of a process of chemical alteration of the pigments by virtue of prolonged burial of the shells.

In order to identify shells to species level, comparisons were made with a collection of modern shells of *M. edulis* and *M. galloprovincialis*. Archaeological shells had a ligament length in the range 9-60 mm, so we used modern shells within this range of dimensions. *M. edulis* shells were purchased from a number of specialist vendors and were from regions where *M. galloprovincialis* does not occur. Those of Caithness, Dunbar and the islands of Orkney and Shetland (Scotland) were collected dead on the beach, being constituted by separated valves. Those of Lough Killary (Ireland, west coast), Perros-Guirec (northern coast of Brittany, France), Yerseke and Zierikzee (Holland) were collected alive, the specimens having the two valves. Shells of *M. galloprovincialis* were collected by one of the authors (JPSC) at the following sites on the Portuguese mainland coast (by decreasing latitude): Ínsua island (Caminha); A Ver-o-Mar; Póvoa de Varzim; Vila do Conde; Pedras da Agudela; Nazaré; Porto Novo; Santa Rita; Foz do Lizandro; São Julião; Alvor. Most of the specimens were collected alive.

In both archaeological and modern shells the variables displayed in Table 2 and Figure 4 were determined whenever they were possible to measure, using the following methods: ANGD with a digital compass; CHAR, MUSC.L and MUSC.W through the measurement of digital photographs taken with a binocular microscope, using as a calibration a micrometer with scale of 1 mm; TEETH by observation of the region of the hinge plate with a binocular microscope; LIG, SL and SW with a digital caliper. Canonical discriminant analysis finds a set of prediction equations based on independent variables (such as shells' morphometric variables) that are used to classify individuals (such as shells) into groups (such as species). This technique can be used to find a predictive equation for classifying new individuals (such as shells) or to interpret the predictive equation to understand better the relationships that can exist among the variables (Hintze 2007: chapter 440). This statistical tool was used in the present work in order to find the best morphometric variables that separate modern *Mytilus edulis* shells from modern *Mytilus galloprovincialis* shells and to apply these variables in order to identify the archaeological shells as either belonging to one species or to the other, and also to compare modern *Mytilus galloprovincialis* shells with the studied the archaeological shells. For canonical discriminant analysis only shells in which it was possible to determine all the variables were used. The statistical treatment of the results was performed with the NCSS program v.07.1.21, by Jerry Hintze, 2007.

| Variable acronym | Description and units |
|---|---|
| ANGD | Angle of the shell at the anterior end (degrees) |
| CHAR | Hinge plate length (mm) |
| LIG | Distance between the dorsal extremity of the shell and the posterior extremity of the ligament (mm) |
| TEETH | Total number of teeth, of all sizes |
| LIG | Distance between dorsal extremity of the shell and posterior end of the ligament (mm) |
| MUSC.L | Length of the anterior adductor muscle scar (mm) |
| MUSC.W | Width of the anterior adductor muscle scar (mm) |
| MUSC.Q | Quotient between the length and width of the anterior adductor muscle scar = MUSC.L / MUSC.W |
| MUSC.A | Muscle scar area, considering an ellipse = (MUSC.L/2) × (MUSC.W/2) × π ($mm^2$) |
| SL | Shell maximum length (mm) |
| SW | Shell maximum width (mm) |

**Table 2. Definition of the morphological and morphometric variables used in this study, and their units.**

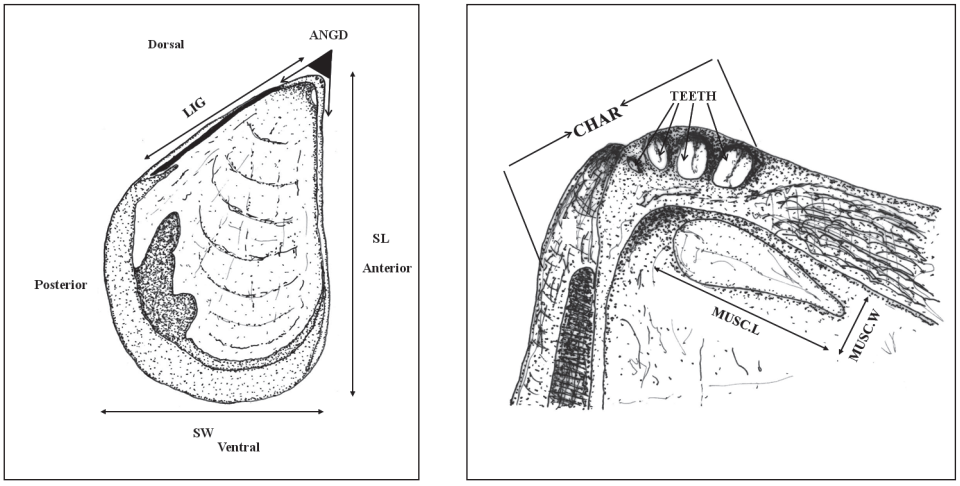


Figure 4. Schematic representation of a whole shell (left) and detail of the dorsal region (right) with representation of some variables used in this work (for a definition of the variables see Table 2).

## 4. Results

Morphological characteristics of studied modern and archaeological shells are presented in Table 3. MAG and PV shells were the largest, having the highest CHAR, LIG, MUSC.A, SL and SW. As reported by Cabral (2016), in modern shells, LIG was highly correlated with SL. Since some archaeological shell were not intact and lacked part of the ventral or posterior sides (Figure 2), we chose to used LIG as a measure of shell size instead of SL (as done in Cabral 2016), allowing the study of a greater number of archaeological specimens.

| Archaeological shells (acronym) Modern shells | Total number of valves (Left+ Right) | ANGD ° (number of valves) | CHAR mm (number of valves) | TEETH (number of valves) | LIG mm (number of valves) | MUSC.A $mm^2$ (number of valves) | SL mm (number of valves) | SW mm (number of valves) |
|---|---|---|---|---|---|---|---|---|
| *Monumento da Bela Vista* (BV) | 15 (7+8) | 47.4 (15) | 3.9 (13) | 4.5 (13) | 17.0 (9) | 1.1 (13) | 37.4 (11) | 19.0 (14) |
| *Praia do Magoito* (MAG) | 3 (2+1) | 44.7 (3) | 6.5 (3) | 2.0 (3) | 41.5 (3) | 5.8 (3) | 52.8 (1) | 31.5 (2) |
| *Tholos da Praia das Maçãs* (PM) | 3 (2+1) | 47.3 (3) | 3.6 (3) | 3.7 (3) | 23.5 (3) | 1.6 (3) | 31.4 (1) | 17.7 (1) |
| *Grutas do Poço Velho* (PV) | 7 (5+2) | 46.1 (7) | 4.5 (7) | 3.0 (6) | 31.9 (6) | 3.7 (7) | 53.0 (4) | 27.8 (4) |
| *Lapa do Suão* (LS) | 37 (19+18) | 57.1 (37) | 3.0 (37) | 3.6 (36) | 21.3 (37) | 2.2 (36) | 31.5 (24) | 18.1 (25) |
| Modern *Mytilus edulis* | 275 (137+138) | 47.4 (275) | 4.3 (239) | 3.9 (190) | 24.9 (275) | 6.3 (236) | 48.6 (255) | 23.8 (255) |
| Modern *Mytilus galloprovincialis* | 585 (288+297) | 47.0 (585) | 3.0 (226) | 3.9 (262) | 19.6 (585) | 1.7 (455) | 39.4 (585) | 20.7 (585) |

Table 3. Main morphological and morphometric characteristics of the archaeological and modern shells used in this study.

| Variable | Modern shells | | Archaeological shells | | | | |
|---|---|---|---|---|---|---|---|
| | *Mytilus edulis* | *Mytilus galloprovincialis* | *Monumento da Bela Vista* (BV) | *Praia do Magoito* (MAG) | *Tholos da Praia das Maçãs* (PM) | *Grutas do Poço Velho* (PV) | *Lapa do Suão* (LS) |
| Number of valves | 173 | 131 | 8 | 3 | 3 | 5 | 35 |
| ANGD (°) | 45.3 | 50.8 | 48.0 | 44.7 | 47.3 | 48.8 | 56.9 |
| TEETH | 3.9 | 4.3 | 4.0 | 2.0 | 3.7 | 3.0 | 3.6 |
| MUSC.Q | 2.8 | 2.4 | 1.9 | 1.6 | 1.4 | 1.6 | 1.8 |
| MUSC.A/LIG | 0.27 | 0.079 | 0.075 | 0.13 | 0.066 | 0.10 | 0.11 |
| CHAR/LIG | 0.17 | 0.13 | 0.23 | 0.16 | 0.15 | 0.14 | 0.15 |

**Table 4. Morphological and morphometric characteristics of the archaeological and modern shells used in the canonical discriminant analysis.**

In agreement with the results published in the literature (Gosling 1984; McDonald *et al.* 1991; Sanjuan *et al.* 1994), in *M. edulis* CHAR/LIG and, especially, MUSC.A/LIG were higher than in *M. galloprovincialis* (Table 4 and Figure 5). Archaeological shells had MUSC.A/LIG values similar to those of *M. galloprovincialis*, and lower than in *M. edulis* (Table 4 and Figure 5). Similarly, MUSC.Q of archaeological shells was closer, albeit lower, to *M. galloprovincalis* than to *M. edulis* (Table 4). ANGD and TEETH were similar in modern and archaeological shells (Table 4), and were not dependent on shell size. Plotting MUSC.A/LIG *versus* CHAR/LIG (Figure 6), the variables that best separate the two mussel species, we found that *M. edulis* and *M. galloprovincialis* points were in two separate areas, with a certain overlap, and that, globally, archaeological shells values fall within the *M. galloprovincialis* area. However, LS #7 and #38, and BV #1, #2 and #3, fell outside or were at the margin of the distribution of *M. galloprovincialis* data points (Figure 6).

Canonical discriminant analysis was carried out in two steps. Firstly, we compared modern *M. edulis* and *M. galloprovincialis* shells, with *a posteriori* identification of archaeological shells. In this analysis, the canonical correlation$^2$ (similar to $R^2$ in multiple regression) was very high (Table 5). The variables with highest loadings (correlations) were MUSC.A/LIG, CHAR/LIG and MUSC.Q (Table 6), confirming data from the literature and results from Cabral (2016). In the *a posteriori* identification of archaeological shells, 2 shells from BV (#2 and #3) and 1 from LS (#38) were identified as *M. edulis*, confirming results by MUSC.A/LIG *versus* CHAR/LIG plot (Figure 6). All the others were identified as *M. galloprovincialis*.

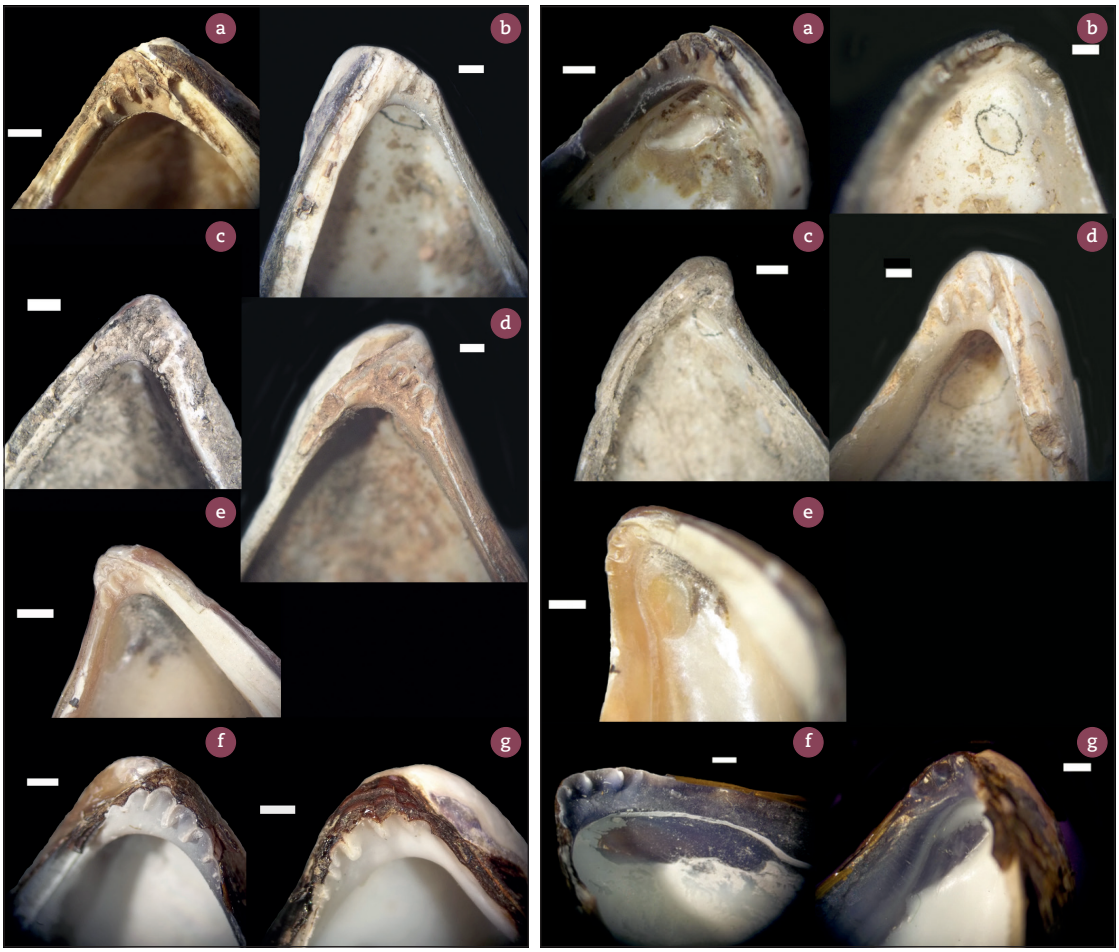


Figure 5. Dorsal view showing the teeth (left) and the anterior adductor muscle scar (right) of archaeological shells from *Monumento da Bela Vista* (a), *Praia do Magoito* (b), *Tholos da Praia das Maçãs* (c), *Grutas do Poço Velho* (d) and *Lapa do Suão* (e), and modern *Mytilus edulis* (f) and *Mytilus galloprovincialis* (g). Scale, 1 mm.

| | Eigenvalue | % of variance | | Canonical correlation | | Wilks' λ |
|---|---|---|---|---|---|---|
| | | Individual | Cumulative | Canonical correlation$^2$ | F (DF/DF) | |
| Fn1 | 2.20 | 100 | 100 | 0.687 | 130 (5/298)*** | 0.313 |

**Table 5. Canonical variate discriminant analysis using morphometric characteristics of modern *Mytilus edulis* and *Mytilus galloprovincialis* shells. (***) Significant for *p*=0.05.**

| *Canonical coefficients* | |
|---|---|
| Variable | *Canonical variate* |
| ANGD | 0.262 |
| MUSC.Q | **-0.327** |
| TEETH | 0.071 |
| MUSC.A/LIG | **0.844** |
| CHARN/LIG | **-0.333** |

Table 6. Standard canonical coefficients in discriminant analysis using modern *Mytilus edulis* and *Mytilus galloprovincialis* shells. Variables with higher loadings are in bold.

Secondly, archaeological shells were compared with modern *M. galloprovincialis* shells. In this analysis, canonical correlation$^2$ was lower than in the first analysis (Table 7). The variables with highest loadings were CHAR/LIG and MUSC.Q (Table 8), confirming the differences found in the mean values of these variables (Table 4). These differences between modern *M. galloprovincialis* and archaeological shells can be due to local specificities.

| | Eigenvalue | % of variance | | Canonical correlation | | Wilks' λ |
|---|---|---|---|---|---|---|
| | | Individual | Cumulative | Canonical correlation$^2$ | F (DF/DF) | |
| Fn1 | 0.667 | 100 | 100 | 0.400 | 24 (5/180)*** | 0.600 |

Table 7. Canonical variate discriminant analysis using morphometric characteristics of modern *Mytilus galloprovincialis* and archeological shells. (***) Significant for $p$=0.05.

| *Canonical coefficients* | |
|---|---|
| Variable | *Canonical variate* |
| ANGD | 0.218 |
| MUSC.Q | **-0.583** |
| TEETH | -0.429 |
| MUSC.A/LIG | 0.333 |
| CHARN/LIG | **0.615** |

Table 8. Standard canonical coefficients in discriminant analysis using modern *Mytilus galloprovincialis* and archaeological shells. Variables with higher loadings are in bold.

## 5. Discussion

Archaeological mussel shells studied in the present work were found in diverse archaeological contexts. In global terms, these shells were identified as belonging to *Mytilus galloprovincialis*. Is this compatible with estimated seawater temperatures for the periods when they were collected?

The main factor for the distribution of *M.edulis* and *M. galloprovincialis* in Iberian Peninsula Atlantic waters is the minimum seawater temperature. *M. edulis* needs a minimum seawa-

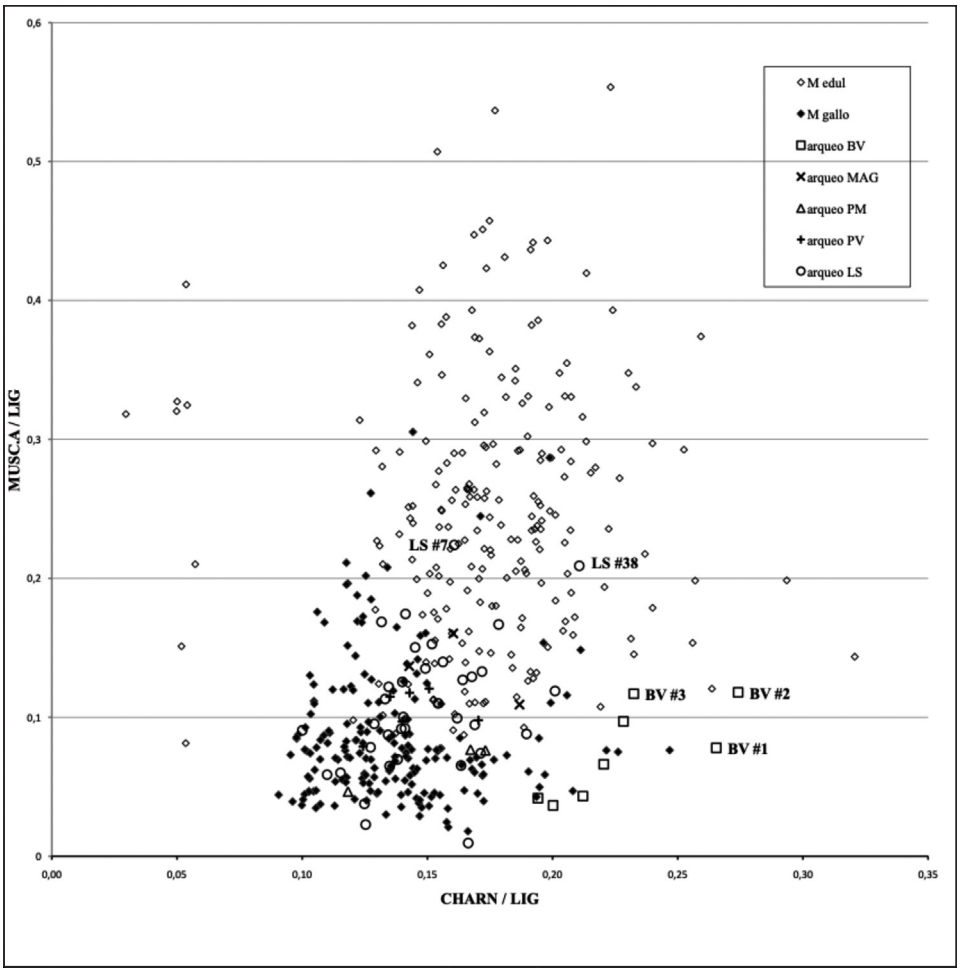


Figure 6. Graphic plot of the anterior muscle scar size against hinge plate size for modern *Myilus edulis* and *Mytilus galloprovincialis* and studied archaeological *Mytilus* shells.

ter temperature lower than 12°C, whereas *M. galloprovincialis* demands that this temperature is higher than 9°C. In the Portuguese continental coast, present minimum seawater temperatures are in the range 13.5°-15°C. Between 19,900 and 15,300 BP, seawater temperatures in Western Iberia were probably similar to modern values, as a result of a warm branch of the North Atlantic Current that flowed along this region during the Last Glacial Maximum (Boessenkool *et al.* 2001). Lower seawater temperatures occurred in the period 14,000-13,000 BP and during Younger Dryas, ca. 11,000-10,000 BP (Bicho 1994; Boessenkool *et al.* 2001: figure 2; Valente 2008), but it is difficult to establish the magnitude of this

decrease. After these cold phases, during the Holocene, seawater temperature increased and reached values not very different from modern ones (Valente 2008). *Praia do Magoito* shells, dated ca. 11,000 BP and *Lapa do Suão* #2, #3, #4 and #9 specimens from the Magdalenian were typical *M. galloprovincialis* suggesting that for these periods the minimum seawater temperature was equal or higher than 12°C, therefore not lower than 1.5°-3.0°C in relation to modern minimum temperatures.

*Monumento da Bela Vista* #1, #2 and #3 specimens, collected in Neolithic or in Chalcolithic levels, were not typical *M. galloprovincialis*. However, the other BV shells were in the range of the variability of this species, although at the margin (Figure 6). These results could be ascribed to local environment specificities of the sites where they were collected, which were different from those of the reference modern collection used for comparison. Cabral (2016) applied this methodology to São Julião D mussel shells dated 2,600 BC (Sousa *et al.* 2016: table 1). Specimens were identified as typical *M. galloprovincialis* shells (Cabral 2016: figure 5). To confirm the results presented here it will be needed to apply this methodology to mussel shells unmistakably dated from periods with fairly cold seawater estimates, with minimum seawater temperatures equal or lower than 9°C, ca. 4.5°-6.0°C below current temperatures.

Finally, it should be stressed that the study of the archaeological mussel shells deposited in Portuguese museums suffers from limitations due to the scarcity of well-preserved specimens and to the fact that many shells came from old excavations. In addition to archaeological information, dating directly the *Mytilus* shells using chemical methods could also contribute to a better understanding of the occurrence of *Mytilus edulis* in the past in the Iberian coasts and, concomitantly, of past seawater temperatures.

## 6. Conclusions

Archaeological mussel shells studied in the present work were identified as belonging to *Mytilus galloprovincialis*. A few specimens were not typical, but differences could be ascribed to local environment specificities. In the Portuguese continental coast, the minimum seawater temperatures at about 11,000 BP and during the Magdalenian was probably not lower than 1.5°-3.0°C in relation to nowadays temperatures.

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