Mollusc collection and Holocene palaeogeographical evolution in a southwestern iberian estuary: Statistical analysis of the early Holocene Cañada Honda shell midden (SW Spain)

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ARTICLE INFO

ABSTRACT

The malacological analysis of the Cañada Honda shell midden (Tinto-Odiel estuary, SW Spain) has allowed an approximation of the palaeo biodiversity of this sector during the Mesolithic. During this period, the progressive marine transgression caused the flooding of this estuary, coinciding with an initial intensive capture of the bivalves *Lutraria* and *Ruditapes decussatus* in the northern and southern sector of this site, respectively. In a second phase, *Ruditapes decussatus* was the main collected species in all sectors. This last period coincided with some diversification in catches, still dominated by *Ruditapes decussatus* but with significant proportions of *Cerastoderma edule*. This stage witnessed a progressive sedimentary filling of the estuary and the creation of marshes and barrier islands. The almost total fragmentation of the specimens would imply that the surface of this shell midden was exposed for a long time while in use. In addition, an occasional charring of some molluscs has been detected. The main molluscs of this site are also the most abundant in other later shell middens (~cal 5.2–4 kyr BP), indicating an important perpetuation of the collecting and/or eating habits in this environment. All the species determined in them are also currently found in this estuary and its surroundings, where they are also captured.

1. Introduction

Coastal shell middens are accumulations of abundant zooarchaeological remains that derive from collection and consumption *in situ* by former inhabitants. They have a worldwide distribution, ranging from tropical regions to circumpolar zones (Herrera and Solis, 2011; Lewis, 2011; Hood and Grovdal, 2016; Ward et al., 2016; Astrup et al., 2021). Research carried out in them has identified the species present and numerous additional interesting results, such as: i) the potential uses of the main species (food, ornament, currency) in different historical periods; ii) diet, technology and seasons of site occupation; iii) population distributions, individuals sizes and species presence or absence; iv) past overexploitation of selected species; v) the spatial and temporal distribution of extinct species; or vi) paleoenvironmental changes in the adjacent coastal areas (Bailey, 1977; Attenbrown, 1992; Álvarez et al., 2011; Bailey et al., 2013; Holdaway et al., 2017; Bailey and Hardy, 2021).

Bivalves and gastropods are some of the best represented groups within shell middens (Ceci, 1984; Stein, 1992; Álvarez et al., 2011; Albert and BujengChia, 2022). Among the former, oysters, cockles, mussels, and scallops have been highly appreciated and collected (Erlandson et al., 2009; Hallmann et al., 2009; Lulewicz et al., 2017; López-Dorigal et al., 2019). Among gastropods, strombids and muricids, as well as pulmonate and freshwater species, are abundant in these shell concentrations (Schapiera et al., 2006; Douka et al., 2014; Harasewych, 2015; Gordon et al., 2016; Magee et al., 2017).

Numerous coastal shell middens have been found in the Atlantic coasts of Europe from Norway to Portugal, ranging mainly from the Mesolithic-Neolithic interval (e.g. Milner et al., 2007; and references therein). Nevertheless, shell middens of the southwestern Spanish

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littoral are still briefly studied (e.g. Ramos et al., 2011; Ruiz et al., 2020). In the Tinto-Odiel estuary (SW Spain), numerous shell deposits have been described in archaeological sites (Fig. 1, A-B), although they still require detailed study.

This paper analyses the macrofauna of the Cañada Honda shell midden (Tinto-Odiel estuary, SW Spain). The main objectives are: i) to obtain an approximation to the palaeo biodiversity of edible species in this estuary during the Mesolithic; ii) to detect temporary changes in feeding strategies based on statistical analysis of the malacological record; iii) to relate the geomorphological evolution of this estuary with the species determined in this shell midden; and iv) to compare the malacological record of this shell midden with those of other more recent shell middens located in the same estuary.

2. The Cañada Honda shell midden

2.1. Study area: Holocene evolution

The Tinto and Odiel rivers make up a wide estuary at their joint mouth in the Atlantic Ocean (Fig. 1, A-B). This estuary is currently in an advanced state of filling, with large internal marshes and barrier islands (e.g. Saltés Island) drained by numerous ebb-tide channels and protected by two sandy spits (Punta Umbría, Punta Arenillas) and two jetties. The main hydrodinamic processes are controlled by tides and, to a lesser extent, by fluvial inputs. The tidal regime is mesotidal and semidiurnal, with an average tidal range of 3.6 m (Borrego et al., 1993). Both the Odiel river (mean: 12.45 m^3s^{-1}; maximum >1000 m^3s^{-1}) and the Tinto river (mean < 10 m^3s^{-1}; maximum >400 m^3s^{-1}) have very irregular flows (Borrego et al., 1994; Cánovas, 2008).

2.2. The Cañada Honda shell midden

The Holocene human occupation of this estuary is evidenced by the presence of numerous archaeological sites (Fig. 1, B). One of them is the Cañada Honda shell midden, located on a hill (4–6 m height) on the western bank of the Odiel river (Fig. 1, C). It is bordered to the north by an ebb-tide channel, to the east by a mining railway and salt marshes (Fig. 1, D) and to the southwest by an aggregate quarry that destroyed more than half of the shell midden total surface. This shell midden is deposited on upper Pleistocene-early Holocene fluvial terraces that mainly consists of conglomerates and gravels (Cáceres, 1992; Martín and Campos, 1995). Thickness varies between 0.5 and 1.5 m and its internal structure is highly compacted by $CaCO_3$ dissolution from the shells.

Two archaeological levels have been distinguished in this shell midden (Borja et al., 1994).

i) Basal level, with a lithic industry composed of flakes and cores. A calibrated age of a shell of the bivalve *Ruditapes decussatus* collected near the base of this level has been obtained (7250 ± 60 yr BP; cal. 7827–7.465 yr BP; 2 sigma; ΔR = −108 ± 31 yr; Reis et al., 2020).

ii) Upper level, with ceramic fragments and bone accumulations. Comparison of these archaeological remains with those extracted from other sites in the estuary of the Tinto and Odiel rivers dates this level to the third millennium BCE (5000–4000 yr BP; Borja et al., 1994). Consequently, this shell midden was occupied for at least 2500 years and it would be situated as a cliff during the maximum of the Holocene transgression, with the adjacent areas occupied by intertidal zones and numerous ebb-tide channels (Borrego et al., 1999; Zazo et al., 2005; Cáceres et al., 2018).

2.3. Shell middens and paleogeographical evolution of the Tinto-Odiel estuary (8–3.5 kyr BP): a review

In the last decades, numerous shell middens have been identified in the Tinto-Odiel estuary, ranging from Paleolithic to Roman times (see some examples in Fig. 1, B). A comparison of their malacological records with those of drill cores extracted in this estuary and the paleogeographical reconstructions inferred from them allows defining five phases between 10 kyr BP and 4 kyr BP.

First phase (~11-10 kyr BP). This estuary was emerged and dominated by the river dynamics, with an erosion of the fluvial valleys (Fig. 2, A; Dabrio et al., 2000). At this time, the sea level was at −30/-35 m in the Spanish continental shelf (Hernández Molina et al., 1994). No malacological record has been found in the associated fluvial sediments.

Second phase (~10-8 kyr BP). The MIS 1 transgression caused the progressive flooding of river valleys, with the presence of tidal sedimentation a in the central basin of the estuary (Borrego et al., 1999; Dabrio et al., 2000). The poorly known malacological record consisted mainly of bivalves, including some edible species (*Acanthocardia aculeata*, *Chamelea gallina*, *Donax* spp., *Ostrea edulis*) (Ruiz et al., 2005).

Third phase (8-6 kyr BP). This phase included the flooding of this area during the maximum of the MIS 1 transgression, with the presence of cliffs around the estuary (Fig. 2, A; Dabrio et al., 2000). This new paleogeographical situation coincided with the transit to more sedentary human societies (Bermejo et al., 2016).Bermejo et al., 2016

Fourth phase (5-3 kyr BP). This phase is characterized by the growing of two sandy spits (Fig. 2, A: Punta Umbría, Punta Arenillas), the expansion of tidal flats and the increase of sandy shoals (Dabrio et al., 2000). Shell middens are more frequent (Fig. 2, A-B: Seminario, El Grillito, Papas Uvas, Casa del Río), with *C. edule* and ostreids as the most collected molluscs in the northern sector of the estuary (Borja et al., 1994) while *R. decussatus* and, to a lesser extent, *S. marginatus* were the preferred species in its central basin and near the mouth (Garrido and Vera, 2015; Nocete et al., 2004-2005).

3. Material and methods

3.1. Field

Three profiles (Fig. 1, D-F) were selected and cleaned back before extraction of samples to avoid the mixing of shells from the uppermost levels. Fifteen samples were extracted with a plastic palette. Each sample was collected every 10 cm vertically and then was placed in a self-sealing plastic bag. Two kilograms of bulk rock were extracted in each sample.

3.2. Laboratory

Two hundred grams of sediment were extracted from each sample and then mixed with water, calcium pyrophosphate and hydrogen peroxide to break up and remove organic matter. After stirring, the resulting solution rested for a minimum of 96 h in a plastic container. This solution was sieved through two sieves (2 mm-125 μm mesh diameter) and the preserved malacofauna specimens were carefully cleaned with a brush. The two resulting fractions were poured into heat-resistant ceramic capsules and dried in an electric oven (60 °C for 36 h). The dried residues were weighed, labelled and packed in *minigrip* bags.

One hundred specimens were identified from each fractioned sample and then stored in plastic containers or on slides depending on the size. Thus, around two thousand specimens were selected and weighed in each sample. Taxonomic identification of the specimens was carried out according to Gómez (2017) and the World Register of Marine Species (WoRMS). In parallel to the taxonomic determination, the state of conservation (a whole or fragmented shell or valve), the type of valve (left or right) and other taphonomic aspects (pigmentation, perforations) were noted. Finally, the best-preserved specimens were photographed.

3.3. Statistical analysis

This analysis has been based on the calculated percentages of the
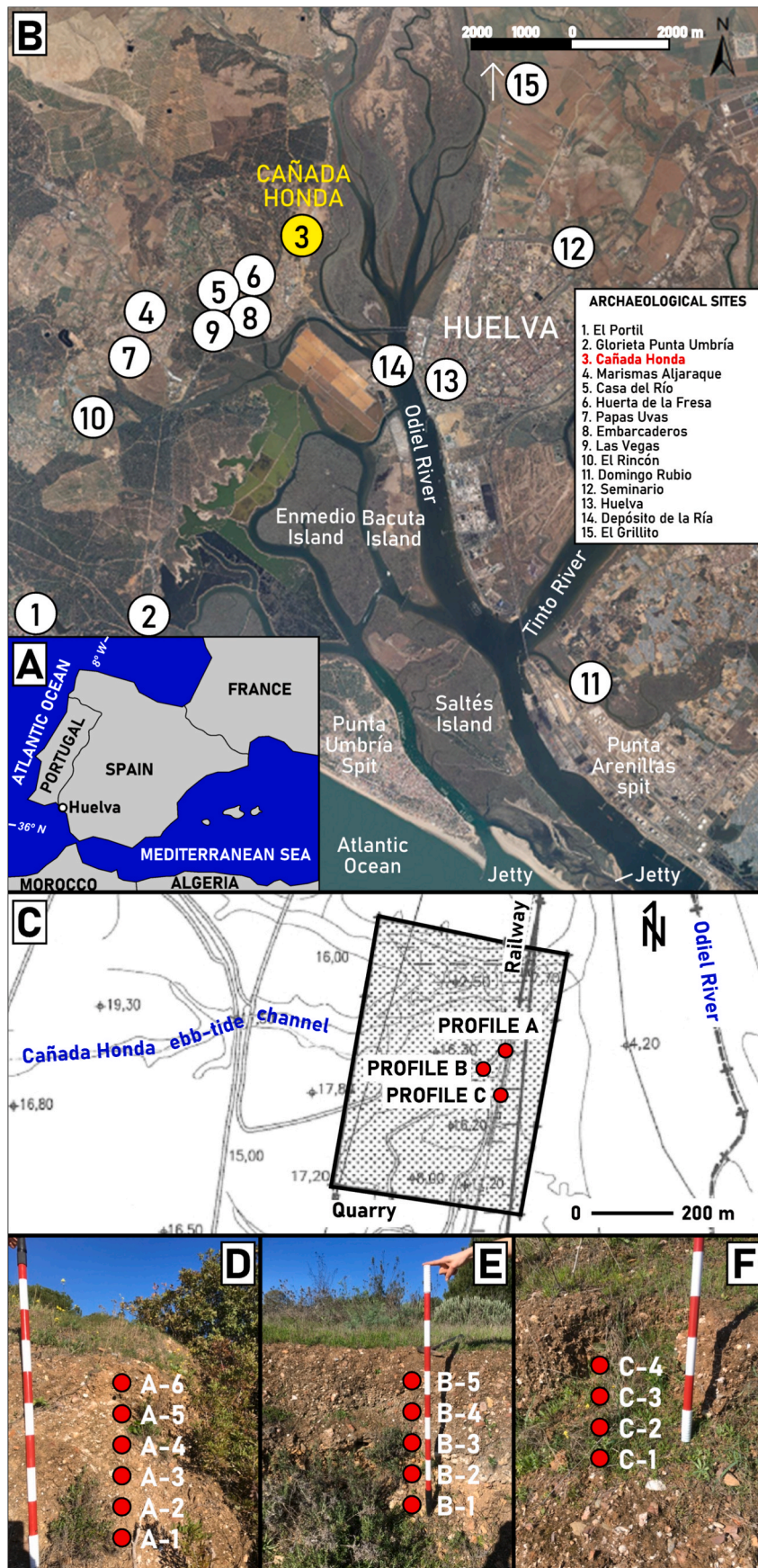
Fig. 1. A–B: location map of the Cañada Honda shell middens and other archaeological sites; C: location of the three profiles studied; D: detail of profile A and samples; E: detail of profile B and samples; F: detail of profile C and samples.
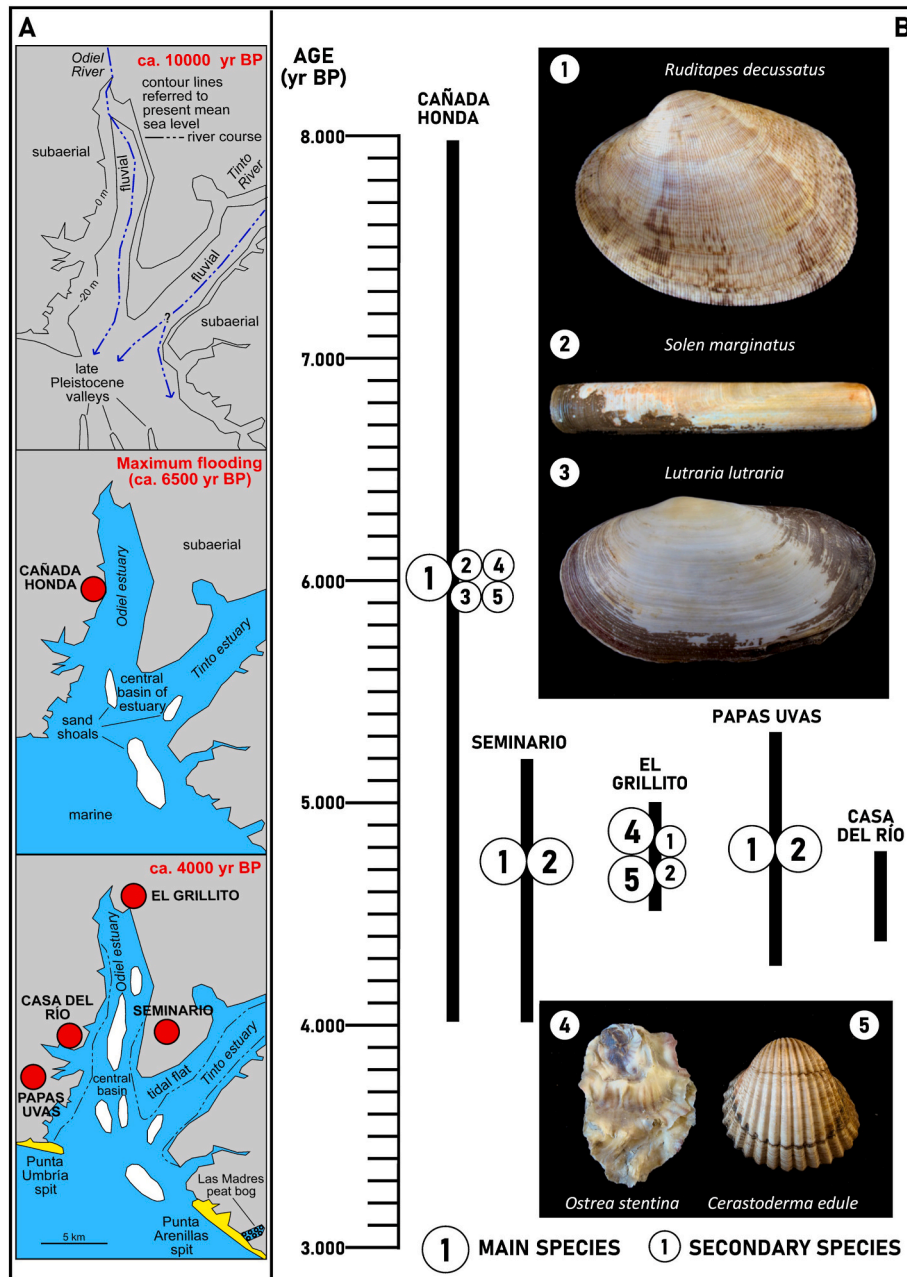
Fig. 2. A: paleogeographical evolution of the Tinto-Odiel estuary (10-4 kyr BP; modified from Dabrio et al., 2000), with location of some shell middens; B: main species collected in shell middens of different ages located in this estuary.

twelve most abundant species. It includes three steps: i) lineal correlation, to look for species assemblages; ii) Q-mode cluster analysis, with the differentiation of sample groups; and iii) principal component analysis. The extreme degree of fragmentation (see section 4.3) prevents the calculation of the mínimum number of individuals (MNI) and consequently the number of identifiable specimens (NISP) of each sample has been used. In some archaeological sites of Kenia, MNI is a less representative descriptor of relative element frequency than NISP (Marshalll and Pilgram, 1993).

4. Results

4.1. Stratigraphy

The three profiles are mainly composed of bioclastic silty sands deposited on around 3 m thick of fluvial gravels and conglomerates.

Profile A (Fig. 3, A: 70 cm thickness) is located on the northern side of Cañada Honda and presents abundant fractured shells, more abundant in the upper 40 cm of this profile. Profile B (Fig. 3, B) consists of 70 cm of which the basal 10 cm are gravels and conglomerates (diameter: 9–11 cm). The uppermost 60 cm includes two levels of scattered and fractured shells separated by lithic fragments. Finally, profile C (Fig. 3, C) is southern and is located in the upper part of the mining railway trench. This profile consists of 40 cm and is divided into three horizons: i) lower horizon (10 cm), with scattered shells, quartz pebbles and slate (1–2 cm diameter); ii) middle horizon (20 cm), with abundant shells with evidence of dissolution and the presence of clayey nodules with blackish colourations and evidence of heating; and iii) upper horizon (10 cm), characterized by quartz and slate cobbles (diameter up to 8 cm) and occasional fragments of fractured shells.
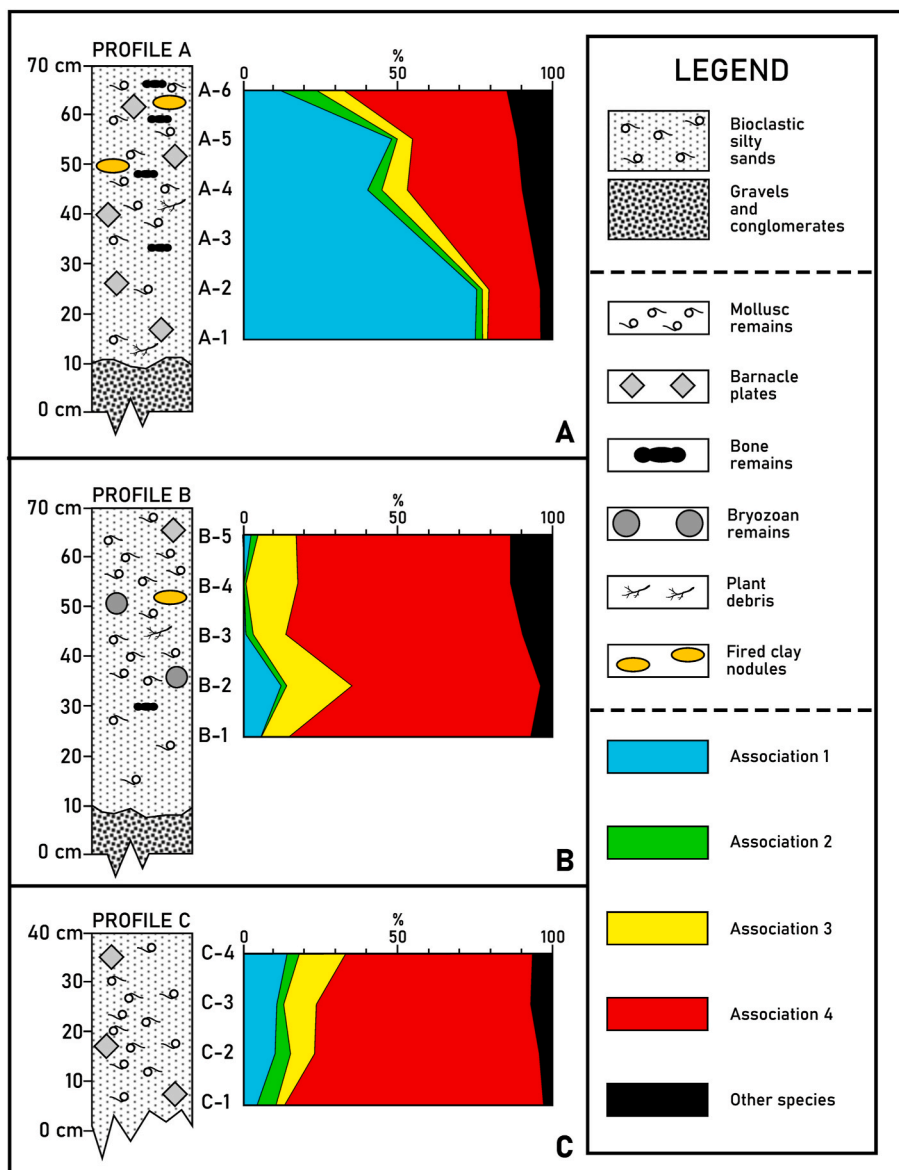
Fig. 3. Stratigraphy of selected profiles and vertical distribution of mollusc associations. A. Profile A; B. Profile B; C: Profile C.

4.2. Zooarchaeology: profile distribution of the malacofauna

In total, 2914 valves, carapaces and shell fragments of molluscs have been studied and sixteen species have been identified (Table 1). In addition, the three profiles contain frequent barnacle plates, crustacean claws, vertebrate bones, fish teeth and fragments of bryozoans. No marine or brackish microfauna (e.g. foraminifera or ostracods) have been found.

Bivalves are the dominant molluscs (95.34%; 7 species). The most abundant species are *Ruditapes decussatus* (Linnaeus, 1758) (Fig. 4,

Table 1
Percentages of the species and mollusc diversity in the three profiles.

		AT	CE	LL	OE	OS	RD	SM	CG	CA	CV	PU	RL
BIVALVES	*Acanthocardia tuberculata (AT)*	1											
	Cerastoderma edule (CE) -Association 3-	−0.38	**1**										
	Lutraria (LL) -Association 1-	−0.16	<u>−0.54</u>	1									
	Ostrea edulis (OE) -Association 2-	−0.18	−0.07	−0.08	1								
	Ostrea stentina (OS)	0.01	0.39	−0.35	0.45	1							
	Ruditapes decussatus (RD) -Association 4-	0.23	0.41	**−0.95**	−0.09	0.09	1						
	Solen marginatus (SM) -Association 1-	0.03	−0.39	<u>0.57</u>	0.08	0.12	**−0.7**	1					
GASTROPODS	*Candidula gigaxii (CG)*	−0.22	0.19	−0.11	0.03	−0.01	0.07	0.1	1				
	Cecilioides aciculata (CA) -Association 2-	0.29	<u>−0.56</u>	0.02	**0.63**	−0.06	−0.02	0.07	−0.26	1			
	Cerithium vulgatum (CV) -Association 3-	−0.37	<u>0.55</u>	−0.47	0.14	0.19	0.4	−0.48	−0.22	−0.02	1		
	Peringia ulvae (PU)	0.28	−0.29	−0.27	−0.06	−0.42	0.37	−0.23	−0.13	−0.15	−0.2	1	
	Rumina decollata (RL) -Association 2-	−0.16	−0.23	0.24	**0.81**	0.27	−0.41	0.37	0.32	−0.42	−0.11	0.31	1

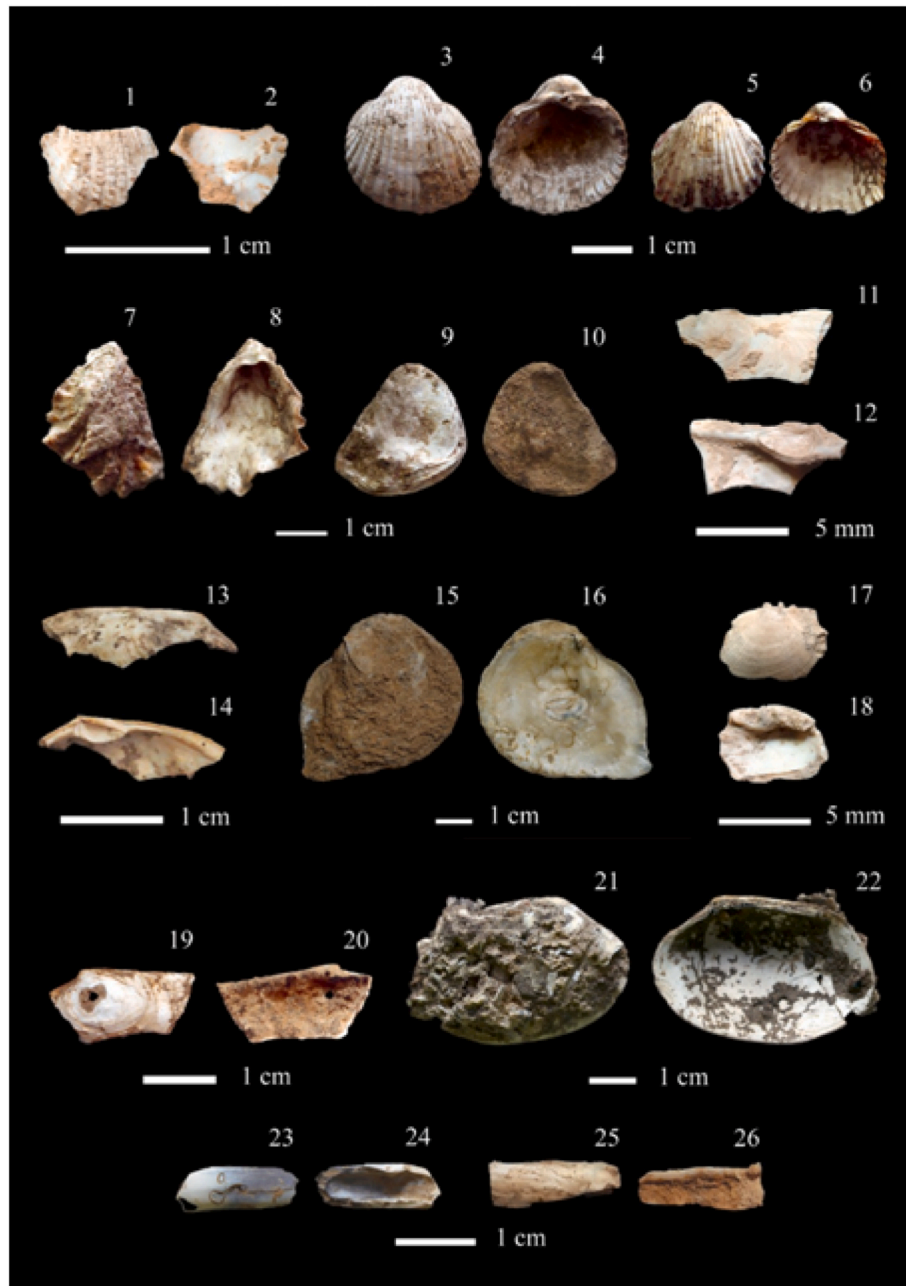Bold: $p < 0.01$; underlined: $p < 0.05$.

Fig. 4. Bivalves. 1–2: *Acanthocardia tuberculata*; 3–6: *Cerastoderma edule*; 7–10: *Ostrea stentina*; 11–14: *Lutraria*; 15–16: *Ostrea edulis*; 17–22: *Ruditapes decussatus*; 23–26: *Solen marginatus*.

17–22; 59.2%), followed by *Lutraria* (Linnaeus, 1758) (Figs. 2, 15–16; 17.46%) and *Cerastoderma edule* (Linnaeus, 1758) (Figs. 4, 3–6; 8.35%). Gastropods are very minoritary (4.66%; 8 species) and are represented by eight species, among which *Cecilioides acicula* (Müller et al., 2017) (Fig. 5, 4–5; 1.3%), *Cerithium vulgatum* Bruguière, 1792 (Figs. 3, 8–9; 1.1%) and *Rumina decollata* (Linnaeus, 1758) (Figs. 5, 18–21; 1.08%) are the most representative species. Finally, a single specimen of scaphopod has been collected (sample B-4).

The taxonomic identification of 1138 specimens from profile A has differentiated seven bivalve species and six gastropod species (Table 1). The dominant species is *L. lutraria* (base: 68.54–71.65%; top: 8.67%), with a remarkable decreasing trend towards the upper edaphic profile and a progressive replacement by *R. decussatus* (base: 17–18%; top: 53.57%). Other species with increasing percentages towards the top of the profile are *Ostrea stentina* Payraudeau, 1826 (Figs. 4, 7–10; base: 2%;

top: 10.5%) and *C. edule* (base: 1.5%; top: 6.5%). *Solen marginatus* Pulteney, 1799 (Figs. 4, 23–26) is well represented in the middle part of the profile (A-3 to A-5: 10–10.5%) and decreases in the upper sample (A-6: 1.5%). Pulmonate species, such as *C. acicula* (1–4.5%) and *R. decollata* (1–3.5%), are the most abundant gastropods. This group only exceeds 10% in the uppermost sample of this profile. Barnacle plates are frequent especially near the base and some isolated crab claws are also present.

Profile B shows a somewhat lower number of species per sample (6–10; mean: 7.4) compared to profile A (7–11; mean: 9). The taxonomic identification of 998 specimens has differentiated six bivalve species, six gastropod species and one scaphopod species (Table 1). The dominant species is *R. decussatus* (61–78.5%), with the maximum percentages at the base of the profile (sample B-1). Other abundant bivalve species are *C. edule* (7–17.5%) and *O. stentina* (3.5–11.56%). Gastropods are very scarce and only exceed 8% in sample B-3, with *C. vulgatum* (4.02%) as
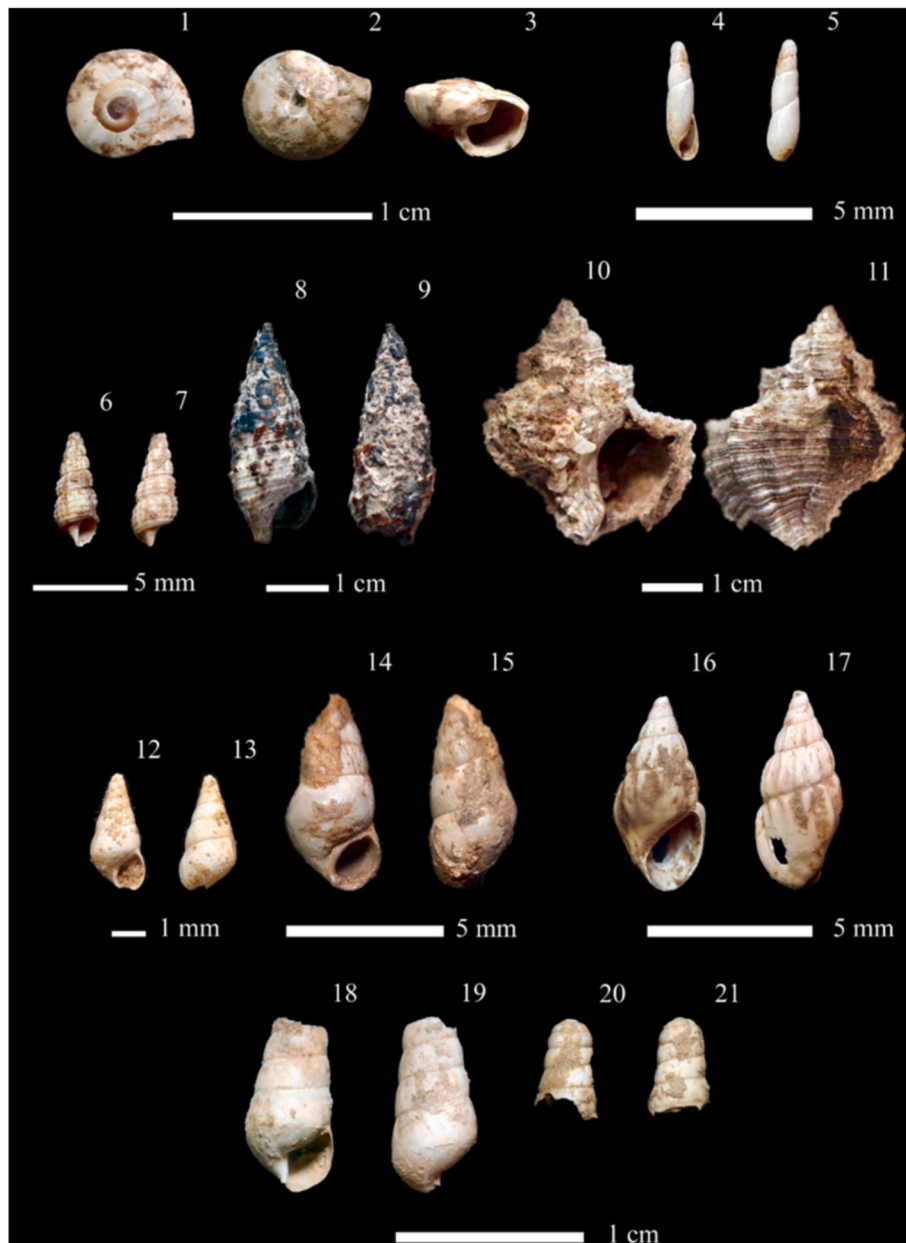
Fig. 5. Marine or estuarine (ms) and terrestrial gastropods (t). 1–3: *Candidula gigaxii* (t); 4–5: *Cecilioides acicula* (t); 6–7: *Bittium reticulatum* (ms); 8–9, *Cerithium vulgatum* (ms); 10–11: *Hexaplex trunculus* (ms); 12–15, *Peringia ulvae* (ms); 16–17, *Rissoa guerinii* (ms); 18–21: *Rumina decollata* (t).

the most representative species.

In profile C, the taxonomic analysis of almost 800 valves, carapaces and fragments has allowed to differentiate five bivalve species of five gastropod species (Table 1). High percentages of *R. decussatus* (>63%) characterise this profile, although there is a decreasing trend from the base (sample C-1: 88.95%) to the top (sample C-4: 63.68%). This species is partially replaced by *C. edule* (base: 2.63%; top: 13.16%), *L. lutraria* (base: 3.16%; top: 10.53%) and *O. stentina* (base: 3.68%; top: 6.84%). Regarding to gastropods, they are scarce (4.08–5.79%), being mainly represented by *C. acicula* and *Peringia ulvae* (Pennant, 1777) (Figs. 5, 12–15). Both species have their maximum percentages of abundance at the base of the profile (sample C-1). Barnacles are frequent in samples C-2 and C-4.

4.3. Taphonomy

The most remarkable taphonomical feature of the Cañada Honda

shell midden is the extremely high degree of fragmentation, with acute fractures in all species collected (Figs. 4 and 5). There are only 10 complete bivalve shells, which represent only 0.36% of the 2788 bivalve specimens determined. Most of the complete shells belong to ostreids [*O. stentina* and *Ostrea edulis* (Linnaeus, 1758) (Figs. 4, 15–16]]. The percentage of complete gastropod specimens is much higher compared to bivalves and 25 complete shells out of 136 specimens determined (18.4%) have been collected. They belong mainly to *C. vulgatum* (profile B: 7 specimens; profile C: 5 specimens) and *P. ulvae* (6 specimens).

Another noteworthy aspect is the presence of bivalve and gastropod specimens with signs of blackish colouring typical of carbonification (Fig. 6). This feature has been observed in some scarce bivalves (*C. edule*, *R. decussatus*) and a gastropod species [*Hexaplex trunculus* (Linnaeus, 1758) (Figs. 5, 10–11]]. In addition, a valve of *R. decussatus* presents a rounded perforation (Figs. 4, 19–20).
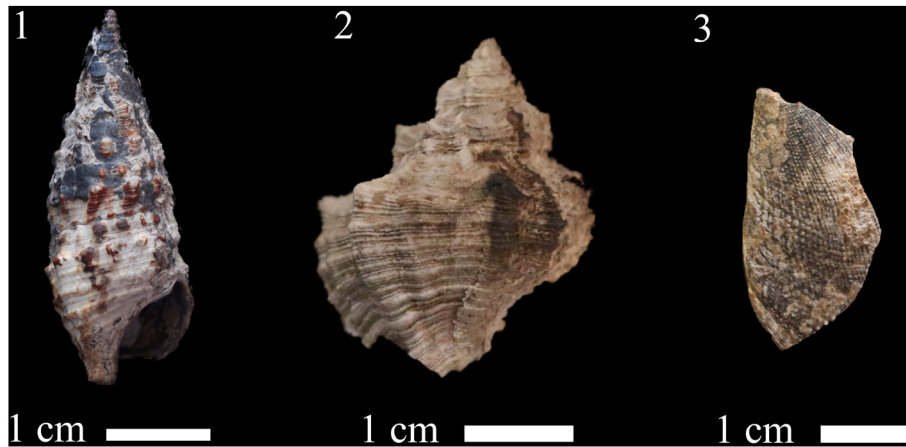
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Fig. 6. Evidence of carbonification. 1: *Cerithium vulgatum*; 2: *Hexaplex trunculus*; 3: *Ruditapes decussatus*.

4.4. Statistical analysis

The linear correlation matrix distinguishes four species associations (Table 2): i) association 1: *L. lutraria, S. marginatus*; ii) association 2: *O. edulis, C. acicula, R. decollata*; iii) association 3: *C. edule, C. vulgatum*; and iv) association 4: *R. decussatus*.

Association 1 is dominant in the basal part of profile A (Fig. 3, A: samples A-1 and A-2) where it constitutes 73–74% of the total mollusc abundance. In this profile, the trend of this association is decreasing due to its direct relationship with the decline of *L. lutraria*. This abundance contrasts with the low percentages of this association in profile C (3.16–10.53%) and especially in profile B, where it even disappears in sample B-4. Association 2 is constituted by *O. edulis* and two pulmonate gastropods. This association is present in all samples of profile A but it only exceeds 10% in sample A-6 (Fig. 3, A), which contains the highest

percentages of pulmonate gastropods (8.16%). It is almost absent in profile B and does not exceed 4.21% in profile C.

In an overview, association 3 shows an increasing trend from the base towards the top in all three profiles (Fig. 3A and B-C). The maximum percentage is low in profile A (7.81%) compared to those of profiles B (20.5%) and C (15.79%). The monospecific association 4 is clearly dominant in profiles B and C (Fig. 3, B–C), as well as in the uppermost samples of profile A. This association is partially replaced by associations 1 and 3 along profile C.

Cluster analysis distinguishes four groups of samples (Fig. 7, A). Group 1 consists of the five lower samples of profile A and it is characterized by the highest percentages of assemblage 1 (38.03–74.23%; mean-M-: 53.9%) and the lowest percentages of assemblage 4 (17.98–38.54%; M: 26.1%) This group includes two subgroups: i) subgroup 1.1 (samples A-1 and A-2), with the highest percentages of

Table 2
Correlation matrix and associations.

| PROFILE		PROFILE A						PROFILE B					PROFILE C			
SPECIES/SAMPLES		A-1	A-2	A-3	A-4	A-5	A-6	B-1	B-2	B-3	B-4	B-5	C-1	C-2	C-3	C-4
BIVALVIA	*Acanthocardia tuberculata*			0.52		1.07						0.5				
	Cerastoderma edule	1.69	2.06	5.24	7.29	5.35	6.63	7	17.5	7.54	14.57	12.5	2.53	7.22	10.71	13.16
	Lutraria	68.54	71.65	45.03	28.65	33.69	8.67	5.5	12.5			3	3.03	6.19	8.16	10.53
	Ostrea edulis				1.56		3.57									
	Ostrea stentina	2.25	4.12	5.24	9.38	11.23	10.71	3.5	4.5	7.04	11.56	10	3.54	4.12	5.1	6.84
	Ruditapes decussatus	17.98	17.01	28.27	38.54	35.83	53.57	78.5	61	75.88	69.35	69.5	84.8	75.77	69.39	63.68
	Solen marginatus	5.06	2.58	11	9.38	10.7	1.53	0.5		1				1.03	2.04	
	Undifferentiated	0.56		1.05			4.08	2.5		0.5	1.51	3.5			0.51	
GASTROPODA	*Bittium reticulatum*	0.56					1.02									
	Candidula gigaxii (p)				1.04			1		0.5					2.04	0.53
	Cecilioides aciculata (p)	1.12	1.55	2.09	1.56	1.07	4.59						3.54	3.09		1.05
	Cerithium vulgatum				0.52		1.02	1.5	3	4.02	2.01	0.5		0.51		2.63
	Hexaplex trunculus									1.51						
	Peringia ulvae	0.56		0.52			0.51		0.5	1			1.52	2.06	0.51	
	Rissoa guerinii									0.5						
	Rumina decollata (p)	1.12	1.03	1.57	2.08	1.07	3.57		1	0.5	0.5	0.5	1.02		1.53	1.58
	Undifferentiated	0.56					0.51									
SCAPHOPODA	*Antalis dentalis*											0.5				
Number of specimens studied		178	194	191	192	187	196	200	200	199	199	200	198	194	196	190
Number of species		9	7	9	10	8	11	7	7	10	6	7	7	8	8	8
Gravels (% weight)-including bioclasts-		51.9	52.8	38.6	42.3	50.1	51.6	41.2	52.2	72.2	64.5	52.5	82.1	70.1	70	28.2
Very coarse sands to fine sands (% weight)		19.5	21.5	31.6	28.6	24.1	21.3	31.7	21	12.1	13.6	21.4	8.3	14.5	13.3	28.9
Very fine sands + silts + clays (% weight)		28.6	25.7	29.8	29.1	25.8	27.1	27.1	27.8	15.7	21.9	26.1	9.6	15.4	16.7	42.9
Bioclasts studied (% weight)		11.6	11.6	10.6	20.3	15.8	21.1	9.8	14	16.5	19.1	11.4	17.2	16.3	4.2	3
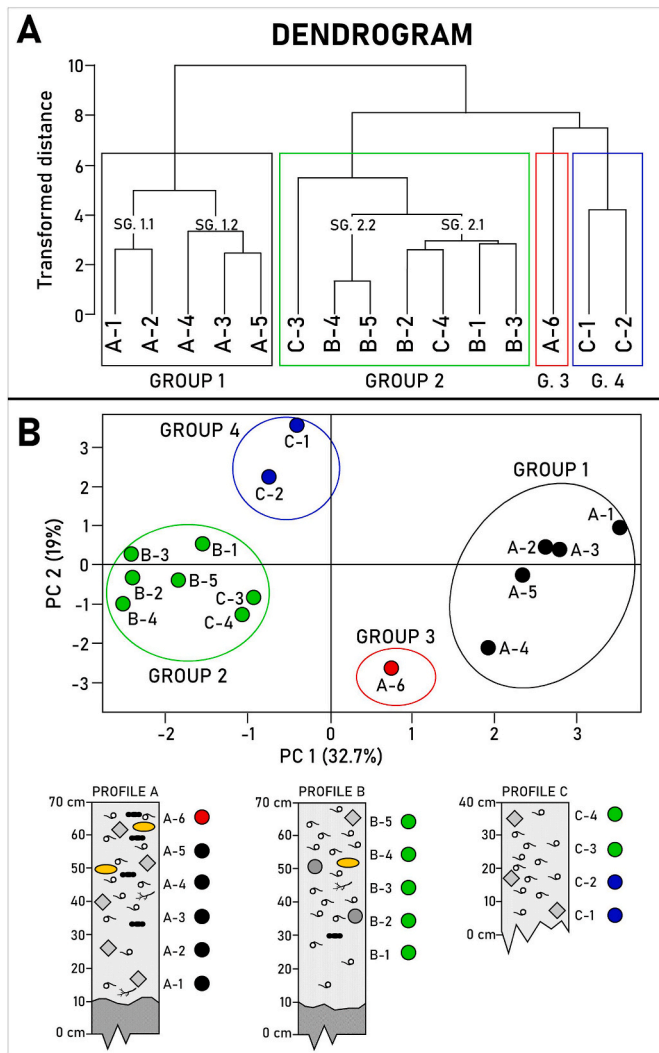
Fig. 7. A: cluster analysis; B: principal component analysis: PC1 vs PC2 and vertical distribution of the sample groups.

L. lutraria (68.54–71.65%); and ii) subgroup 1.2 (samples A-3 to A-5), with a partial replacement of this species (28.65–45.03%) by *R. decussatus* (28.27–38.54%).

All samples of profile B and the upper two samples of profile C are clustered into group 2 (Fig. 7, A). This group presents moderate to high percentages of assemblage 4 (61–78.5%; M: 55%) and the highest percentages of assemblage 3 (up to 20.5%). Two subgroups are also recognized: i) subgroup 2.1 (three basal samples of profile B and sample C-4), with moderate percentages of association 3 (8.5–20.5%) and a dominance of association 4 (61–78.5%); and ii) subgroup 2.2 (samples B-4 and B-5), which includes the highest percentages of *C. edule* and *O. stentina*.

Group 3 is represented by sample A-6, which is characterized by the highest diversity, moderate percentages of assemblage 4 and the highest percentages of ostreids (14.28%). Finally, the highest percentages of assemblage 4 (up to 88.95%) were found within group 4, constituted by the two basal sample of profile C.

The first two principal components (PC1 and PC2) explain 51.7% of the variance and its graph clearly separates the four previous groups (Fig. 7, B). Group 1 is linked to the highest values of PC1 (PC1>2), while group 2 presents the lowest values of this component [PC1<(−0.9)]. On the other hand, PC2 differentiates group 3 [PC2<(−2)] from group 4 (PC2>2). Consequently, both multivariate analyses support the existence of the four groups of samples.

5. Discussion

5.1. Where do the molluscs of Cañada Honda come from?

The malacological record of the Cañada Honda shell midden denotes the exploitation of different estuarine paleoenvironments such as: i) patches of the common otter shell *L. lutraria* in sublittoral soft substrates (sand, mud) (Kerr, 1981; Parry et al., 2003); ii) abundant populations of the carpet shell clam *R. decussatus* in mesolittoral to 5 m depth areas with freshwater inputs (Juanes et al., 2012; Gómez, 2017); iii) ebb-tide channels, estuarine depressions, low-energy beaches or tidal flats with numerous individuals of the common cockle *C. edule* (Flach, 1996; Flor et al., 1996); iv) intertidal rocky bottoms with specimens of the crested oyster *O. stentina*; or v) sandy-muddy intertidal zones with infaunal bottom communities of the razor clam *S. marginatus* (Saedi and Costello, 2019).

5.2. Taphonomic history of the cañada honda shell midden

The fragmentation of the shells leads to a significant loss of information and greater difficulty in taxonomy. The Cañada Honda shells have sharp, abrupt and highly fragmented edges. The geological movement/displacement could not have caused this high degree of fracturing because the edges of the shells should have been smooth and rounded. Therefore, the fracturing is related to various anthropic actions: i) the use of tools to open the shells of edible molluscs; ii) the very action of throwing the shells on the ground; or iii) trampling the shells in an area that they used as a "rubbish dump" close to the settlement site (e. g. Bermejo et al., 2016). The presence of some complete valves and shells (mainly oysters and *C. vulgatum*) may be due to: i) the robustness of these species and their greater resistance to taphonomic phenomena, from burial to *in situ* collection; or ii) variations in the way these species are prepared for consumption.

These shells can be grouped according to their taphonomic history into four groups: food remains, worked remains, intrusive remains and remains of unknown anthropic functionality. The most abundant taphonomic group at Cañada Honda is that of food remains (>95%). This group is made up of edible mollusc species which were collected by man and transported to the site to be consumed (Moreno, 1992). There are nine potentially edible species, including seven bivalve species (*A. tuberculata, C. edule, L. lutraria, O. edulis, O. stentina, R. decussatus, S. marginatus*) and two gastropod species (*C. vulgatum, H. trunculus*) (Theodoropoulou, 2008; Gómez, 2017).

Worked remains are constituted by several specimens of molluscs with evidence of carbonization because they were exposed to fire to be cooked or because the shells were part of the floor of their homes and on it, they made fires. This coincides with the presence of clay nodules with blackish colourations (Fig. 6), from the same process. The specimen of *R. decussatus* with a perforation belongs to this same taphonomic group because it could have been used as an ornament. This practice is usual in shell middens (Araujo, 2016).

The intrusive remains are made up of species that have been accumulated unintentionally in the shell midden, either at the same time or after the occupation of the site. This taphonomic group is formed by the three species of pulmonate gastropods (*C. gigaxii, C. acicula, R. decollata*) and the balanids, which appear as epifauna of the Cañada Honda oysters (Rodríguez et al., 2007).

Finally, the group of remains of unknown anthropic functionality is made up of malacological material that was collected by humans and shows no signs of consumption, modification and/or use (Moreno, 1992). The men from Cañada Honda may have accidently collected specimens of scaphopods, balanids, crabs or ichthyofauna (fish vertebrae) during mollusc gathering. The presence of crab fragments and fish remains indicate that the exploitation of marine resources was not exclusive to molluscs. Crustaceans and fish were a marginal resource due to their accidental appearance during harvesting, but

complementary to the diet. In the case of the scaphopod, its striking morphology may have been attractive for collection during the search for molluscs on the shores of the site (Fernández Rodríguez et al., 2008; Garrido and Vera, 2015).

5.3. Evolution of the cañada honda shell midden

Two episodes can be defined in the evolution of the Cañada Honda shell midden, according to the archaeological and malacological records:

Episode 1. This episode includes the basal samples of the three profiles, differentiated by cluster analysis (subgroups 1.1, almost the entire subgroup 1.2, part of group 2 and group 4). These samples are arranged below the level with evidence of cooking or fire, detected both in the shells and by the presence of calcined clay nodules. During this period, there is a selective collection of bivalves, which are classified and stacked in the different profiles depending on the species (profile A; association 1: *L. lutraria*, *S. marginatus*; profiles B–C; association 4: *R. decussatus*). These species live in estuaries and lagoons, although association 1 is more common in deeper infralittoral areas while *R. decussatus* is more abundant in mesolittoral zones (Saedi and Costello, 2019). The different spatial concentrations of these two associations could be due to: i) a species-selective process after capture, according to the present-day culinary tastes (*L. lutraria*: low quality; *R. decussatus*: high quality) (Consejería de AgriculturaPesca, 2001); ii) a differential capture of shallow (e.g. *R. decussatus*) and deep (e.g. *L. lutraria*) burrowing species; or iv) the temporary exploitation of patches of *L. lutraria*, an usual distribution of this bivalve (Kerr, 1981).

Episode 2. This episode is characterized by the substantial use of the venus clam *Ruditapes decussatus* as the most consumed mollusc (up to 78.5% of the total specimens), a significant reduction in the percentages of *L. lutraria* and the progressive increase of *Cerastoderma* spp. (up to 14.6%) and *Ostrea* spp. (up to 14.3%). This episode includes further evidence of combustion both in shells and silty-clayey fragments (Fig. 8). These changes may be due to: i) an overexploitation of *L. lutraria* in the estuarine environment, as it has happened with other molluscs in various south Atlantic sectors of the Iberian Peninsula (Valente, 2010); ii) the paleogeographic evolution of this estuary, with a progressive increase of intertidal sedimentary areas favorable for *Cerastoderma* spp. owing to the growing of external sandy spits and marshes (Dabrio et al., 2000); iii) a diversification of harvesting areas, including new rocky zones with oysters; or iv) a simple change in the feeding habits of the collecting populations.

6. Conclusions

The analysis of almost 3000 specimens of molluscs extracted from the Cañada Honda shell midden (Tinto-Odiel estuary, SW Spain) allows to differentiate two phases in the evolution of this site. The first phase is characterized by a selective collection of bivalves, with *Lutraria* as the most representative species in the northern part of this shell midden while *Ruditapes decussatus* was extremely abundant in its southern sector. The second phase witnessed a predominance of *R. decussatus* throughout this site, a more diversified catch of bivalves (mainly ostreids and cockles) and the evidence of carbonification in some specimens. The most remarkable taphonomical feature is the extremely high degree of fragmentation (98.8%) and the presence of four groups (food remains, worked remains, intrusive remains and remains of unknown anthropic functionality). A comparison with other shell middens of this estuary shows that *R. decussatus* was the preferred mollusc species between 8 kyr BP and 4 kyr BP in the outer estuary, while oysters and cockles were abundantly collected in the inner estuary.

Author contributions

Conceptualization: all authors; Data curation: LF, FR, JRV; Formal

Fig. 8. Evidence de carbonization in clay nodules.

analysis: all authors; Funding acquisition: FR, JRV, MLGR; Investigation: all authors; Methodology; LF, FR, GG; Project administration: MLGR; Resources: all authors; Software: FR; Supervision: JRV; Validation: LMC, PG, AT; Visualization; MLGR; Roles/Writing - original draft: all authors; Writing - review & editing: LF, FR.

Data availability

All data for this article are available in the manuscript and citations. In addition, the raw data have been included (see Supplementary data).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Applied Ecology of the University of Huelva.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quaint.2023.02.008.

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