Taphonomic analysis of archaeomalacological assemblages: shell middens on the northern coast of Santa Cruz (Patagonia, Argentina)

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ABSTRACT

This paper proposes a method of studying archaeomalacological assemblages from shell middens, and describes an application of this method in the analysis of remains recovered from systematic excavations at sites located south of the Ría Deseado estuary (northern coast of Santa Cruz Province, Argentina). This methodology aims to isolate taphonomic variables affecting archaeomalacological records to aid identification of the agents and processes involved in shell midden formation and to improve interpretations of the human activities performed at the sites. These analyses are also relevant to paleoenvironmental and paleoecological reconstructions, and to interpretations of site variability through assessments of assemblage integrity and structure.

Keywords: Archaeolomalacology; Taphonomy; Shell middens; Formation Processes; Northern Coast of Santa Cruz.

RESUMEN

ANÁLISIS TAFONÓMICOS DE CONJUNTOS ARQUEOMALACOLÓGICOS: CONCHEROS EN LA COSTA NORTE DE SANTA CRUZ (PATAGONIA, ARGENTINA). En este trabajo se presenta una propuesta metodológica para el estudio de conjuntos arqueomalacológicos de concheros y su aplicación en el análisis de restos recuperados a partir de excavaciones sistemáticas en sitios ubicados al sur de la ría Deseado, en la costa norte de Santa Cruz, Patagonia argentina. Esta metodología se focaliza en el estudio de diferentes variables tafonómicas que afectan el registro arqueomalacológico para avanzar en la interpretación de los agentes y procesos involucrados en la formación de las estructuras de concheros y sobre las actividades humanas desarrolladas en los sitios. Además estos análisis son significativos para realizar interpretaciones paleoambientales, paleoecológicas, así como para evaluar la integridad de los conjuntos, interpretar las características estructurales y la variabilidad de los sitios.

Palabras clave: Arqueomalacología; Tafonomía; Concheros; Procesos de formación; Costa norte de Santa Cruz.

INTRODUCTION

Studies on the northern coast of Santa Cruz Province, Argentina (hereafter NCSC; Figure 1) identified a large number of shell middens distributed along the coast, near the present-day shoreline. Shell middens are located on geomorphological features in areas where food resources such as molluscs and pinniped colonies are abundant (Zubimendi *et al.* 2005). Shell middens are composed of different archaeological materials in a sedimentary matrix: animal bones (seals, seabirds, fish, and terrestrial mammals, among others), lithic artifacts, charcoal and, primarily, mollusc shells. The shells' calcareous composition affords them high preservation potential (Waselkov 1987; Orquera and Piana 1999; Aguirre *et al.* 2009). The study of taphonomic modifications to mollusc shells can provide information about past human activities and formation processes at archaeological sites, as well as paleoenvironmental and paleoecological conditions (Kidwell 1991; Claassen 1998; Aguirre *et al.* 2011). As such identification of taphonomic variables can clarify the natural and anthropic process that affected archaeological assemblages (Fernández López 1999; Gutiérrez Zugasti 2008).

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Figure 1. Northern coast of Santa Cruz Province and archaeological locations mentioned in the text.

The aim of this paper is to present a methodology for the study of archaeomalacological assemblages. The focus is on identification of taphonomic processes that affect archaeological shells and the method is offered as a preliminary approach to assessing both the integrity of shell middens and the formation processes associated with these features within the study area. Additionally, results of analyses of three archaeomalacological assemblages provide a test case for the proposed methodology. The assemblages were recovered from three archaeological localities on the NCSC: Puerto Jenkins –Puerto Jenkins 2 site (PJ2)–, Bahía del Oso Marino –Las Hormigas site (LH)–, and Isla Lobos –112 site (S112)– (Figure 2).

STUDY AREA

The NCSC study area comprises approximately 420 km of coastline, bounded to the north by the boundary between Chubut and Santa Cruz Provinces, and to the south by the Bahía Laura archaeological locality (Castro *et al.* 2003). The area is characterized by an arid to semiarid climate with average temperatures between 4 °C and 17 °C, and average precipitation of 200 mm, falling largely as winter rain. Predominant winds are from the west and are strongest during the summer months. Vegetation is of the Patagonian Province of the Andean-Patagonian domain and characterized by shrub steppes composed of grasses and *coirones* (*Stipa humilius* and *S. speciosa*) and interrupted by patches of *mata negra* shrubs (*Verbena tridens*). Geomorphologically, the San Jorge gulf consists of wide sand or boulder beaches, and rocky tidal flats where mollusc shoals (*restingas*) develop. To the south of the Cabo Blanco area, the Atlantic coast extends to the Ría Deseado estuary and is characterized by beaches and small intertidal zones with some mollusc shoals. The area south of Ría Deseado is geomorphologically variable with large sand and boulder beaches interspersed with porphyritic outcrops of the Bahía Laura Formation. Mollusc shoals develop in this area and species of edible molluscs belonging to the Magellanic Biogeographic Province are available.

Archaeological materials from sites located south of Ría Deseado are used here as case studies. Archaeological records in this area indicate intensive but uneven use by hunter-gatherer populations. Major concentrations of archaeological materials are found in areas where animal resource availability –particularly marine resources– tends to be high (Zubimendi *et al.*

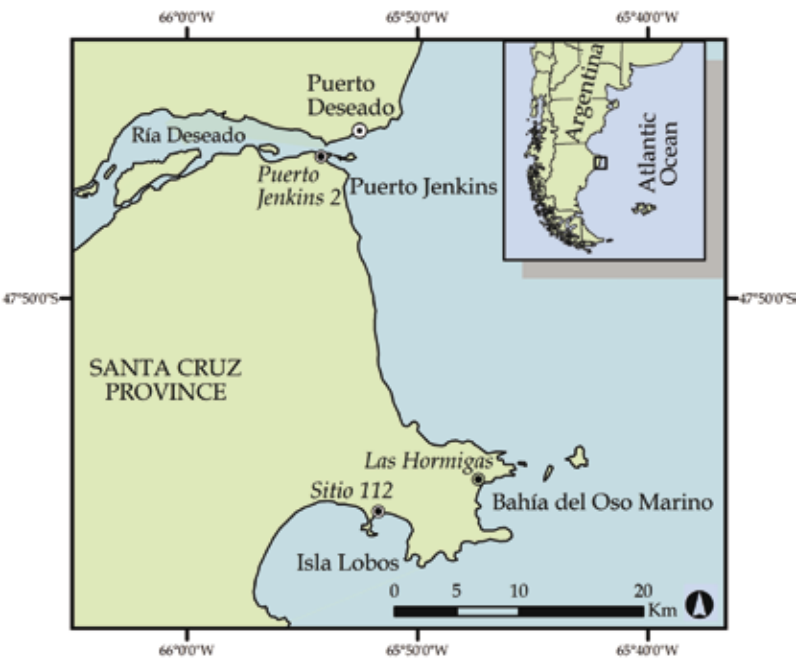

Figure 2. Archaeological sites mentioned in the text.

2005), as in the Isla Lobos, Bahía del Oso Marino, and Punta Medanosa areas (Figure 2).

SHELL MIDDENS

Table 1 provides a contextual description of the shell middens analyzed in this paper. PJ2 is located in the Puerto Jenkins archaeological locality (Figure 2) where numerous shell middens are concentrated near identified mollusc shoals. Middens are found up to 400 m from the modern shoreline (Zubimendi *et al*. 2004). PJ2, dated to 690 ± 60 years BP, is located 100 m from the Ría Deseado shoreline. LH is located in the Bahía del Oso Marino locality, where shell middens are heterogeneously distributed (Zilio and Hammond 2013). The site is radiocarbon dated to 370 ± 40 years BP and located at 16 masl and 80 m from the present coastline. S112 is located in the Isla Lobos archaeological locality (Castro *et al*. 2003), where shell middens cluster near the coastline. S112 is located 100 m away from the current shoreline and 11 masl. Fragments of charcoal associated with archaeological materials date to 2870 ± 60 years BP (Table 1).

MATERIALS AND METHODS

Excavation

On the NCSC, shell middens are composed of very thick lenses of archaeological materials, so excavations proceeded in 5-cm artificial levels. According to Bejega García (2010), stratigraphic differences between massive levels of mollusc shells may be based on biological composition where the presence or absence of particular species defines the stratigraphy. Therefore, excavating by artificial levels aids detection of differences in high-density shell lenses that may not be identified otherwise. Recovery of small items was performed using a 2 mm mesh sieve (Claassen 1998), and the "bottom sieve" –the smallest items remaining after sieving– was collected for classification and further analysis in the laboratory (Bowdler 2009).

The following section details the methodology for identification, classification, and quantification of mollusc shells. It also describes different taphonomic agents (Lyman 1994) and lists selected taphonomic variables that should be considered in any taphonomic approach to archaeomalacological assemblages.

Mollusc shell analyses: identification, classification and quantification

1. Anatomical and taxonomic identification and quantification of archaeological shellfish assemblages

In archaeological shellfish assemblages, anatomical and taxonomic identification is based firstly on distinctive features of the shells, such as morphology, color, sculpture and decoration; and secondly on biogeographical distributions. Once a shell has been identified anatomically, taxonomic identification proceeds using diagnostic features that permit assignment, ideally to the species level (Gutiérrez Zugasti 2008). Taxonomic features used in the identification of the molluscs are: (for gastropods) shape of the shell, characteristics of the umbilicus and aperture, and characteristics of ornamentation; (for bivalves) shape of the shell, hinge features, number and arrangement of muscular impressions, and ornamentation (Moreno Nuño 1994: 16); and (for polyplacophorans) shape of the shell and ornamentation (Gordillo 2007). Shells are grouped into categories according to their preservation:

- *Complete shells* (VCOM) are those exhibiting more than 90% of the original shell and an individual diagnostic element, known as a *Non-Repetitive Element* (NRE; Mason *et al*. 1998). An NRE is a part of a shell that is diagnostic for each species or genus, which can be counted a number of times to infer the presence of an individual. In gastropods, NRE include the apex, *columella,* and foramen. In bivalves, it is the hinge or the umbo, to be differentiated right from left. Polyplacophorans (chitons) are composed of eight plates, one cephalic, one caudal, and six intermediate; individuals can be counted taking the highest value of cephalic or caudal plates. On complete shells, biometric measurements are made, including length, width, and height of the shell.
- *Diagnostic shell fragments* (VFRA) are shells less than 90% complete but that still contain an NRE. Gastropod fragments were assigned to one of two categories.1) IFRA are fragments with intact *columella* ends but that lack the buccal area. Among *Nacella magellanica,* IFRA contain the apex and part of the shell. 2) FAPI are fragments that include apex or portions of it. On bivalves the identifiable fragments were subdivided into: VFRA (fragmented shell) and FCHC (fragment of umbo or hinge complete) (Álvarez Fernández 2007).

Archaeological locality	Archaeological site	Age ^{14}C (years BP)	Location	Excavated área (m^2)	Stratigraphic thickness (cm)
Puerto Jenkins	Puerto Jenkins 2 –PJ2–	690 ± 60 (LP-2603)	cord of coastal boulders with sandy cover burdensome	0.5	43
Bahía del Oso Marino	Las Hormigas –LH–	370 ± 40 (LP-2504)	aeolian mantle on Holocene terrace	1	55
Isla Lobos	Site 112 –S112–	2870 ± 60 (LP-2141)	Aeolian mantle	0.25	17

Table 1. Description of archaeological sites presented in this paper.

- *Fragments* (FRAG) are pieces of shell that lack diagnostic elements. Fragments can contribute to measures of abundance including NISP, the number of identifiable specimens (complete shells plus fragments), and MNI, the minimum number of individuals for each genus or species. For gastropods, MNI is calculated according to the formula: VCOM + FAPI + IFRA. For bivalves, MNI is calculated as VCOM + FCHC + VFRA (taking the highest value between left and right VFRA; Álvarez Fernández 2007). Fragments are also used to calculate taxonomic richness, defined as the total number of taxa in a collection. Assemblage diversity is the number of individuals (NISP or NMI) distributed across all the identified species or taxa (Claassen 1998; Dupont 2003).

In the NCSC contexts analyzed to date, we have identified three groups of molluscs –gastropods, bivalves, and polyplacophorans– using specific literature (Castellanos 1970; Aguirre 2003; Aguirre *et al*. 2009 and Gordillo 2007 for polyplacophora, among others), and a comparative collection consisting of both modern and archaeological specimens (Bejega García 2010), and following the nomenclature of the World Register Marine Species (WoRMS 2012) database.

2. Biometric analysis

Following taxonomic identification of archaeomalacological assemblages, biometric analysis (length, width, and height) of complete shells is required. Shell size is related to the age of the individual, the microenvironment in which it developed, and ontogenetic growth rate, which decreases as age increases (Claassen 1998). At NCSC shell middens, the most abundant conchological species are *Nacella magellanica* (limpet), *Aulacomya atra* (ribbed mussel), *Mytilus edulis* (blue mussel), and *Perumytilus purpuratus* (Zubimendi *et al*. 2005; Zubimendi 2012; Hammond and Zubimendi 2013). To gauge shell size, the maximum diameter of the base of the shell is measured in *Nacella magellanica*; in bivalves, maximum diameter is measured from the umbo to the distal end of the shell. Usually, biometric analyses are used to interpret the processes of overexploitation, in studies of growth environments, for estimating season of harvest (Claassen 1998), and to determine whether there may have been size selection during harvesting (Álvarez Fernández 2009). Occasionally these analyses have also been used to explore the mode of harvest, estimate the size of the sampled population, and identify rare or uncommon species at archaeological sites (Claassen 1998).

3. Weight of the remains

The weight of archaeomalacological assemblages is a variable that has been widely discussed by many authors (Claassen 1998, 2000; Mason *et al*. 1998, 2000; Glassow 2000). Claassen (1998: 107) points out that criticisms of shell weight quantification center primarily on the loss of weight with diagenesis, which affects different species at different rates. The author notes that the older the site or the more acidic the soil, the greater the loss of calcium carbonate and conchiolin and the greater the differential loss of calcium carbonate between species. Álvarez Fernández (2007) indicates that we must consider that different taphonomic agents and processes that could affect archaeomalacological remains and the weight of shells, such as descaling or precipitation of calcium carbonate and matrix acidity. Moreover, Bejega García (2008) notes that despite the limitations of weight for estimating abundance, weight values are still important as they may reflect changes in the shell composition of archaeological levels within a site. In the same way, if a sample is highly fragmented, weight is sometimes the only available criterion of analysis.

Taphonomic agents and taphonomic processes

1. Taphonomic agents

A taphonomic agent is a source of force applied to materials, and the physical cause of modification (Morlan 1984; Lyman 1994). Archaeological materials have their own taphonomic histories, and it is necessary to identify the agents and processes responsible for any signs of modification. Agents that modify materials in the archaeological record have predictable physical effects (Schiffer 1983) that can be inferred (Nash and Petraglia 1987). In this way, taphonomic studies in archaeology contribute to our understanding of the formation of archaeological sites (Borrero 1988).

A variety of taphonomic agents alter the remains that compose shell middens:

- *Biological*: Fauna (both vertebrates and invertebrates) and flora are considered among biological agents. At NCSC, fossorial rodents (*Ctenomys* sp.), Magellanic penguins (*Spheniscus magellanicus*), and armadillos (*Zaedyus pichiy* and *Chaetophractus villosus*) are among the animals that modify remains and their spatial arrangements in shell middens by moving and scattering archaeological material. These animals can also introduce foreign remains through the caves they excavate (Hammond *et al*. 2013). The modern introduction of livestock (sheep) is another factor that disturbs shell middens; trampling causes the removal, displacement, and fragmentation of archaeological remains. Vegetation may also cause movement and mixing of archaeological remains, and root growth in fissures or cracks may fracture shells, all of which can mechanically change the original structure of deposits. Roots between the shells can also trigger chemical dissolution (Gutiérrez Zugasti 2008).
- *Anthropic*: Human populations can modifiy the archaeological record in several ways, whether deliberately or accidentally. Such modifications can

be divided into ones produced during occupation of the site and those that occur after abandonment. For example, trampling of archaeomalacological remains post-deposition can cause considerable fragmentation and horizontal displacement. Subsequent reoccupation of archaeological sites can further modify preexisting structures.

Excavation by non-specialists, construction of roads, urban growth, and the use of vehicles in coastal areas are also agents of archaeological site destruction (Ceci 1984; Zubimendi *et al.* 2012).

- *Physical-geological*: The primary physical agents affecting shell middens are water and wind. In open-air shell middens, fluvial processes and wind can transport archaeological remains, resulting in the modification of site morphology and structure. Wind erosion, storms, and sudden changes in temperature can accelerate the degradation, fragmentation, and mobilization of the shells (Claassen 1998). Moisture and sunlight are other agents that may alter the remains.
- *Chemicals*: Archaeological remains can be chemically altered according to chemical conditions within the sedimentary matrix. A variety of variables, including pH and the relative proportion of organic matter, phosphate, carbonate and salt, can be studied to assess conservation, pollution, and other chemical processes that affect assemblages. The pH level of the matrix affects the preservation of certain archaeological remains. Stein (1987) suggests that soil pH is affected by the amount of organic waste introduced by people during site occupation. Generally, an abundance of calcium carbonate, of which shells are composed, causes a neutral or slightly alkaline pH, which tends to preserve many organic remains (Orquera and Piana 2000). However, a highly alkaline environment creates unfavorable conditions for the preservation of organic remains such as bone because it induces collagen hydrolysis (Favier Dubois and Bonomo 2008). High salinity and high levels of organic matter within the midden matrix cause a higher incidence of corrosion.

2. Taphonomic processes on shells

People and animals are geomorphological agents that produce archaeological sediments, the physical, biogenic, and cultural components of which require identification and interpretation (Butzer 1982: 66). Thus, shell accumulations are considered archaeosediments (Butzer 1982; Stein 1987). The identification of natural and anthropic components is therefore critical to the interpretation of formation processes at archaeological sites. For this reason, analysis of taphonomic processes that have affected archaeological remains is a means of understanding their origins and the changes they have undergone throughout the formation of the archaeological deposit.

Taphonomic variables

- *Preservation of periostracum*: The periostracum is an outer membrane composed of protein that covers the shells of some gastropods and bivalve molluscs (Figure 3A). This membrane is especially visible in the shells of species within the family *Mitilidae,* particularly *Aulacomya atra* and *Mytilus edulis*. This organic layer is secreted by a mantle portion of molluscs, and its main function is to protect the limestone part of the shell against various hazards including acidic substances (Camacho 2007). Preservation of the periostracum on archaeological shells is interpreted as a sign of the record's integrity and of rapid burial (Zubimendi 2012; Hammond and Zubimendi 2013). Preservation of this membrane in stratigraphic contexts is also determined by conditions within the sedimentary matrix (moisture, organic content, and pH). Under unfavorable conditions of burial, periostracum loss will progress through time. When exposed to environmental conditions (wind, sun, rain, and moisture) the periostracum dries quickly, fractures and falls off easily. The preservation of periostracum is recorded as present (1) or absent (0).

Figure 3. A. *Aulacomya atra* shells with preserved periostraca; B. Shells with evidence of surface corrosion; C. Shells with evidence of surface abrasion.

- *Corrosion*: Corrosion occurs when calcium carbonate –in the form of calcite or aragonite (Camacho 2007)– or other mineral components of the shell dissolve due to chemical conditions in the environment (Gutiérrez Zugasti 2008; Figure 3B). Chemical erosion first attacks thinner surface areas, which leads to characteristic shapes on particular taxa. Some effects of chemical dissolution of shells are a corroded appearance of surfaces, loss of ornamentation, and thinning and development of holes and cracks (Fernández López 1999: 81). Identification of such alterations can indicate the environmental conditions in the organism's habitat or deposition matrix. Moreover, corrosion can be inferred from analyses of the substrate where the remains were deposited. Corrosion and dissolution of shells' mineral components are greater in areas where salinity is high, temperatures are low, and bioturbation is common (Claassen 1998: 59). Chemical dissolution is also related to sediment moisture conditions, climatic fluctuations, and the abundance of vegetation in the substrate (Aguirre *et al*. 2011). Corrosion is recorded as present (1) or absent (0).
- *Abrasion*: Abrasion refers to the removal of calcium carbonate, of which shells are composed, by physical processes or bioerosion (Claassen 1998). This process leads to weathering of shells' most prominent exterior ornamentation, modifying their original texture and creating porous surfaces (Figure 3C). *Corrasion* is abrasion caused by wind (Breed *et al*. 1997) and its effects vary according to wind speed, hardness of the abraded surface, concentration of abrasive particles (such as sand), and the density and distribution of vegetation and topographic features (Waters 1992).Time of exposure on the land surface is also a factor. Abrasion analysis can provide information regarding sedimentation at the archaeological site, displacement of archaeological remains, and post-depositional processes. It is important to assess abrasion to identify which remains were incorporated in to the site by people, and which by natural processes. For example, small gastropods that form natural coastal cords where archaeological sites are sometimes located generally have evidence of marine abrasion and can be integrated as part of the sedimentary matrix of sites. Shell abrasion is recorded as present (1) or absent (0).
- *Deformation*: Deformation refers to changes in the size, shape, structure, and/or texture of shells due to mechanical stress. This process may cause folds, fissures, cracks, or fractures. Sediment pressure may cause deformation of overall shape (Álvarez Fernández 2009). This process is enhanced if the sediment column has high levels of moisture or organic material, which affect the microstructure of the shell and its resistance (Zuschin *et al*. 2003). At NCSC, deformation has been observed mainly on limpet shells.
- *Fragmentation*: Fragmentation is one of the most common processes observed in archaeomalacological assemblages and involves breakage of shells and separation of the fragments. This process can affect anatomic and taxonomic identification of the remains (Gutiérrez Zugasti 2008). Shells, particularly those of bivalves, tend to fragment along existing features, such as growth and ornamentation lines (Farinati and Zavala 1995). Fragmentation will vary according to the morphology, microstructure, thickness, ornamentation, size and strength of the shell, as well as biostratinomic processes (Claassen 1998; Aguirre *et al*. 2011). Other factors that may affect the structure of shells and increase fragmentation of an assemblage are exposure to heat (Claassen 1998), decalcification and biodegradation (Gutiérrez Zugasti 2008), and the amount of organic matter and moisture in the sedimentary matrix (Zuschin *et al*. 2003). Sedimentary processes such as compression (Claassen 1998), and biological (*e.g.*, bioturbation and root action) and natural processes (*e.g.*, effects of water, wind and temperature fluctuations) may also influence increase fragmentation rates. Fragmentation increases the susceptibility of the particles to size sorting and transport by different agents (Claassen 1998: 55). Different anthropic processes can produce fragmentation such as trampling, site cleaning (removal of remains), production of artifacts or instruments, or the mode of shellfish gathering.
- *Thermal alteration*: Heat alters the crystallographic structure of shells. The higher the temperatures they are exposed to, the faster they will deteriorate and, ultimately, break. Shells affected by thermal exposure experience changes in the original color of the surface and weight loss relative to unburned shells (Claassen 1998). For example, limpets that have not been affected by heat are brown whereas those exposed to high temperatures for longer periods are dark gray, often carbonized, and their structure is very weak, which causes them to be easily fragmented (Claassen 1998; Villamarzo 2009), thereby affecting conservation of the entire assemblage. Carbonification is related to the exposure of shells directly to flames, and involves carbon enrichment. Typically, molluscs are covered by a layer of very fine gray sediments (Gutiérrez Zugasti 2008).
  Thermal alteration of shells is determined by macroscopic appearance and color and recorded as not burned (0, original color); burned (1, light brown-gray); carbonized (2, dark brown to black color); or calcined (3, white color) (Villamarzo 2009; Villagran *et al*. 2010).
- *Breakage and/or deliberated impact of shells*: It has been suggested that breakage and/or impact on shells may be related to the way some species of molluscs were harvested (Pailler *et al*. 2007). In particular shell middens at NCSC, many limpet shells are cracked or broken (Figure 4A). These breaks may be due to the use of an instrument to release the molluscs from the rocks where they grow. When a hard blow is delivered to detach a shell, breaks along the margin or side may occur. Classification and recording of impacts and breakage follows Pailler and colleagues (2007). These authors divide shells of the gastropod *Nacella magellanica* into eight zones and in three areas in relation to the height of the shell (Figure 4B). By this method, the location of impacts / breakage can be recorded in a way that permits comparison.
- *Bioerosion*: The analysis of bioerosion can provide paleoecological information. Many marine organisms are capable of eroding and modifying shells, for predatory reasons or otherwise (Figure 5). Algae, fungi, foraminifera, bryozoans, bivalves, gastropods, sponges, and barnacles can cause such modifications before and/or after death of the shellfish (Claassen 1998). Some gastropods, particularly

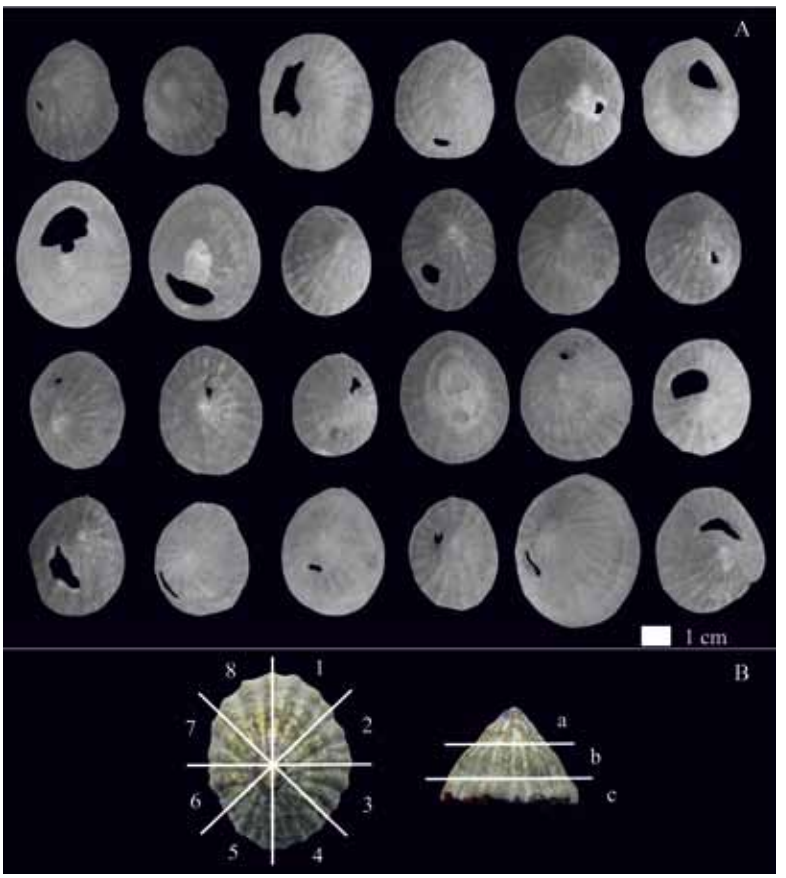

Figure 4. A. Shells with evidence of impacts and breaks; B. Segmentation of shells to record the position of impacts and breaks.

naticid and muricid, drill shells with their radula leaving circular holes with slightly tapered or straight sides (Álvarez Fernández 2009). The holes produced by mollusc drilling can result in either complete perforation or incomplete, "unsuccessful" perforation. Perforations are made in exposed or weak areas of shells; among bivalves, this is usually near the umbo, and among gastropods, near the apex. Drilling facilitates future fracture of shells (Claassen 1998; Zuschin *et al*. 2003). Completely perforated shells likely entered the deposits dead because of the action of bioeroding organisms to obtain soft tissue or calcium.

Sometimes mollusc shells have other epibiont organisms attached to them. Such organisms erode and remove the periostracum, and produce erosion and surface marks. Heavy encrustation occurs on dead organisms' shells exposed at the water–sediment interface in low energy habitats (Claassen 1998). It is important to identify these types of marks to avoid confusion with marks produced by humans. Bioerosion studies allow understanding the presence of certain species in the malacological assemblage, which could be incorporated to the site embedded on shells collected by human groups. In the archaeomalacological assemblages of the NCSC, *Balanus* sp. is the predominant encrusting species (Hammond and Zubimendi 2013). Sometimes the encrustations occur on the inner surface of the shells, which indicates that they were incorporated into the archaeological record after the death of the organism. The presence of encrustations or epibiont organisms can prevent the effects of bioeroders on shell surfaces (Claassen 1998: 40).

• *Color preservation*: This variable is recorded as an indicator of preservation of the remains. The preservation of color depends primarily on the chemical composition and stability of the pigment that colors the surface, and the mineralogical composition of shell (Claassen 1998). Color loss is determined by different agents. It is important to distinguish the processes involved and their effects because different processes can have similar effects (Lyman 1994: 38). Abrasion, corrosion, and thermal alteration are the main taphonomic processes related to the loss of original shell color, and can significantly affect the surface coloration and ornamentation. Color loss due to sunlight exposure causes shells to acquire a white color superficially. Preservation of original shell color was recorded using the following scale: conservation of the original color (0); partial conservation of the original color (1); total loss of original color (2); total color loss by sun exposure (3) (Figure 6).

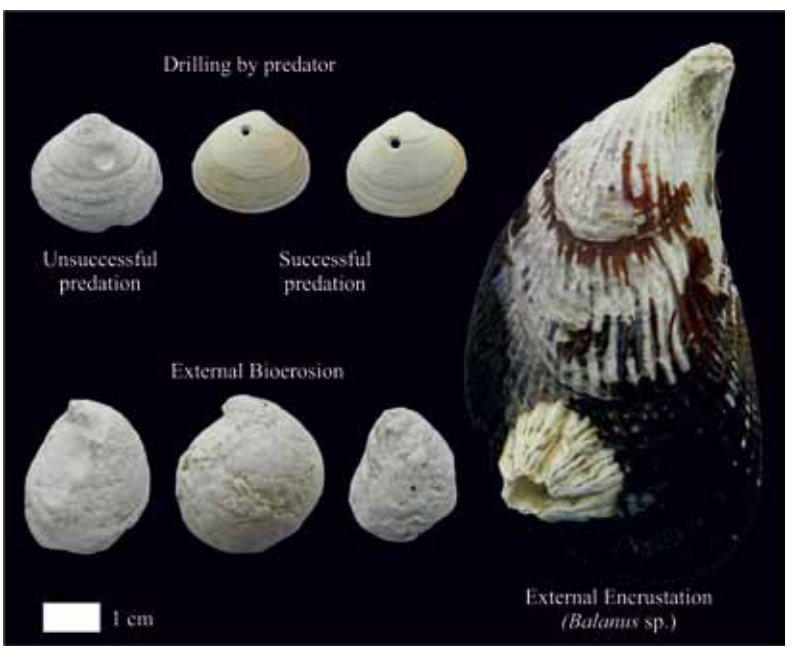

Figure 5. Shells with surface bioerosion.

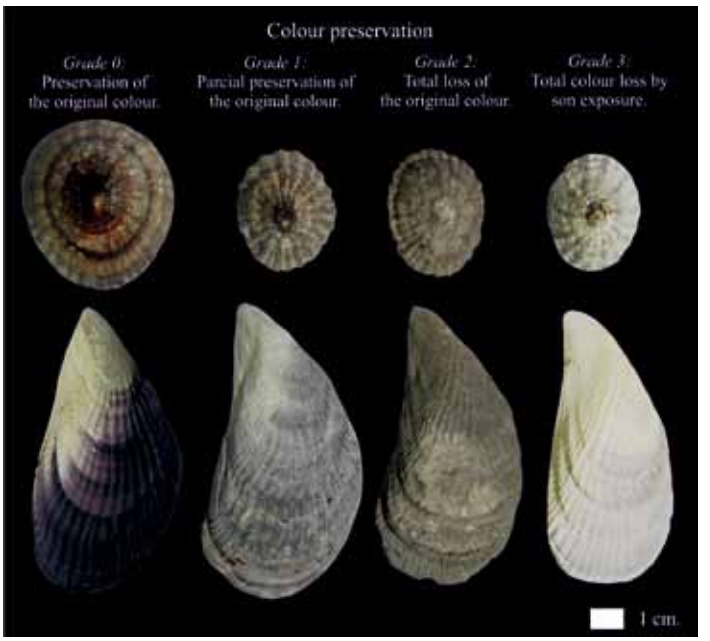

Figure 6. Degrees of color preservation of shells.

RESULTS

Table 2 presents a characterization of shells identified in each of the middens analyzed in terms of the variables proposed by Favier Dubois and Borella (2007), Zubimendi (2012), and Hammond and Zubimendi (2013). Excavations profiles are presented in Figure 7. Shell middens are located on different geomorphic surfaces: lines of coastal boulders with sandy cover and sandy aeolian mantles. The shell concentration at the PJ2 site is described as having tabular stratigraphic geometry with a high density of shells in contact with each other (bioclast-supported structure). The LH and S112 sites are described as having lenticular geometry affected by erosion and deflation that has exposed the surfaces of archaeological remains. These processes generated mound-shaped accumulations formed by a surface layer of shells redeposited above aeolian sediments that compose the dunes (Hammond *et al*. 2013). In all three case studies, individual lenses with high-density archaeological remains were identified in the stratigraphic sequence. The surfaces on which the sites are located are horizontal to subhorizontal. During excavations, articulated mussel shells were recorded in LH and S112, and imbricated limpet shells were recorded *in situ* at PJ2. These features indicate rapid burial without mobilization of the archaeological remains.

Malacological composition of shell middens

Table 3 presents mollusc species NISPs and MNIs for each excavation. Twenty-three species were identified, and some specimens remain unidentified. Most of the species are gastropods and *Nacella magellanica* is the predominant species in all assemblages. The remaining gastropod species occur in smaller amounts. Of the bivalves, *Mytilus edulis*, *Aulacomya atra* and *Perumytilus purpuratus* predominate; the rest of the species are represented by a few specimens each. Regarding species richness, LH has the highest conchological diversity, while S112 exhibits

Variables analyzed		Puerto Jenkins 2	Las Hormigas	Site 112
Concentrations of shells	Thickness	15 cm	8 cm	6 cm
	Location	sandy cover burdensome	aeolian mantle	aeolian mantle
	Geometry	Tabular	Lenticular	Lenticular
	Estratigraphy	1 lens of shells	1 lens of shells	1 lens of shells
	Orientation	No preferential orientation	No preferential orientation	No preferential orientation
	Tilt	Subhorizontal	Subhorizontal	Subhorizontal
	Shells articulated *in situ*	Yes	Yes	Yes

Table 2. Features of shells concentrations at the shell middens.

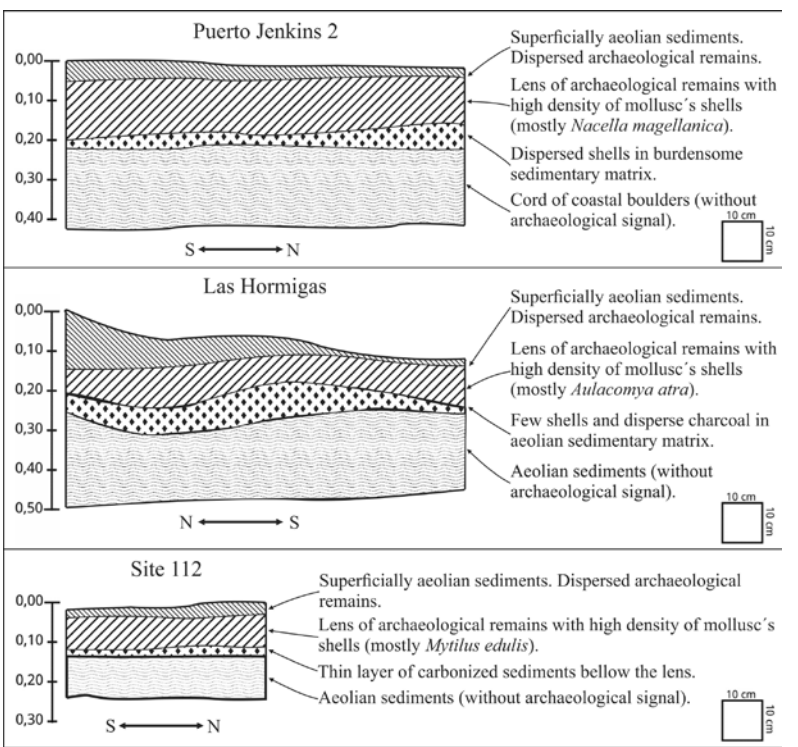

Figure 7. Excavations profiles.

Mollusc	Puerto Jenkins 2		Las Hormigas		Site 112	
Cl. Gasteropoda	*NISP*	*MNI*	*NISP*	*MNI*	*NISP*	*MNI*
Nacella magellanica	2440	2440 (69.2%)	509	509 (18.85%)	35	35 (5.8%)
Crepipatella dilatata	94	94 (2.66%)	72	72 (2.7%)	4	4 (0.7%)
Pareuthria plumbea	2	2 (0.05%)	7	7 (0.25%)	2	2 (0.35%)
Trophon geversianus	2	2 (0.05%)	5	5 (0.2%)	-	-
Buccinanops globosum	-	-	2	2 (0.07%)	-	-
Adelomelon sp.	1	1 (0.02%)	-	-	-	-
Epitonium magellanicum	-	-	1	1 (0.04%)	-	-
Siphonaria lessoni	5	5 (0.14%)	12	12 (0.45%)	7	7 (1.16%)
Fissurella sp.	5	5 (0.14%)	11	11 (0.4%)	-	-
Acantina monodon	-	-	1	1 (0.04%)	-	-
Kerguelenella lateralis	31	31 (0.9%)	9	9 (0.35%)	9	9 (1.5%)
Iothia coppingeri	-	-	1	1 (0.04%)	-	-
Gasteropodoindet.	3	3 (0.08%)	10	10 (0.35%)	-	-
Cl. Bivalvia	*NISP*	*MMI*	*NISP*	*MNI*	*NISP*	*MNI*
Mytilusedulis	1390	726 (20.6%)	1462	761 (28.2%)	941	488 (81%)
Aulacomyaatra	164	101 (2.9%)	1658	873 (32.5%)	10	6 (1%)
Perumytilus purpuratus	207	114 (3.2%)	709	389 (14.4%)	82	50 (8.3%)
Ensis macha	-	-	17	11 (0.4%)	1	1 (0.16%)
Hiatella solida	1	1 (0.02%)	3	2 (0.07%)	-	-
Hiatellaartica	-	-	1	1 (0.04%)	-	-
Taweraelliptica	1	1 (0.02%)	18	11 (0.4%)	-	-
Petricolaria patagonica	-	-	1	1 (0.04%)	-	-
Darina solenoides	-	-	2	2 (0.07%)	-	-
SF. Veneridae	1	1 (0.02%)	3	3 (0.11%)	-	-
Cl. Polyplacophora	*NISP*	*MNI*	*NISP*	*MNI*	*NISP*	*MNI*
Neoloricata	-	-	15	4 (0.14%)	-	-
Richness	13	13	18	18	9	9
Total	4347	3527	4529	2698	1091	602

Table 3. Species of molluscs at the shell middens (NISP and MNI).

the minimum value, the latter being both the earliest site and the one with the smallest excavated area. Table 4 presents the weight of the shell remains at each site, sorted by mollusc class and quantification category.

Taphonomic alterations of the shells

The taphonomic analysis of mollusc shells presented here is preliminary and, accordingly, we focus our analysis of taphonomic processes on complete mollusc shells (VCOM).

Preservation of the archaeomalacological remains is uneven at our study sites (Table 5). The main processes that have affected the shells in these assemblages are fragmentation, corrosion, and thermal alteration. Regarding shell color preservation at LH, a very low percentage of the specimens retain their original color (2.2%) and more than half of the assemblage reflects a partial loss of original shell color (68.9%). In the PJ2 and S112 assemblages, almost all of the shells have completely lost their original color, possibly due to high levels of thermal alteration and corrosion. The total loss of color by sun exposure is very low at LH, and was observed primarily among remains exposed on the surface. At LH, a high percentage of shells (primarily *Aulacomya atra*) retain their periostraca, which may indicate rapid burial and a high-integrity record (Zubimendi and Hammond 2009; Zubimendi 2012; Hammond and Zubimendi 2013).

The PJ2 assemblage has a high incidence of corrosion (99.5%), while the proportion of abraded shells is low in all of the analyzed assemblages. Abrasion is evident on shells that were exposed on the surface and in contact with particles that abraded and polished surfaces.

Thermal alteration among shells from LH, indicate that part of the assemblage was exposed to heat. However, well-preserved shell structures suggest the heat exposure may have been of short duration or the temperature relatively low. At S112, the malacological remains have been severely affected by thermal

Archaeological sites	Mollusc	Weight of the remains of shells (grams)			
		VCOM	VFRA	FRAG	TOTAL
Puerto Jenkins 2	Cl. Gasteropoda	13,514	2,862	12,689	33,315
	Cl. Bivalvia	667	3,583		
	Cl. Polyplacophora	0	0		
Las Hormigas	Cl. Gasteropoda	1,945	191	9,615	20,927
	Cl. Bivalvia	4,084	5089		
	Cl. Polyplacophora	2	1		
Site 112	Cl. Gasteropoda	237	44	2,513	5,840
	Cl. Bivalvia	558	2,488		
	Cl. Polyplacophora	0	0		

Table 4. Weight of the remains of shells.

Variables analyzed			Puerto Jenkins 2	Las Hormigas	Site 112
Color preservation	Original color		0 (0 %)	39 (2.22%)	0 (0%)
	Partial conservation of color		70 (3.6%)	1207 (68.9%)	3 (2%)
	Total color loss		1877 (96.4%)	489 (27.9%)	175 (98%)
	Total color loss by sun exposure		1 (0.1%)	17 (1%)	0 (0%)
Taphonomic variables	Periostracum conservation		1 (0.1%)	1006 (57.4%)	0 (0%)
	Evidence of corrosion		1939 (99.5%)	649 (37.05%)	118 (66%)
	Evidence of abrasion		6 (0.3%)	8 (0.45%)	0 (0%)
	Presenceofencrustations		5 (0.3%)	18 (1.03%)	0 (0%)
	Evidence of bioerosion		11 (0.6%)	4 (0.25%)	0 (0%)
	Thermal alteration	not burned	0 (0%)	406 (23%)	0 (0%)
		burned	840 (43%)	1349 (77%)	0 (0%)
		carbonized	0 (0%)	0 (0%)	0 (0%)
		calcined	1108 (57%)	0 (0%)	178 (100%)
	Breakage and/or deliberate impact on shells of *Nacella magellanica*		460 (23.6%)	139 (7.95%)	3 (2%)
Total of mollusc shells (VCOM) on which color and taphonomic variables were calculated			1948	1752	178

Table 5. Color preservation and taphonomic processes that have affected the malacological remains.

alteration. The shell lens was located above a burned layer of sediment, ash and charcoal; the shells' surfaces are light gray to white (calcined), they have lost the original color, and their crystallographic structure has been altered and deteriorated. During excavation, shells were easily fractured when removed from the sediment. The PJ2 malacological assemblage was also thermally altered, which accounts for the high percentage of shells exhibiting total loss of original color, that are brown (43% burned) or are light gray to white (57% calcined). Also, there is a high percentage of *Nacella magellanica* shells with impacts or breaks, interpreted as anthropic alteration due to the irregularity of the fractures, similarity to other excavated sites, and based on experimental replication. The proportion of shell alterations by other marine organisms (encrustation and perforation) is insignificant, and the primary encrusting species recorded at the sites is *Balanus* sp.

Fragmentation of archaeomalacological assemblages

The malacological assemblages analyzed here all have similar percentages of fragmentation: approximately 70% of *Nacella magellanica* shells are complete (Figure 8), while *Mytilus edulis* and *Aulacomya atra* shells are highly fragmented. Mussel shells are best preserved at LH (23% of *Mytilus edulis* and 30.5% of *Aulacomya atra* were complete), whereas only 10% of *Mytilus edulis* and *Aulacomya atra* shells are complete at S112 (Figure 8). Fragmentation may be influenced by deterioration of the shells due to thermal alteration. *Perumytilus purpuratus* shells were differentially preserved at the sites. At PJ2, 47.3% of this species is complete; while at LH and S112 71.8% and 73.2% of *P. purpuratus* shells are complete, respectively. Signs of *in situ* fragmentation of *Mytilus edulis* and *Aulacomya atra* shells were observed at LH and S112, which may be the result of trampling and/or sediment compression.

Unidentifiable fragments (FRAG) represent large volumes of malacological material in the study area. To date, we have used weight to estimate the relative abundance of this type of debris (Table 4). Some authors identify the remains at the level of the species and perform quantification thereof (Moreno Nuño 1994; Álvarez Fernández 2007; Bejega García 2009). Another approach is assessing the size of fragments to evaluate factors of fragmentation and depositional history (Stein 1987; Ford 1992). Such analyses of unidentifiable fragments (FRAG) should be part of future studies designed to more thoroughly investigate the multiplicity of agents and factors that determine the preservation of shells (Muckle 1985; Ford 1992; Claassen 1998).

DISCUSSION

The archaeomalacological assemblages presented in this paper correspond to single discard events. The shells were in contact with one another (bioclast-supported fabric) at all sites, creating discrete lenses of archaeological remains with good integrity. At LH and S112, deflation and erosion have exposed the archaeological materials, which begin to deteriorate

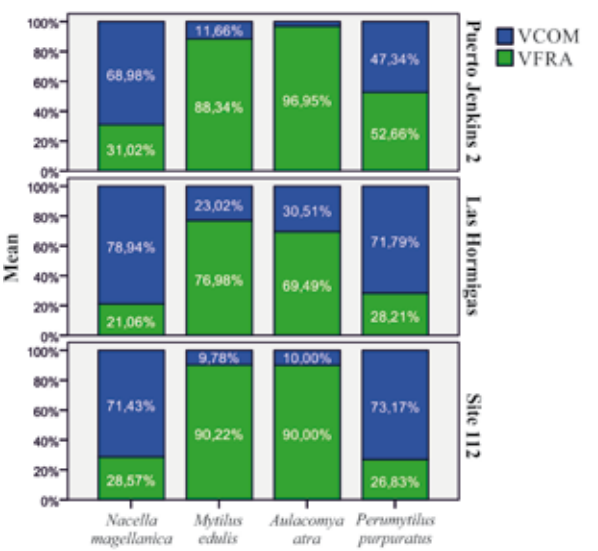

Figure 8. Percentages of complete (VCOM) and fragmented (VFRA) shells of the main species represented at the sites.

rapidly when subjected to environmental conditions. At PJ2, the archaeological remains are completely buried, and the site surface was covered by vegetation that fixed the surface sedimentary layer and prevented exposure of the archaeological remains. The integrity of the assemblages is good; burial was likely rapid and archaeological materials appear not to have been scattered. This resulted in the formation of massive archaeological deposits, resistant to disaggregation. At all sites the level of abrasion is low, and evidence of abrasion was observed only on shells found in superficial layers, indicating that they were not exposed to environmental conditions (wind, water effect) for long time.

The taphonomic processes most evident among the assemblages are fragmentation, corrosion, and thermal alteration, although the malacological remains are generally well preserved. At LH, rapid burial preserved periostraca and original color in high proportions (though it should be noted that this is also the youngest site). Articulated mussel shells were found *in situ* at the three sites, and imbricated limpet shells were found at PJ2. High percentage of corrosion and thermal alteration were also recorded at PJ2, which led to a high percentage of shells exhibiting loss of original color. At S112, shells were severely altered by heat, which made them very weak; bivalve shells in particular have not preserved periostracum neither the original shell color.

Similar trends in fragmentation are observed in all assemblages. *Mytilus edulis* and *Aulacomya atra* shells have the highest percentages of fragmentation, while *Perumytilus purpuratus* and *Nacella magellanica* have higher percentages of complete shells. This could be due to structural and morphological characteristics of the shells themselves, although it must be recognized that different processes (*e.g.*, corrosion, thermal alteration, sediment pressure) can significantly affect their structure and lead to fragmentation. Study of the NCSC shell middens indicates that mussels usually have higher levels of fragmentation than gastropods such as *Nacella magellanica* (Zubimendi 2012; Hammond and Zubimendi 2013). Future studies should incorporate analyses of diagnostic or identifiable (VFRA) mollusc shell fragments to obtain more comprehensive information regarding the processes that have affected the archaeological remains.

Archaeological remains at all three sites are associated with fragments of charcoal and thermally altered sediments, which suggests that the molluscs may have been exposed to heat for cooking and opening the shells of bivalves. At the three shell middens, we also recovered lithic artifacts and faunal remains (generally highly fragmented) in association with the shell lenses and charcoal (Hammond y Zubimendi 2013).

We observed that the predominant taxa in the malacological assemblages are those identified as important foods (*Nacella magellanica*, *Mytilus edulis* and *Aulacomya atra*), which develop on hard substrates in the intertidal zone (Zubimendi *et al*. 2005). We have also observed low frequencies of various taxa that, because of their small size, cannot be considered as food (for example *Crepipatella dilatata*, *Siphonaria lessoni*, *Kerguelenella lateralis*, *Iothia coppinheri* or *Balanus* sp.). These species are important because they provide information about environmental conditions and site formation processes. These small molluscs may have been deposited in the site as an unintentional by product of particular harvesting techniques, such as collecting in bunches (Orquera and Piana 1999).

CONCLUSIONS

In this paper, we presented a proposal for the study of shell midden archaeomalacological assemblages, and emphasized the importance of taphonomic studies in the identification of agents that modify shells and processes that affect shell midden formation in the study area. Based on the results of our analyses of malacological assemblages at NCSC, we argue that it is possible to infer the agents (natural and anthropic) and processes (pre- and post-depositational) that have produced physical and/or chemical modifications on the shells.

The advantage of our methodological approach to archaeomalacological assemblages is its applicability to different kinds of archaeological records composed of molluscs. Due to their composition, shells are more resistant than other organic remains such as bone (Linse 1992) or wood. Moreover, insights gleaned from the study of archaeomalacological assemblages extends beyond interpreting the records themselves, contributing to discussions of archaeological site formation.

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