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ARTICLE

FOOD AND TOOLS FROM THE SEA: THE RELEVANCE OF MARINE TETRAPOD FAUNA IN CULTURAL PRACTICES OF THE SAMBAQUI BUILDERS FROM SOUTHERN BRAZIL

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ABSTRACT

Anthropogenic modifications on faunal remains, such as cut marks, thermal alterations such as burning and calcination, and artifact production, constitute key indicators of cultural practices in past societies. However, in the archaeological record of sambaqui sites (shell mounds), evidence of such modifications remains relatively scarce or insufficiently documented, particularly regarding tetrapod remains. This study adopts a multi-method analytical approach to examine anthropic alterations in tetrapod bones from sambaqui contexts, describing the most comprehensive dataset of its kind to date. We analyzed 3,682 remains, 1,837 of which contained anthropic modifications. The zooarchaeological assemblage predominantly consists of marine taxa (including Mysticeti indet., Cetacea indet., Otariidae indet., *Arctocephalus australis*, and *Spheniscus magellanicus*). While terrestrial vertebrates were also exploited for tool production, the distribution and frequency of cut marks, biomass estimations, and the presence of bone artifacts indicate that marine tetrapods played significant functional and symbolic roles in the lifeways of sambaqui-building societies.

Keywords: Shell mounds; Bone industry; Human-animal interactions; Zooarchaeology.

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ARTIGO

ALIMENTAÇÃO E FERRAMENTAS MARINHAS: A IMPORTÂNCIA DA FAUNA TETRÁPODE MARINHA NAS PRÁTICAS CULTURAIS DOS CONSTRUTORES DE SAMBAQUIS NO SUL DO BRASIL

RESUMO

Modificações antrópicas em restos ósseos, como marcas de corte, alterações térmicas como queimaduras e calcinação e a confecção de artefatos, constituem evidências fundamentais para a compreensão das práticas culturais de sociedades antigas. No entanto, no contexto dos sambaquis, os dados sobre esse tipo de modificação ainda são escassos ou incompletos, especialmente no que se refere aos tetrápodes. Neste estudo, realizamos uma análise de múltiplas abordagens e apresentamos o conjunto de dados mais completo até o momento sobre modificações humanas em ossos de tetrápodes provenientes desses depósitos arqueológicos. Nós analisamos 3.682 vestígios, 1.837 dos quais apresentaram modificações antrópicas e a maioria dos ossos identificados pertence à fauna marinha (incluindo Mysticeti indet., Cetacea indet., Otariidae indet., *Arctocephalus australis* e *Spheniscus magellanicus*). Embora vertebrados terrestres também tenham sido utilizados como matéria-prima para a confecção de artefatos, as análises de marcas de corte, estimativas de biomassa e instrumentos ósseos indicam que os tetrápodes marinhos desempenharam um papel central, funcional e simbólico, na cultura dos povos sambaquieiros.

Palavras-chave: Sambaqui; Indústria óssea; Interações humano-animal; Zooarqueologia.

ARTÍCULO

ALIMENTACIÓN Y HERRAMIENTAS MARINAS: LA IMPORTANCIA DE LA FAUNA TETRÁPODO MARINA EN LAS PRÁCTICAS CULTURALES DE LOS CONSTRUCTORES DE CONCHEROS EN EL SUR DE BRASIL

RESUMEN

Las modificaciones antrópicas en restos óseos, como marcas de corte, alteraciones térmicas como quema y calcinación, y la producción de artefactos, constituyen una evidencia clave para comprender las prácticas culturales de las sociedades del pasado. Sin embargo, en los sitios arqueológicos de concheros, los datos sobre este tipo de modificaciones siguen siendo escasos o incompletos, especialmente en lo que respecta a los tetrápodos. En este estudio, aplicamos un enfoque metodológico múltiple y presentamos el conjunto de datos más completo hasta la fecha sobre la modificación humana en huesos de tetrápodos provenientes de estos depósitos. Analizamos 3.682 de restos, de los cuales 1.837 contenían modificaciones antrópicas y la mayoría pertenecían a fauna marina (como Mysticeti indet., Cetacea indet., Otariidae indet., *Arctocephalus australis* y *Spheniscus magellanicus*). Aunque también se utilizó fauna terrestre como materia prima para la elaboración de artefactos, los análisis de marcas de corte, estimaciones de biomasa y objetos óseos indican que los tetrápodos marinos desempeñaron un papel central, tanto funcional como simbólico, en las prácticas culturales de los pueblos constructores de concheros.

Palabras clave: Concheros; Industria ósea; Interacciones humano-animal; Zooarqueología.

INTRODUCTION

The analysis of vertebrate remains from archaeological contexts offers crucial insights into past faunal assemblages and paleoenvironmental conditions and into the cultural practices and lifeways of ancient human societies (Reitz; Wing, 2008; Russell, 2012). Bone modifications, resulting in perimortem or postmortem alterations such as cut marks, thermal damage, and evidence of artifact production, directly indicate a wide range of cultural behaviors, including hunting, fishing, carcass processing, technological activities, and mortuary practices (Mazza *et al.,* 2018). Among these modifications, cut marks are particularly informative for reconstructing ancient butchering strategies (Egeland, 2003; Otárola-Castillo, 2010), with their frequency in faunal assemblages suffering the influence of variables such as carcass size, meat yield, and intensity of tissue removal (Binford, 1988; Costamagno *et al*., 2019). Moreover, evidence of thermal alteration is often interpreted as a proxy for cooking and food consumption (Nicholson, 1993), although burning may also result from ritual offerings, accidental exposure to fire, or refuse disposal (Reitz; Wing, 2008). Bone tools, in turn, provide valuable information on animal procurement and processing methods and on broader technological systems (Kneip, 1994).

In the case of sambaqui sites (Brazilian shell mounds), constructed by pre-Columbian human groups along the southeastern and southern coasts of Brazil from about 8,000 to 1,000 years BP (Gaspar, 1998; Lima, 1999; Schmitz, 1987), taphonomic analyses of faunal remains have historically received limited attention. Until the late 2010s, few studies had systematically addressed cut marks and thermal alterations on animal bones (Rosa, 2008). A notable early contribution is Castilho and Simões-Lopes (2008), which examined bone surface modifications in otariid and cetacean remains to explore human-faunal interactions along the Brazilian Atlantic coast. In recent years, this line of inquiry has gained momentum in Brazilian archaeology, with several studies offering more systematic approaches (e.g., Ferrasso *et al*., 2021; Klokler, 2020; Santos; Pavei; Campos, 2018). Nevertheless, such analyses remain underrepresented in the broader literature on sambaqui culture.

Conversely, research on bone artifacts from sambaqui contexts was prolific during the mid-20th century (e.g., Beck *et al*., 1970; Beck, 1972, 1974; Fossari, 1985; Kneip, 1987, 1994; Rohr, 1977; Tiburtius, 1960; Tiburtius; Bigarella, 1953; Tiburtius; Leprevost; Bigarella, 1949). Despite this extensive body of descriptive work, detailed anatomical and quantitative analyses of the raw materials in artifact production remain rare (Castilho; Simões-Lopes, 2008).

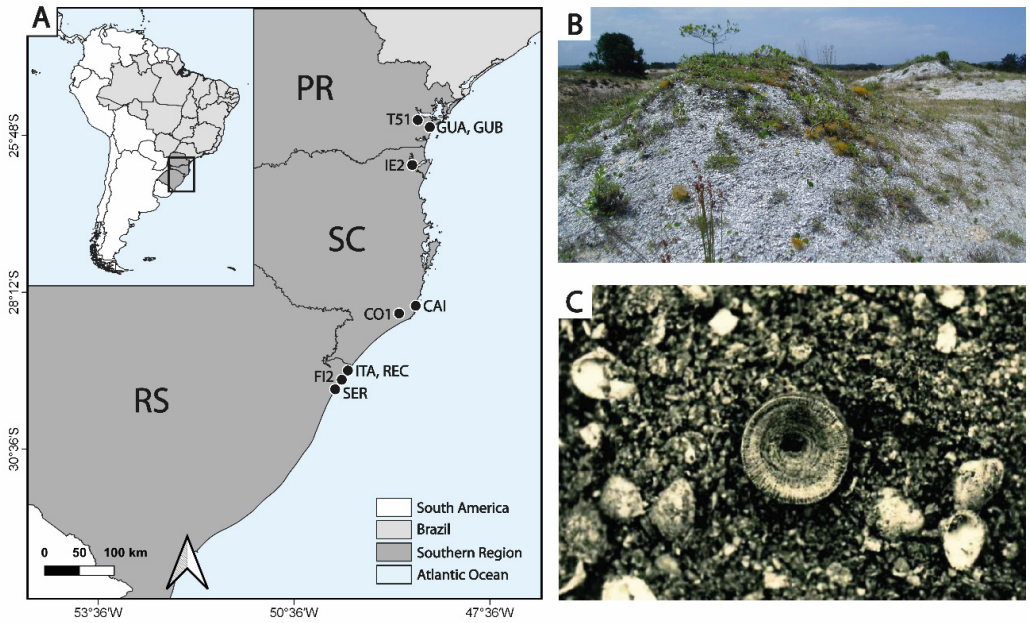
In light of these research gaps, this study aims to systematically investigate anthropogenic modifications (butchering marks and bone artifacts) on tetrapod bones recovered from shell mounds in southern Brazil. By focusing on medium- and large-bodied vertebrates, we aim to contribute to a deeper understanding of the cultural practices of sambaqui builders, particularly regarding their interactions with and use of animal resources.

MATERIAL AND METHODS

Study Area and Material

This study analyzed faunal remains from 10 sambaqui sites in southern Brazil: Toral 51 (T51), Guaraguaçu A (GUA), Guaraguaçu B (GUB), Ilha dos Espinheiros II (IE2), Caieira (CAI), Congonhas I (CO1), Itapeva (ITA), Recreio (REC), Figueira II (FI2), and Sereia do Mar (SER), distributed across the states of Paraná (PR), Santa Catarina (SC), and Rio Grande do Sul (RS) (Figure 1). For detailed contextual information on each site, see Mendes and Rodrigues (2024).

Figure 1. A: Map of the southern region of Brazil with the locations of the sambaqui-sites. B: REC panoramic view. C: In situ bone artifact (perforated object made on a fish vertebra) in IE2.



Source: Laboratório de Pesquisas Arqueológicas of the Museu de Ciências e Tecnologia of the Pontifícia Universidade Católica do Rio Grande do Sul (B) and Museu Arqueológico de Sambaqui de Joinville (C).

The archaeological materials are currently curated in the collections of the following institutions: Museu de Arqueologia e Etnologia, Universidade Federal do Paraná (T51, GUA, and GUB; Curitiba, Brazil); Museu Arqueológico de Sambaqui de Joinville (IE2; Joinville, Brazil); Museu de Arqueologia e Etnologia, Universidade Federal de Santa Catarina (CAI and CO1; Florianópolis, Brazil); and Laboratório de Pesquisas Arqueológicas, Museu de Ciências e Tecnologia, Pontifícia Universidade Católica do Rio Grande do Sul (ITA, REC, FI2, and SER; Porto Alegre, Brazil).

ANALYTICAL PROCESSES

Anatomical and Taxonomic Identification

Tetrapod remains were anatomically and taxonomically identified by direct comparisons with reference specimens in the mammalogy, ornithology, and herpetology collections of several Brazilian institutions (see Mendes; Rodrigues, 2024 for the full list). All analyses (anatomy, taxonomy, anthropogenic markers, quantification, representation of skeletal parts, and biomass) in this research were done globally, i.e., without considering the occupation of the studied sambaqui sites over time and the internal changes within each site, which, according to Colonese *et al.* (2025), are important to understand the origin of a sambaqui and its changing nature. For now, most of the studied sites have only a single dating (Mendes; Rodrigues, 2024) and no systematic dating by layers. Thus, it was impossible to place the data within a chronological framework.

Burning Analysis

Thermal alteration was assessed using the five-category colorimetric scale established by Shipman, Foster, and Schoeninger (1984), which correlates bone coloration

with estimated burning temperatures: category 1 - neutral white, pale yellow, or yellow (20–285°C); category 2 - reddish-brown, dark grey, or reddish yellow (285–525°C); category 3 - black with traces of reddish yellow (525–645°C); category 4 - white with light grey (645–940°C); category 5 - white with medium grey (above 940°C). Remains classified in category 1 were not considered as burnt since, due to the temperature range, they may not necessarily have been exposed to fire.

Cut Mark Analysis

Cut marks were classified following the reference collection in Costamagno *et al.* (2019), which established three types of cut marks: skinning (primarily transverse, relatively deep, and occurring principally in clusters on the medial and lateral surfaces, most frequently on metapodials but also present on phalanges), defleshing (present on all of the meaty parts with a wide range of orientations; on the vertebrae, present on the axis, the dorsal surfaces of the cervical vertebrae, and the spinous process of the thoracic vertebrae; on long bones cutmarks are primarily transverse or oblique and on the scapula and ulna primarily longitudinal), and disarticulation (primarily short, with transverse or oblique orientations, and mostly located near articular surfaces in the case of long bones). Taphonomic and zooarchaeological methodologies (Fernández-Jalvo; Andrews, 2016; Lyman, 1994; Serjeantson, 2009) were also searched to aid identification. The total number of modified bones was recorded to quantify butchery patterns and intensities.

Cut marks were distinguished from trampling and rooting marks. Trampling marks generally show macroscopic diagnostic characteristics: a U-shaped cross-section and an absence of a pattern of location and distribution (Olsen; Shipman, 1988; Pineda *et al.*, 2014). Root etching marks show dendritic patterns and shallow grooves on bone surfaces (Lyman, 1994).

Bone Artifact Classification

Bone artifacts were classified using a typological approach that considered morphological traits, manufacturing techniques, and the type of bone material (Sidéra, 1993). The traditional classifications in Brazilian archaeology (e.g., Rohr, 1977) were intentionally avoided as many of them presume specific functions without supporting microscopic or experimental analyses. Instead, typologies from the national (Beck, 1972, 1974; Fossari, 1985; Gaspar, 1991, 2003) and international literature (e.g., Sidéra, 1993) were adopted and adapted in this research.

Artifacts were grouped into categories, including: beveled objects, piercing and perforated tools, double-point and grooved double-point hooks, symmetric and asymmetric composite hooks, and spheres and zoomorphic figures.

Within the "piercing tools" category, terminology such as "points" and "double points" from previous literature were retained, but the more functionally neutral term was chosen to avoid unsubstantiated assumptions about use (e.g., as projectiles or needles). Similarly, the "beveled" category includes artifacts traditionally referred to as "spatulas" or "gouges," identified here by the presence of a beveled (typically rounded, straight, or tapered) apical zone.

Hook-like objects were classified based on their morphological resemblance to ethnographic and archaeological examples associated with fishing and similar practices (e.g.; Calippo, 2011; Nabais; Soares, 2017; O'Connor *et al*., 2017; Perttula; Walters, 2016; Tiburtius; Bigarella, 1953; Walters, 1988). Finally, spheres and zoomorphic figures were identified based on their formal similarities to specimens in the sambaqui literature in

general (e.g., Chmyz; Sganzerla; Chmyz, 2003; Ferreira *et al*., 2018; Tiburtius; Leprevost; Bigarella, 1949; Tiburtius, 1960, 1966).

Quantification and Analytical Methods

Following the methodological framework in Mendes and Rodrigues (2024), faunal assemblages were quantified using multiple parameters, such as: total weight, number of identified specimens (NISP), minimum number of individuals (MNI), and minimum number of elements. For the IE2, CAI, and CO1 sambaqui sites, fish remains had been separated from other vertebrate taxa in the collections, enabling the specific quantification of ichthyofaunal material by weight.

Skeletal part representation (PR) and biomass estimates were calculated based on MNI values (Borges, 2015; Reitz; Wing, 2008; Vigne, 1991). PR evaluates the proportional frequency of each anatomical element within a given taxon, and was calculated using the formula in Borges (2015): PR = (FO × 100) / (FT × MNI), in which FO is the observed frequency of a specific skeletal element, FT is the number of that element in a complete skeleton, and MNI is the minimum number of individuals for the taxon. This calculation can find potential selectivity in the use of carcass parts. PR was calculated for the taxa with the highest MNI values within each vertebrate class: otariids [including Otariidae Gray, 1825 indet., *Otaria flavescens* (Shaw, 1800), and *Arctocephalus* sp. Geoffroy Saint-Hilaire; Cuvier, 1826], Magellanic penguins (*Spheniscus magellanicus* Forster, 1781), and sea turtles [including Cheloniidae Linnaeus, 1758 indet. and *Chelonia mydas* Linnaeus, 1758].

Biomass was estimated using established methods (Borges, 2015; Reitz; Wing, 2008; Vigne, 1991) by multiplying the average edible meat weight per individual by the corresponding MNI for each taxon. The edible portion was calculated using published coefficients (White, 1953), adjusted according to species-specific data. Whales were excluded from the biomass analysis due to the disproportionate impact of their large body mass on quantitative results (Borges, 2015; Cardoso, 2018).

Average body weights were compiled from the literature and curated databases: Paglia *et al*. (2012) for mammals, Schreiber and Burger (2002) and WikiAves (2021) for birds, and Pritchard (1979) and Verdade (1995) for reptiles. Estimates of consumable meat percentages were based on White (1953), Smith (2011), and Borges (2015). As Borges (2015) emphasizes, biomass calculations have inherent limitations, particularly their potential underestimation of meat yield due to their reliance on MNI and general exclusion of age and sex variation within species. Despite these constraints, biomass remains a valuable metric for assessing the relative dietary and subsistence contributions of taxa in archaeological contexts.

RESULTS

In total, we analyzed 3,682 remains and identified 46 taxa, 25 of which were mammals, 17 birds, three non-avian reptiles, and one amphibian. Most identified taxa referred to marine animals (e.g. Cetacea Brisson, 1762 indet., NISP = 1,696; Mysticeti Cope, 1891 indet., NISP = 811; Otariidae indet., NISP = 53; *Arctocephalus* sp., NISP = 193; *Spheniscus magellanicus*, NISP = 34; and Cheloniidae indet., NISP = 41); see Mendes and Rodrigues (2024) for detailed anatomic and taxonomic data. The estimated biomass showed a greater contribution of marine animals (79.63%) in hunting than terrestrial ones (see Supplementary Table 1 for biomass calculated for each taxon).

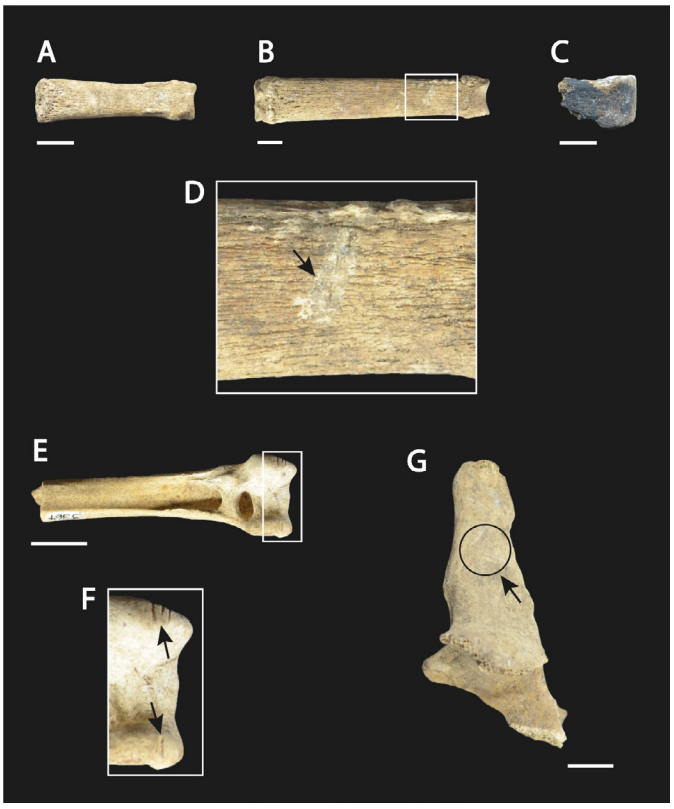
The weight of fish material from IE2, CAI, and CO1 totaled 2.954, 10.802, and 16.249 kg, respectively and the weight of tetrapod remains, 0.762, 6.984, and 0.362 kg, respectively.

We found cut marks (Table 1 and Figure 2), most of them in marine animals (in 15 otariid bones, eight in cetacean bones, and eight in Magellanic penguin bones), which show patterns consistent with skinning (47.27%). These marks mainly occurred on long bones such as the humerus, radius, ulna, femur, tibia, and phalanx (63.64%), being primarily made on their diaphyses (64.71%, see the Supplementary Table 2 for complete data).

Table 1. Number of bones with and without human-made modifications.

Modifications	Mammalia	Aves	Reptilia	Not id.	Total
Cut marks	40	11	1	3	55
Skinning	21	4	0	1	26
Defleshing	10	1	1	2	15
Disarticulation	9	6	0	0	14
Burning marks	1598	12	35	10	1655
Category 2	1507	12	35	10	1564
Category 3	91	0	0	0	91
Artifact manufacturing	127	0	0	0	127
Absent	1573	220	15	58	1857

Figure 2. Vestiges with cut marks and burning marks. Phalanges of Otariidae in ventral view in categories 1 (A), 2 (B), and 3 (C) of thermal alteration; the arrow in D (detail of B) indicates a skinning cut mark. Distal portion of tibiotarsus of *Spheniscus magellanicus* in anterior view (E); arrows in F (detail of E) indicate disarticulation cut marks. Spinous process of thoracic vertebrae of Mammalia indet. in lateral view; arrow indicates a group of defleshing cut marks (G). Remains are from CAI (A, B, and G) and FI2 (C and E). Scale bars: 1 cm.



Source: Photos by the authors. Remains from Museu de Arqueologia e Etnologia, Universidade Federal de Santa Catarina (CAI) and Laboratório de Pesquisas Arqueológicas, Museu de Ciências e Tecnologia, Pontifícia Universidade Católica do Rio Grande do Sul (FI2).

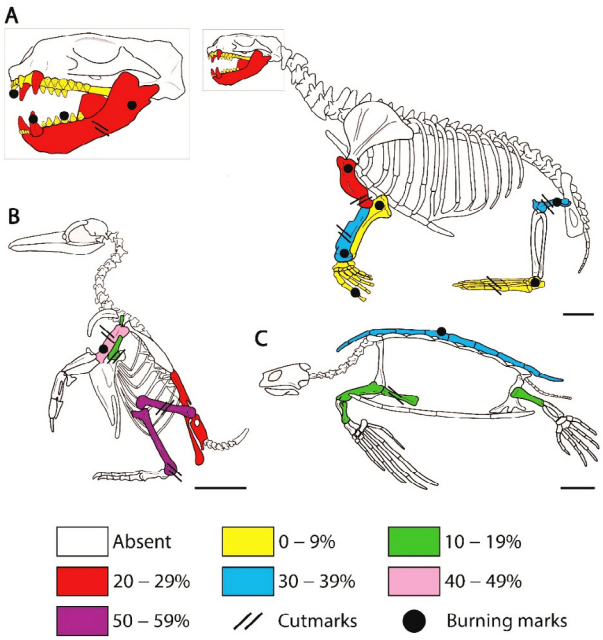
Table 2. Number of artifacts for each taxon. See Supplementary Table 3 for detailed data on each sambaqui.

Artifact	Taxon						Total
	Mammalia indet.	Cetacea indet.	Mysticeti indet.	*Eubalaena australis*	Tayassuidae indet.	*Tapirus terrestris*	
Beveled object	0	11	51	10	0	0	72
Piercing object	12	2	1	0	2	0	17
Perforated object	0	0	6	0	0	1	7
Double point hook	12	0	0	0	0	0	12
Grooved double point hook	1	0	0	0	0	0	1
Symmetric composite hook	5	0	0	0	0	0	5
Asymmetric composite hook (stem)	5	0	0	0	0	0	5
Asymmetric composite hook (point)	6	0	0	0	0	0	6
Sphere	0	0	1	0	0	0	1
Zoomorphic item	0	1	0	0	0	0	1
Total	**41**	**14**	**59**	**10**	**2**	**1**	**127**

This study included most burned bones in category 2, whereas category 3 only occurred on mammalian bones (Table 1 and Figure 2).

The remains of otariids, Magellanic penguins, and sea turtles included bones such as femur, radius, and humerus (in some cases with high representativeness) (Figure 3). On the other hand, autopod bones had lower representation than the other bones in otariids (see Supplementary Table 4 for complete data about skeletal part representation-PR).

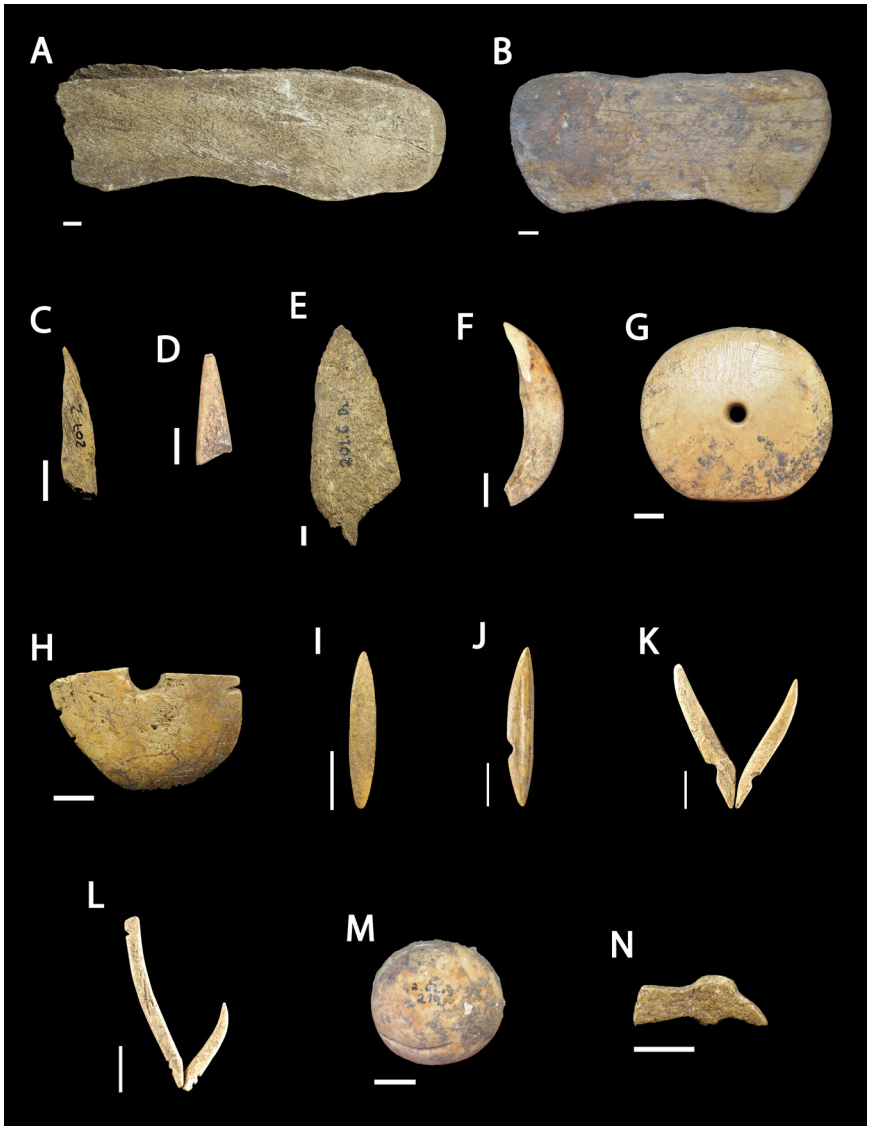
Figure 3. Percentage of representation of skeletal parts and anthropic modification marks in otariids (A), Magellanic penguins (B), and sea turtles (C). Scale bars: 10 cm.



Source: Skeletal illustrations by R. Buchmann and adapted from Berta, Sumich and Kovacs (2006) for the otariid, Chávez Hoffmeister (2012) for the Magellanic penguin, and CoMBINe (2017) for the sea turtle.

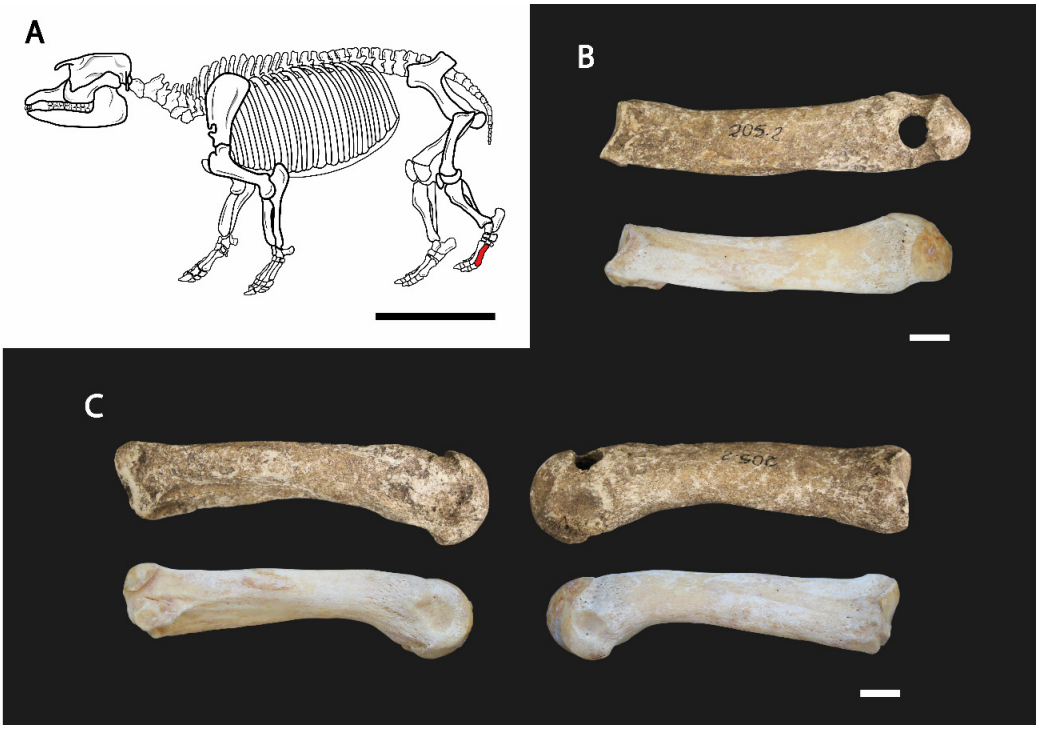
Regarding the artifacts, we recorded 127 objects (bone modified for artifact manufacture) at T51, GUA, GUB, CAI, and ITA, manufactured from the bones of Mammalia Linnaeus, 1758 indet. (33.07%), Cetacea indet. (10.24%), Mysticeti indet. (46.46%), *Eubalaena australis* (Desmoulins, 1822) (7.87%), Tayassuidae Palmer, 1897 indet. (1.57%), and *Tapirus terrestris* Linnaeus, 1758 (0.79%) (Table 2 and Figures 4 and 5).

Figure 4. Bone artifacts in the sambaqui sites. A and B: beveled objects made from Mysticeti indet. (ITA and GUB, respectively); C and D: piercing objects made from Mammalia indet. (ITA and T51, respectively); E: piercing object made from Cetacea indet. (ITA); F: piercing object made from canine tooth of Tayassuidae indet. (GUB); G: perforated object made from tympanic bulla of Mysticeti indet. (GUA); H: grooved perforated object made from tympanic bulla of Mysticeti indet. (ITA); I: double point hook made from Mammalia indet. (ITA); J: grooved double point hook made from Mammalia indet. (ITA); K: symmetric composite hook made from Mammalia indet. (ITA); L: asymmetric composite hook made from Mammalia indet. (ITA); M: sphere made from tympanic bulla of Mysticeti indet. (GUB); and N: aviform zoomorphic item made from Cetacea indet. (ITA). Scale bars: 1 cm.



Source: Photos by the authors. Remains from Museu de Arqueologia e Etnologia, Universidade Federal do Paraná (T51, GUA, and GUB), Laboratório de Pesquisas Arqueológicas, Museu de Ciências e Tecnologia, Pontifícia Universidade Católica do Rio Grande do Sul (ITA).

Figure 5. Perforated object made of *Tapirus terrestris* (ITA). Skeleton of tapir with IV left metatarsal in red (A). Comparison between the sambaqui artifact (top) and a IV left metatarsal of modern tapir (bottom) in posterior (B) and right and left lateral (C) views, respectively. Scale bars: 40 cm (A) and 1 cm (B and C).



Source: Photos by the authors. Skeletal illustration adapted from Tong, Liu and Han (2002) by R. Buchmann. Remain conserved at Laboratório de Pesquisas Arqueológicas, Museu de Ciências e Tecnologia, Pontifícia Universidade Católica do Rio Grande do Sul (ITA). Modern bone from the Mammalogy Collection of Universidade Federal do Espírito Santo, Brazil.

DISCUSSION

Diet and Faunal Exploitation Strategies

Sambaqui builders, commonly identified as fisher-hunter-gatherers, developed a sophisticated and enduring system for exploiting coastal ecosystems. Their subsistence strategies, particularly during the mid- to late Holocene, largely centered around the harvesting of mollusks and the intensive exploitation of fish (Figuti, 1993; Klokler; Gaspar, 2019). Early interpretations, prevalent up to the 1990s, framed these groups as nomadic foragers who primarily depended on mollusks, later shifting to fishing as shellfish stocks declined (Klokler *et al*., 2010). However, by comparative studies of caloric return from shell and vertebrate remains, Figuti (1993) argued that mollusks offered limited nutritional value, thereby positioning fish as the dietary cornerstone of sambaqui societies.

Stable isotope analyses have corroborated this interpretation, consistently finding fish as the dominant protein source, whereas mollusks seemed to have played a supplementary dietary role (Masi, 2009; Klokler, 2014; Oppitz *et al*., 2018). Consequently, sambaqui builders are now seen as socially complex and semi-sedentary, strategically located in ecologically rich zones that included coastal, lagoon, mangrove, and forest environments, all of which provided ample and diverse resources (Klokler *et al*., 2010).

Archaeofaunal data from IE2, CAI, and CO1 strongly support this model. In all three sites, fish remains overwhelmingly outnumbered those of tetrapod for mass and NISP,

even in contexts with large marine mammals such as cetaceans. For example, Benz (2000) recorded 8,846 fish remains at IE2, compared to only 65 tetrapod specimens in this study. Similarly, at REC, Hilbert (2011) noted 1,128 fish remains against 21 tetrapod specimens.

Marine species predominated in the tetrapod assemblage. Our MNI and biomass estimates closely align with those from Galheta IV—a site in SC and culturally associated with the Macro-Jê linguistic trunk (Taquara-Itararé ceramic tradition) and sambaqui traditions—in which Cardoso (2018) recorded 58.34% MNI and 90.67% biomass from marine mammals. Conversely, Borges (2015) reported only 16.76% MNI and 34.31% biomass for marine mammals at Mar Casado in São Paulo. As in our study, both authors excluded Mysticeti from biomass estimations due to the disproportionate weight of their individuals.

These regional contrasts suggest that marine tetrapods had a more pronounced role in the diets of southern sambaqui builders. Overall, two primary hypotheses may explain this pattern: (i) cultural variations in dietary preferences or taboos and/or (ii) differential availability of marine resources. The southern Brazilian coast lies within important migratory and breeding routes for cetaceans due to the convergence of the Malvinas and Brazilian currents (Castilho; Simões-Lopes, 2001). Additionally, the historical presence of otariid colonies, now extinct due to overhunting, would have further enriched the local resource base available to pre-Columbian populations. Nonetheless, broader comparative data from additional sambaqui sites are required to further test these hypotheses.

Skeletal part representation data evince selective carcass processing patterns. The underrepresentation of autopod elements in otariids, for instance, suggests that flippers were discarded at or near the kill site, likely due to their limited meat yield (Lyman; Savelle; Whitridge, 1992). Borges (2015) documented similar practices involving otariids and dolphins at Mar Casado. These observations support the hypothesis that high-utility skeletal elements were preferentially transported to sambaqui settlement sites (Castilho, 2008).

The cut marks on 55 bones, including otariids, cetaceans, and *Spheniscus magellanicus*, indicate extensive butchering such as skinning, defleshing, and disarticulation (Binford, 1981). These patterns mirror previous findings. For example, Ferrasso *et al*. (2021) recorded 25 cut-marked otariid bones at Xangri-Lá; Castilho (2008) found 24 cut-marked cetacean bones across six sites in SC; and Cardoso *et al*. (2014) documented 178 cut-marked Magellanic penguin bones at Galheta IV. In all cases, long bones were the primary targets, reflecting their greater meat and fat content. These modifications are consistent with the lithic tools (including choppers, axes, scrapers, and cutters) at GUB, CO1, and SER (Andreatta; Menezes, 1975; Beck, 1969; Wagner, 2012).

Regarding thermal alteration, most burnt and calcinated bones fell into categories 2 and 3. Their color, a very dark brown and black, indicates that they were probably more often exposed to temperatures totaling 285–525ºC (42.48%, category 2), and more rarely 525–645ºC (2.47%, category 3, Figure 3). Uneven coloration suggests some bones were burned while still covered in soft tissue (Buikstra; Swegle, 1989). This study ruled out the possibility of manganese staining due to the absence of dendritic structures (Fernández-Jalvo; Andrews, 2016; Tomassini *et al*., 2010).

Thermal alteration in bones fails to necessarily mean that the animal remains were intentionally burnt for dietary purposes (Reitz; Wing, 2008). For instance, buried bones may suffer thermal action if under a fire. Thus, they may have been accidentally burnt if deposited in layers close to the bonfires (Stiner *et al.*, 1995). However, in the CAI and FI2 sambaqui sites more than half (51.35% in CAI and 89.85% in FI2) of the bones in categories 2 and 3 of thermal alteration occurred in layers that had large bonfires,

charcoal, ashes, and even ovens (source: Diário de Campo de Anamaria Beck, jazida SC.LL.29 – Sambaqui da Caieira, available at MArquE-UFSC; and Relatório IPHAN Arqueologia do Litoral Norte, available at LPA-MCT-PUCRS), suggesting that they were probably intentionally exposed to fire, corroborating Menezes (1968) and Hurt (1974), who pointed out the importance of bonfires in the feeding of sambaqui builders for GUA and CAI, respectively. Pinto (2013) also observed, in the sambaqui Amourins in Rio de Janeiro, that the layers with several bonfires showed the most burnt bones.

Beyond their dietary value, some animals held symbolic or funerary significance. Magellanic penguins (*Spheniscus magellanicus*), likely favored for their ease of capture and high meat yield (Cruz, 2006), also appear in ritual contexts. Cardoso *et al.* (2014) reported their association with five of eight burials at Galheta IV, suggesting a role in funerary offerings or symbolic functions, possibly as clan emblems or spiritual guides. Comparable associations have been recorded in other Santa Catarina sambaqui sites, including Jabuticabeira II and Cabeçuda (Klokler, 2016). Our study found 36.84% (7 of 19) of the *S. magellanicus* remains from CAI near human burials, supporting the hypothesis of their symbolic significance among the builders of this sambaqui site.

Bone Artifacts

In addition to their dietary and ritual functions, animals served as important sources of raw material for artifact production among sambaqui builders. Although modified bone artifacts are less abundant than lithic materials at most Brazilian sites (Mingatos; Okumura, 2020), their presence reflects a broader technological repertoire. The relative scarcity of bone tools in archaeological assemblages and their fragmentary preservation may partly explain the absence of comprehensive identification manuals for osseous artifacts, unlike the more established classifications for lithic (Bueno; Isnardis, 2007; Martins; Kashimoto, 2014; Prous, 1986) and ceramic industries (Amorim, 2010; Kashimoto; Martins, 2019; La Salvia; Brochado, 1989).

Although some studies have proposed typologies based on morphology and raw material (e.g., Gaspar, 2003), most classifications rely on object form or presumed function, often lacking empirical validation from traceological (Mansur; Lima; Maigrot, 2014) or experimental methods (e.g., Beck, 1972; Rohr, 1977). Indeed, tool use-wear (traceological) and experimental replication studies remain relatively recent developments in sambaqui archaeology (Gilson *et al.*, 2021; Gilson; Lessa, 2021; Nami, 2025; Sousa *et al.*, 2020). Due to the absence of a standardized analytical framework for bone tools and the scope of this research, we opted to focus on anatomical and taxonomic identifications. This study proposes functional hypotheses based on comparisons with similar items in the literature considering shape, manufacturing techniques, and raw materials in known sambaqui bone industries.

Previous reports of bone artifacts from sambaqui sites such as GUB (Andreatta; Menezes, 1975) and ITA (Gazzaneo; Jacobus; Momberger, 1989; Thaddeu, 1995) often lack the taxonomic identification of the faunal material. In our assemblage, the most frequently artifact type refers to beveled objects (n=72), primarily manufactured from the ribs of baleen whales and indeterminate cetaceans. Although such items are rarely documented in southern sambaqui sites, examples include two spatulas from the Praia das Laranjeiras site and 14 from ITA (Gazzaneo; Jacobus; Momberger, 1989; Rohr, 1984). This apparent scarcity may result from the fragility of cetacean axial skeletons, which possess low mineral density and are prone to fragmentation, complicating their identification (Buckley *et al.*, 2014; Murray, 2008).

Modified cetacean bones comprised 65.35% (83 of 127, grouping Cetacea indet., Mysticeti indet., and *E. australis*) of the artifacts in our study, underscoring their importance in local bone industries (McGrath *et al.*, 2026). As early as the mid-20th century, Tiburtius, Leprevost and Bigarella (1949) highlighted the extensive use of whale skeletons, particularly ribs and tympanic bullae, by sambaqui builders. Due to their size, curvature, and relatively low bone density, whale ribs were well-suited for producing beveled and piercing tools (Figure 4) (Borella, 2004; Margaris, 2014), such as those at the Macedo sambaqui in Paraná (Hurt; Blasi, 1960).

Conversely, these builders used the dense and ivory-like tympanic bullae to produce polished, perforated, and spherical items, although their brittle structure made them more difficult to shape (Tiburtius; Bigarella; Bigarella, 1954). Overall, 10 such objects were associated with burials at Rio Pinheiros (SC), suggesting ritual or funerary uses, possibly as amulets or adornments (Figure 4). Additional burial-associated tympanic bulla artifacts have been reported at Matinhos and Araújo II (Chmyz; Sganzerla; Chmyz, 2003; Orssich, 1977), further supporting their symbolic or ceremonial significance.

One remarkable find was a zoomorphic artifact resembling the head of a bird, carved from a cetacean bone and recovered at ITA (Figure 4). Aviform bone sculptures have been documented at sites such as Matinhos (Chmyz; Sganzerla; Chmyz, 2003), Conquista (Tiburtius, 1966), and various sambaqui sites in Joinville (SC) and Paraná (Prous, 2018), often carved into the ends of bone sticks and interpreted as spear-thrower hooks or propellant ornaments (Scheinsohn, 2016). Based on morphology and analogues, we hypothesize that the zoomorphic piece from ITA may have served as a decorative element of a spear-thrower, which could have been used in everyday hunting practices or even as a mortuary offering and ceremonial symbol since some similar artifacts were associated with burials in sambaqui sites in Santa Catarina (Ferreira *et al.*, 2018).

Terrestrial mammal bones were also utilized for toolmaking, including hooks, points, and burins. Our study found composite hooks, possibly carved from long bone fragments, constituting a new typological record for sambaqui sites. The absence of previous records fails to necessarily indicate their nonexistence as fragmented or unrecognizable parts may have been misclassified as generic piercing tools or ornaments (Thaddeu, 1995). Most hooks in the literature are single-piece and curved (Beck *et al*., 1970; Bryan, 1993; Rohr, 1984; Tiburtius; Bigarella, 1953).

We classified composite hooks into two morphological types: symmetric and asymmetric (Figure 4). The asymmetric form consists of a larger stem and a smaller pointed element, featuring grooves likely used to bind the components with vegetal fibers (Sá *et al.*, 2025). Evidence of plant fiber use has been recorded in sambaqui sites such as Cubatão I (Bandeira; Oliveira; Santos, 2009; Peixe; Melo Junior; Bandeira, 2007) and Espinheiros II (Afonso; Blasis, 1994), although preservation is rare due to taphonomic conditions (Bandeira, 1992).

In line with Beck *et al*. (1970), who reported low frequencies of modified teeth at sambaqui Enseada I (SC), we only found two modified lower canines of Tayassuidae indet., interpreted as piercing tools (Figure 4). Similar artifacts made from *Dicotyles tajacu* (Linnaeus, 1758) have been recorded at Rio Pinheiros and were likely multifunctional, possibly used for cutting, smoothing, scraping, or perforation (Tiburtius; Bigarella; Bigarella, 1954).

Another noteworthy artifact was a perforated object fashioned from the metatarsal of a lowland tapir (*Tapirus terrestris*) at ITA (Figure 5). Although mentioned by Thaddeu (1995), this specimen had been neither taxonomically nor anatomically identified. The use of bone, rather than teeth for pendant-like objects is atypical, as ornaments are generally

fabricated from dental elements (Tiburtius, 1960). The suggestion of the symbolic role of tapirs within sambaqui culture stems from the discovery of a tapir-like sculpted object at Rio Vermelho (SC) (Prous, 2018), indicating that this species may have held cultural or ritual significance.

CONCLUSIONS

This study applied a comprehensive analytical framework, including anatomical and taxonomic identification, cut mark and thermal alteration analysis, artifact classification, skeletal part representation, and biomass estimation, to investigate the role of marine tetrapods in the cultural and subsistence practices of sambaqui builders in southern Brazil. Its findings show that, for tetrapods, marine fauna—particularly mammals—played a central role in subsistence strategies and technological traditions involving bone tool production.

We described the most comprehensive data on human modification of tetrapod bones from sambaqui sites. This study derived most of its specimens from marine taxa, including whales, dolphins, fur seals, and Magellanic penguins. Biomass estimates showed a greater dietary contribution from marine tetrapods than from terrestrial animals, although total weight values underscore the continued predominance of fish as the primary protein source.

Anthropic modifications, especially cut marks, predominantly occurred on otariids, cetaceans, and penguins, with anatomical distributions indicating a targeted selection of meaty anatomical regions. The consistent underrepresentation of low-utility skeletal elements, such as autopods, suggests intentional discard at or near kill sites. Burnt bones frequently occurred in association with domestic features such as hearths and ovens, reinforcing the interpretation of fire use in food processing.

Beveled tools constituted the most frequently recorded artifact type in the assemblage, with cetacean bones, particularly ribs and tympanic bullae, serving as the primary raw material. Terrestrial mammals were also used in tool production, and the assemblage includes notable finds such as composite hooks and a perforated artifact made from a tapir metatarsal, object types not previously documented in sambaqui contexts.

Corroborating previous studies, our results suggest that animals were not only essential to subsistence activities such as fishing, hunting, butchery, and toolmaking, but also played symbolic and ceremonial roles, particularly in funerary contexts. Despite the gained insights, the limited number of systematic studies on osteological specimens curated in collections still constrains functional interpretations. Future research incorporating use-wear analysis, experimental replication, and microscopic examination will be critical for advancing our understanding of these complex human–animal interactions within sambaqui societies.

Furthermore, this study aimed to identify cultural markers (cut marks, burning marks, and artifacts) in faunal remains from sambaqui sites within a broad framework without considering the chronology of the archaeological sites or the changes in the sambaqui culture over time. Further excavations and/or a return to this collection will enable the study of technological changes in the patterns of cut marks and in the production of osteo-dental industries throughout the occupation of these sites across thousands of years. Future research may also help to understand how these artifacts were produced (raw materials and manufacturing technology) and to further the understanding of the relationship between these tools and other types of remains in sambaqui sites (lithic industry, seeds, and plant fibers).

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SUPPLEMENTARY MATERIAL

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