Journal of Anthropological Archaeology 58 (2020) 101167

Contents lists available at ScienceDirect

Journal of Anthropological Archaeology

journal homepage: www.elsevier.com/locate/jaa

Fishing for "lucky stones": Symbolic uses of otoliths in Brazilian shell sites

Daniela Klokler

Universidade Federal de Sergipe, Praça Samuel de Oliveira, s/n, Laranjeiras, SE 49.170-000, Brazil

ARTICLE INFO

Keywords:
Shell mounds
Zooarchaeology
Otoliths
Ritual
Sambaquis
Brazil

ABSTRACT

Otoliths are concretions of aragonite located in fish neurocrania, also popularly known as "lucky stones". These elements are commonly found in Brazilian shell mounds and middens, and have long been regarded as a by-product of food processing and consumption. Zooarchaeologists commonly use them to identify species, estimate age, quantify fish, and to discuss capture methods and seasonality of occupation, among other aspects of fish and human populations. My research at Jabuticabeira II, a cemetery site with large quantities of otoliths closely associated with burials, explores alternative uses of otoliths by past coastal populations that inhabited the southern Brazilian coast. I reviewed ethnographic and historical accounts of the use of otoliths to check distinct uses of these fish elements. I analyzed 9258 otoliths and 76,990 fish bones from Jabuticabeira II to identify patterns of fragmentation, thermal alteration, element representation and distribution across contexts. The results indicate that otoliths were deliberately placed in burials, pointing to the symbolic value of otoliths. This research reinforces the need to consider the non-economic uses of fish by pre-historic populations.

1. Introduction

Fish bones are the second most common component of Brazilian shell mound deposits following shell valves. The countrýs eight thousand kilometers of coast were the preferred location for the construction of hundreds of shell mounds and middens during most of the Holocene, particularly between 6000 and 2000 years ago. Research on these sites mainly focused on subsistence, and scholars argued that shellfish was the staple food for their builders, later replaced by a diet also composed of fish meat (Bandeira, 1992; Garcia, 1972; Lima, 1991). After many decades of debates, most archaeologists now agree that fishing was their most important economic activity, and fish the most important dietary resource, despite the prevalence of mollusk valves at these sites (Colonese et al., 2014; DeMasi, 1999; Figuti, 1993; Figuti and Klokler, 1996; Klokler, 2014a; Pezo-Lanfranco et al., 2018).

Analysis of the matrix of a large shell mound from southern Brazil, particularly the deposits associated with mortuary contexts, indicates that fish otoliths were intentionally placed separately from the rest of the skeleton (Klokler, 2016a, 2016b). Concentrations of these particular elements within funerary features seem to suggest alternative uses of otoliths by past shell mound building populations. In light of historical and ethnographic accounts demonstrating the current and past uses of otoliths as medicine, amulets and charms, we believe that shell mound building coastal groups regarded fish otoliths as special elements.

Archaeofaunal studies demonstrate that fishes assumed roles as daily food resources and feasting "delicacies" for some communities in southeastern and southern Brazil (Klokler, 2008, 2014a, 2017). Fish had important roles in the lives of shell mound groups beyond their use as a daily source of protein, calories and nutrition: they were also a source of entertainment, pleasure and fulfillment during feasts. The representation of fish in stone sculptures (or zooliths), usually deposited in mortuary contexts within shell mounds, reinforces the idea that fish also held important symbolic roles in these societies. However, the symbolic meaning of fish remains in these archaeological contexts is not often explored.

Aligned with the call for zooarchaeologists to go beyond the perception of the relationship between humans and animals as mostly based on economic interests (Russell, 2012), this paper explores the study of an assemblage of 9258 otoliths from funerary contexts at the Jabuticabeira II site, dated between 2500 and 1800 years BP. The results of our analysis of ancient otoliths—including patterns of fragmentation, element distribution, and carbonization, as well as contextual data—show clear indications that in the distant past, otoliths had non-dietary significance for some fishing communities.

2. Otoliths: Fish ear stones and lucky stones

2.1. Archaeological uses

Otolith research has a long history and involves several disciplines (ecology, sclerochronology, geochemistry). Lately the literature about these fish elements has increased in number and scope, with more

E-mail address: danik@alumni.usp.br.

https://doi.org/10.1016/j.jaa.2020.101167
Received 31 March 2019; Received in revised form 11 February 2020
Available online 27 March 2020

Fig. 1. Catfish (*Genidens genidens*) and whitemouth croaker (*Micropogonias furnieri*) right and left otoliths (bottom). Ventral and dorsal view of catfish otoliths (top).

studies focusing on their structure and chemistry (Campana, 2005), demonstrating that otolith research as a field with continued interest by scholars. Zooarchaeologists use otoliths to assess the season of capture, individual age of fish and/or size selection and capture methods, among other aspects of human societies exploiting fish (Andrus and Crowe, 2002; Andrus et al., 2008; Disspain et al., 2016; Doucet, 2012; Peacock et al., 2016). Otoliths are concretions of aragonite, a form of calcium carbonate, that are located within the inner ear of fish. These elements are commonly known as ear stones (Casteel, 1976; Wheeler, 1978) because they resemble little polished pebbles. They exert multiple functions in the fishes' inner ear complex, such as helping maintain equilibrium, sense depth, and aiding acoustic perception (Andrus and Crowe, 2002; Bastos, 1990; Casteel, 1976; Duffin, 2007; Kefous, 1977). There are three pairs of differently-sized otoliths within the auditory capsule found inside the base of the fish neurocranium. In most species, the sagitta is the largest pair and therefore, often the most useful for faunal analysts (Fig. 1).

Otoliths exhibit features that are especially valuable for zooarchaeologists. Otoliths have diagnostic characteristics that allow for taxonomic identification of fish to species level. Moreover, otoliths are the densest elements in fish (Treacy and Crawford, 1981), which contributes to their preservation in archaeological sites. This is particularly true in shell mound sites where concentrations of mollusk valves create an alkaline environment that allows otoliths to preserve well. Since fish have small elements that can be missed during recovery (depending on the screen size used by researchers) and fragile bones that can fragment easily (obscuring diagnostic traits), otoliths can provide a more accurate identification and quantification of fish in archaeological sites. Otoliths grow as aragonite is deposited in increments throughout a fish's lifespan (Andrus and Crowe, 2002). Fish biologists and archaeologists alike use these growth rings to estimate age or size of individual fish and season of capture. Although growth rings also appear in other fish elements such as scales, opercula, cleithra, vertebrae, and spines (Casteel, 1976; Colley, 1990; Ham, 1982), growth rings are especially well-marked in otoliths.

In Brazil, otoliths have been commonly recovered from prehistoric shell mound sites and thoroughly used in zooarchaeological analyses in Brazil (Klokler, 2008, 2016a). In the 19th century, Von Ihering (1895) first mentioned the presence of otoliths in Brazilian shell mounds. Since then, the study of otoliths in archaeological research has been mostly limited to taxonomic classification and quantification. More recently, otoliths are also used, albeit rarely, in fish age and size estimations (Calippo, 2000; Chim, 2013; DeJesus, 2018; Figuti, 1993; Fossile et al., 2019; Klokler, 2008, 2014a; Lima, 1991). Although the analysis of otoliths has greatly contributed to the study of pre-historic fishing economies in Brazil, even if seasonality and isotopic indicators are rarely explored, less attention has been given to other possible roles that otoliths may have assumed in the past lives of human communities. Here I examine otoliths recovered from Jabuticabeira II shell mound to explore evidence that groups that occupied the Brazilian coast possibly assigned otoliths with roles similar to those seen in ethnohistorical records.

2.2. Past and present uses of otoliths

Throughout time, fish ear stones probably caught the attention of individuals who were involved in fishing activities. Those in charge of capturing, processing, cooking, and disposing of fish remains were possibly drawn to the distinct color, shape and texture of otoliths. In different societies across time, literature shows that otoliths assumed particular roles as medicinal ingredients, talismans or elements auxiliary to divinations. Nowadays, otoliths are reportedly used as a medicine and also recognized as having magical powers by communities around the world. Historical, ethnographic and archaeological data provide some examples of possible uses in the past and present.

One of the key uses of otoliths is within zootherapy, or the use of animals or animal parts as treatment for human illnesses. Fish, whole or in parts, are used around the world as ingredients in remedies for different ailments. In Latin America, fish comprise the third most important animal source of ingredients for medicinal purposes (Alves and Alves, 2011; Alves et al., 2007), while in Brazil fish are the most important source of folk remedies according to ethnologists (Alves et al., 2007). Hence, it should not be surprising that prehistoric societies – particularly coastal ones – also used fish as ingredients to prevent or treat health conditions. Otoliths are familiar to ethnomedicine scholars interested in zootherapy, and their use reaches back over thousands of years (Alves and Rosa, 2005; Alves and Alves, 2011). The earliest reference to otoliths is in Egyptian medical texts (Dawson, 1932). These texts recommended using otoliths, in conjunction with oil, to treat sore toes (1932:151). Dawson (1932:151) also describes how otoliths were utilized in medieval times as charms to combat colic, among other ailments, and were added to medications in powdered form. Their use to relieve stomach or intestinal pain, among other illnesses, was so widespread that otoliths became known as colic stones (Adams, 1940). A review of the use of animals in medicine (Lev, 2006) revealed that Muslim doctors referred to otoliths as fish stones in 9th century texts. Kunz (1915:169) describes the use of otoliths, in association with a "green lizard", to cure eye problems. In Cadiz, López Amador (2003) affirms that these elements are used against headaches. Duffin (2007) also mentions how otoliths present in pendants are believed to prevent fevers.

Traditional Brazilian fishing communities are known to use otoliths in folk remedies for renal failure (Alves and Alves, 2011; Alves et al., 2007). Otoliths are ground up and added to water as a sort of tea; for example, communities along the São Francisco River in northeast Brazil use freshwater croaker (or *corvina*) otoliths in an infusion for kidney problems and to help heal sores and cuts. Authors cite the use of otolith powder to treat asthma and urinary problems and to prevent back pain (Alves and Alves, 2011; Alves et al., 2007).

Aside from their medicinal uses, otoliths are often believed to hold

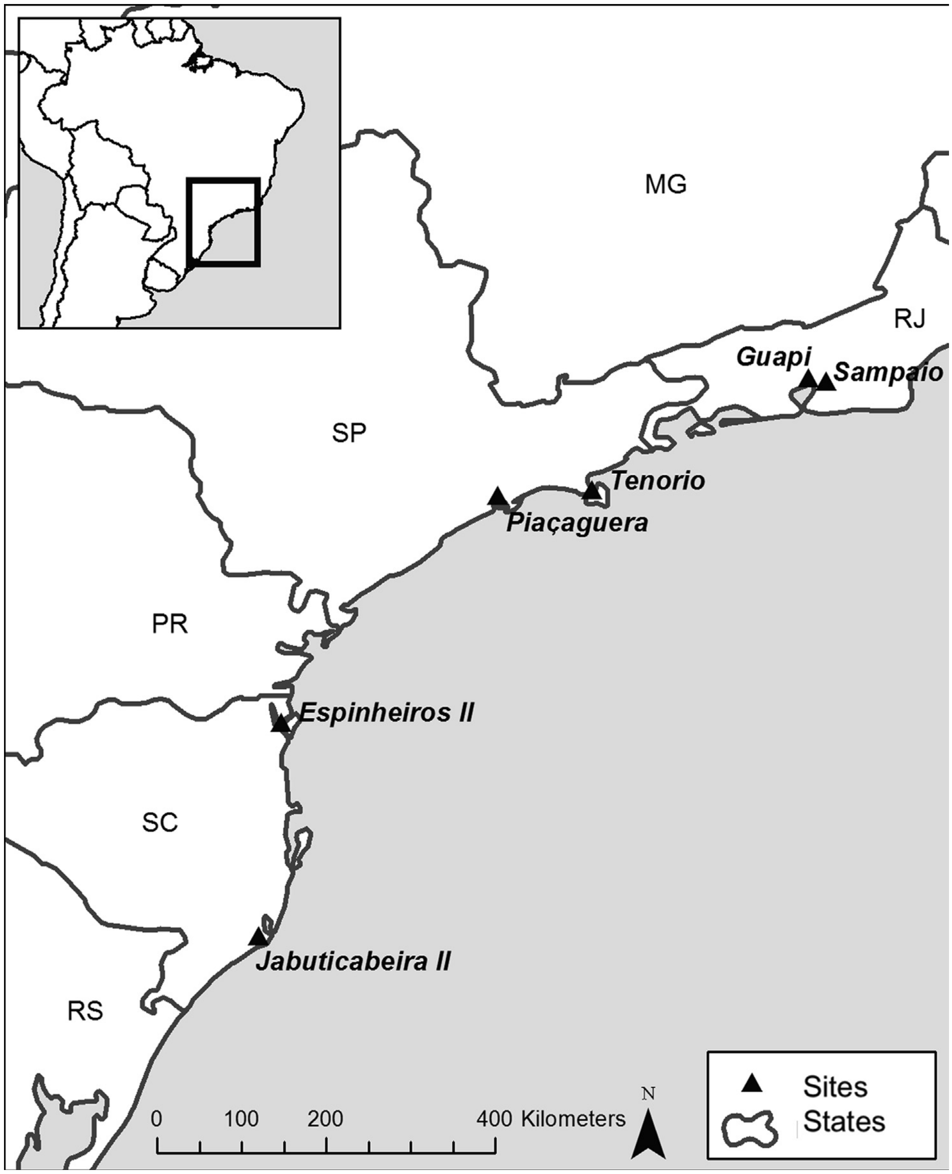

Fig. 2. Map with locations of sites mentioned in the text.

magical powers or appear in superstitious tales, particularly in societies connected to the sea. There are many examples of the magical and divinatory powers of otoliths in past and present societies, but two key themes are their association with good fortune and their use in predictions of sea and weather conditions. López Amador (2003) highlights the uses of otoliths as adornments and talismans in maritime societies across the Mediterranean. For example, today's communities in the Gulf of Cadiz believe that otoliths bring good fortune and/or keep evil at bay when carried around attached to clothes or as a pendant.

In the first century AD, Pliny the Elder (1938) mentions otoliths (Cinædia stones – *Argyrosumus* sp.) as possessing "marvelous virtues" within which lies the prediction of calm or stormy seas. Kunz (1915) reaffirms this use and asserts that differences in the surfaces of these elements could relate to the degree of air humidity and hence inform about the conditions of the sea. Duffin's (2007) discussion of otoliths' presence in European folklore enumerates the many purposes of these elements, including their use as mechanisms to ascertain weather changes, as well as to predict calm or stormy seas.

Reinforcing the antiquity of otoliths' association with the supernatural are finds such as a cache of 49 otoliths dating from the Late Bronze age, and found at the Pocito Chico site in Cadiz, which are considered as a likely form of offering from the time the structure was abandoned (López Amador, 2003:15). In Cadiz, researchers found *Argyrosomus regius*, or corvina otolith offerings in a Phoenician sanctuary in Gibraltar and in the Las Cumbres necropolis (tomb 1) (López Amador, 2003). Otoliths were also found in other sanctuaries across the coastal region (Lopez Amador and Ruiz Gil, 2010).

In medieval times, otoliths were often part of the elements included in little pouches attached to clothes or in necklaces as talismans, attesting to their continued association with magical powers in Europe, Africa, and subsequently in the Americas (Souza, 1984). The use of otoliths as amulets against bad luck and the evil eye has also been described in Venezuela and two European countries, namely Spain and Italy (Hildburgh, 1913; López Amador, 2003; Ruiz, 2012). During colonial times in Brazil, healers used fish ear bones in divinatory sessions and to cure certain diseases (Souza, 1984). In the U.S. Midwest, people associated otoliths with prosperity and good fortune (Bonnerjea, 1931).

In many instances, the use of otoliths as adornments or talismans mentions their power to prevent or cure illnesses, and it is important to highlight that spiritual forces can be thought to cause diseases and adversities (Miller and Sykes, 2016: 257). Such uses can be difficult to identify archaeologically, especially due to the strong influence of the economy-derived explanations in the faunal analysis field. Unfortunately, a number of references do not provide details of specific use, fish species and the 'mode of administration of otoliths as medicine. The latter can have consequences for their study in the archaeological record since some prescriptions can obliterate the elements (Miller and Sykes, 2016), such as the example from Northeastern Brazil in which otoliths must be taken in grounded form. Consumption also can deteriorate them to the point that it is impossible to recognize their diagnostic characteristics.

The major struggle is to find ways to differentiate animals and animal parts used for food, medicine, talismans, oracles, etc. The problem is that a clear-cut separation between realms is a characteristic of a Western worldview not shared by many populations, particularly prehistoric ones (Klokler, 2016a;Miller and Sykes, 2016).

This brief review of social uses of otoliths demonstrates the long temporality and wide geographic distribution of alternative traditional uses of otoliths. Unifying these descriptions is the recurring use – for the last 3000 years – of croaker otoliths, their association with the treatment of ailments (particularly renal), and their importance in predicting weather or sea conditions and as good-luck charms.

3. Materials and methods

3.1. Study site

Jabuticabeira II is a shell mound located on the southern coast of Brazil (Fig. 2). It is currently one of the shell sites with the largest amount of data available for researchers in the country. Jabuticabeira II is a cemetery site built between 2880 ± 75 and 1400 ± 40 years BP (DeBlasis et al., 1999, 2007). The site's construction involved the amassing of mostly animal materials that resulted in a mound, 320,000 cubic meters in volume, so faunal analyses have been instrumental in providing information about the coastal societies who built the mounds.

The Jabuticabeira II construction was achieved through the repeated performance of funerary feasts, interment of the community members and the recurrent deposition of the events' remains topped by layers with great quantities of mollusk valves, particularly the Pointed Venus (*Anomalocardia flexuosa*) (Klokler, 2001, 2008, 2014a). Fish was the main dish served during burial feasts, and fish remains dominate the contents of funerary areas, layers where 99% of the burials and associated contexts (hearths, pits, postholes) are located. The dominance of fish in funerary layers demonstrates the importance of these animals for the mortuary ritual. The mounded layers with a prevalence of shells also contain fish bones but in lower numbers. The repetition of mortuary activities: interments, feasts, covering of funerary areas resulted in a complex stratigraphy with alternating dark and light deposits.

3.2. Sample collection and analysis

Due to its large size, researchers divided Jabuticabeira II in 6 loci for excavation. The sampling devised for faunal analyses targeted its several loci, distinct funerary events and other distinct features, such as postholes, hearths, and burial pits. The main objective was to try to detect changes in the funerary ritual and site formation through time, to verify the possibility that specific groups of burials had feasts with special menus and whether inequalities regarding access to resources could be distinguished (Klokler, 2008, 2014a). The samples used in the present study include bulk samples from shell and funerary contexts (and their features: burial pits, hearths and postholes) in 4 loci, patterned by volume (1,5 and 8 L). Samples were wet sieved using 4 and 2 mm mesh, and all materials larger than 4 mm were subjected to analyses[1].

Taxonomic identification of the materials was achieved using the comparative skeletal collections located at the Stanley J. Olsen Laboratory of Zooarchaeology at the Arizona State Museum (the University of Arizona) and at the Laboratory of Studies in Zooarchaeology and Bioarchaeology at the Museu de Arqueologia e Etnologia (Universidade de São Paulo). Whenever possible, specimens were identified to the most specific taxon. Frequency of fish was estimated through examination of the number of identified specimens (NISP) and the minimum number of individuals (MNI). MNI estimates for fish were based on otoliths or osseous diagnostic pieces (whichever was identified in larger quantities) considering laterality and size, in order to avoid overrepresentation of croakers, drums and catfish.

Fragmentation levels were assessed by noting the percentage of the completeness of the otoliths. Three stages of burning were identified based on the color of the specimens: otoliths with darker hues, or reddish to black coloration, were considered burned; carbonized otoliths had a blackened appearance due to exposure to intense heat; and calcined specimens exhibited blue-gray to white hues.

In rain-soaked environments (such as the coast of southern Santa Catarina), otoliths calcium carbonates react with the stronger carbonic acid to form calcium bicarbonate, which is also water soluble. Humic acids from organic materials can also contribute to weathering (Waselkov, 1987). These weathering processes cause the deterioration of the calcium carbonate that forms otoliths, creating a dark brown pellicle. In its later stages, weathering can completely dissolve the element, leaving only an outer shell and a completely hollow otolith. The assessment of presence of weathering and its causes might help understand the history of the site. Weathering affects specimens differently and this affected the quantification of remains.

Unfortunately, 1492 otoliths from excavations of Locus 2 - unavailable for further examination of modifications – could not be analyzed for weathering, fragmentation and degree of burning. Since the numbers account for roughly 15% of the otolith assemblage presented here, this probably would not greatly affect the results.

Measurements of sagittae otoliths were recorded to examine possible differences in fish size. Measurements of length and height were taken from both left and right otoliths. The allometric formula used to transform otolith length into fish length for species found on the Brazilian coast was introduced by Bastos (1990) and later expanded by Lima (1991). The allometric formula used was $y = ax^{ß}$ (where y is the total fish weight; x is the otolith length; a is the y- intercept; and ß is the slope) (Reitz et al., 1987). The values for catfish are: $a = 0.000127$ and $ß = 6.4713$, while the whitemouth values are: $a = 0.0854$ and $ß = 3.0674$ (Lima, 1991). I followed the same formula in order to allow for comparisons with other studies in Brazil. I measured the otoliths from catfish and whitemouth croakers in order to infer body weight, because these taxa had the largest quantity of available otoliths for analysis.

Digital calipers were utilized in all measurements, and a single person took all measurements so as to prevent inter-user error. Growth can be affected by genetic and environmental factors, so assuming a linear relationship between otolith length and fish size is not advisable (Munk and Smikrud, 2002; Ross et al., 2005). Nevertheless, for the purposes of archaeological research, the inherent inaccuracies attributable to fish growth variability are minimal and should not interfere with the analysis. The decision to measure otoliths that were subjected to heat was due to the low number of otoliths recovered from shell layers. Weathering, a common process in funerary features, diminished the number of elements that could be measured due to breakage. So, in

[1] Research carried out by the author (in 2001), and Nishida (2007) showed that fractions smaller than 4 mm did not contain identifiable faunal remains in quantities that would change results obtained with the larger mesh size. Only small fragments of otoliths were recovered from 2 mm samples and no recognizable otoliths appeared in the 1 mm samples.

order to maximize the number of otoliths that could be analyzed, some minimally weathered elements were also included for measurement. Only those that were whole, with no discernible breaks under magnification, were selected for the analysis.

4. Results

4.1. Taxonomic identification

A total of 9378 otoliths were identified during the research[2]. These elements are ubiquitous in all samples recovered from the shell mound. At Jabuticabeira II, the most common otoliths belong to whitemouth croaker, catfish, black drum (*Pogonias chromis*), and weakfish (*Cynoscion acoupa*, *Cynoscion leyarchus*) (Table 1). Otoliths from snook (*Centropomus* sp.), ground croaker (*Bairdiella ronchus*), and shorthead drum (*Larimus breviceps*) were also recovered, but very rarely.

During the whole occupation of Jabuticabeira II, feasting events were composed primarily of whitemouth croaker (*Micropogonias furnieri*) and catfish (*Genidens barbus* and *Genidens genidens*) and these fish also predominate in the composition of shell layers. Feasting episodes – distinguished by the different funerary layers – show differences in scale in terms of the overall quantity of food but not in the proportions of different types of animal foods, namely shellfish, since other animals were seldomly recovered from the site. Furthermore, the proportion of fish to shellfish is similar between shell-dominant layers and funerary areas.

4.2. Element distribution and fragmentation

It was surprising that otoliths are the second most common fish element at Jabuticabeira II, following vertebrae (Table 2). The presence of both cranial and postcranial fish elements indicates that whole individuals were deposited at the site; however, postcranial elements slightly supersede the cranial (54% to 46%). Considering the larger number of vertebrae present in fish skeletons (between 25 and 55 depending on the species), the ratio between vertebrae and otoliths should be 13:1, while at Jabuticabeira it is 2.3:1. Even in relation to other cranial remains, otoliths impress by their numbers.

As can be seen in Fig. 3, NISP values of skeletal elements of the fish taxa included in this paper, particularly cranial ones, are underrepresented in relation to otolith NISP values. The only element that comes close are catfish frontal plaques, the second most common cranial element, which are still outnumbered by otoliths.

From the total, 7615 otoliths are complete (Fig. 4). Unless heavily weathered, otoliths do not exhibit high levels of fragmentation. Bones, on the other hand, exhibit higher levels of fragmentation. Approximately 42% of elements were considered to be more than 50% complete, as expected, since fish bones are more fragile and tend to break and be impacted by post-depositional factors.

4.3. Thermal alteration

Evidence of burning can suggest cooking techniques, processing methods, disposal of food waste or ritual fauna, and unintentional fires (Lyman, 1994; Reitz and Wing, 1999:231) so its analysis is important to understand the uses of animal materials. Sixty-seven percent of the fish bone assemblage have signs of thermal alteration, while 57% otoliths are heat altered. Otoliths have higher percentages of carbonization (15%), but lower frequencies of burning (26%) than the rest of the fish assemblage (6% and 58% respectively). Catfish and whitemouth croaker have slightly higher frequencies of burning than otoliths of other fish (Fig. 5), which is probably related to their common presence in hearths, features that naturally contain more heat-affected elements. On average, hearths have approximately 109 otoliths per sample of 8 L, while funerary areas have 52, and burial pits have 46 otoliths. Although otoliths are more common in hearths, these features do not contain a corresponding increased amount of fish bones (respectively 1044, 1126 and 904) and while it could be expected that heat could be damaging to bones, it does not completely explain the increased number of otoliths in relation to other funerary contexts. Average numbers from funerary areas and burial pits' sediments contain proportions of bones × otoliths closer to what is expected in fish skeletons. The deposition in higher numbers in these features suggests intentional removal from neurocrania.

Table 1
NISP of otoliths from Jabuticabeira II analyzed in this study.

Taxon	NISP
Genidens sp	4386
Micropogonias furnieri	4115
Pogonias chromis	303
Cynoscion sp	189
Mugil sp	20
Centropomus sp	2
Bairdiella ronchus	1
Larimus breviceps	1
Undetermined	361

Table 2
Total Fish Element Distribution of funerary features (NISP Values). Note: fish elements from Klokler (2001) were not included.

Anatomical unit	NISP
Vertebrae	21,757
Otolith	9258
Ray	4497
Frontal plaque	3283
Rib	3078
Scale	1629
Pectoral spine/ray	1404
Tooth	1326
Cleithrum	910
Pterygiaphore	799
Basiocciptal	742
Spines	712
Dentary	615
Quadrate	567
Operculum	557
Hypural	518
Dorsal spine/ray	510
Lower pharyngeal (pdf)	506
Premaxilla	459
Dorsal plaque	456
Articular	367
Palatine	324
Ptm	298
Atlas	245
Maxilla	213
Scapula	210
Supraocciptal	148
Hyomandibular	140
Basipyterigium	94
Vomer	78
Terminal vertebrae	38
Upper pharyngeal (pdp)	27
Apofise	16
Spine (ray)	12
Preoperculum	9
Dermethmoid	2
Paraesphenoid	1
Unidentified cranial	8118
Unidentified	22,325

[2] Quantification does not include otoliths recovered at the same site during research by Paula Nishida in 2007.

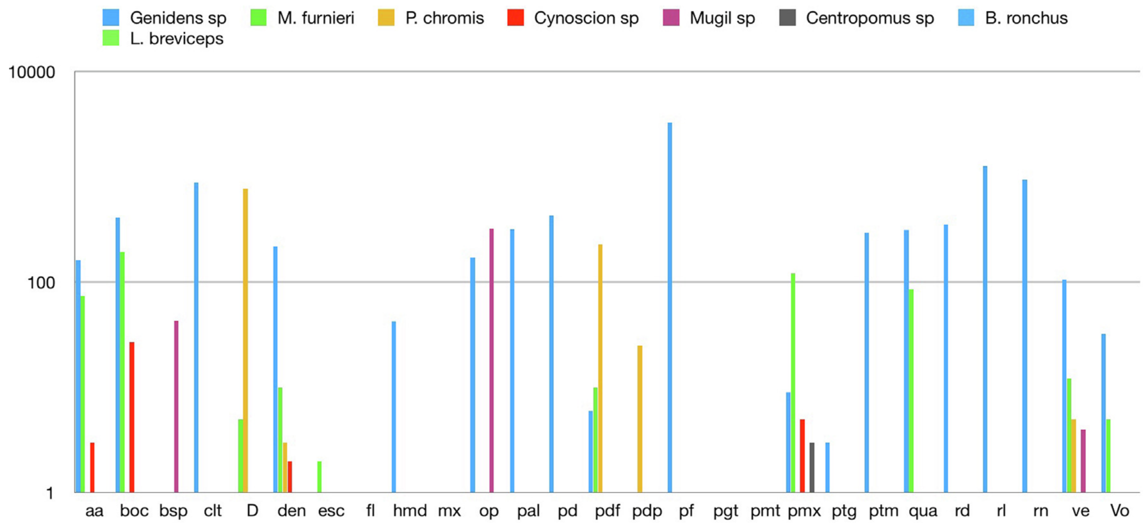

Fig. 3. NISP values of fish elements (without otoliths). Element codes: Aa = Articular, boc = Basiocciptal, bsp = Basipyterigium, clt = Cleithrum, d = Tooth, den = Dentary, esc = Scapula, fl , hmd = Hyomandibular, mx = Maxilla, Op = Operculum, Pal = Palatine, pd = dorsal plaque, pdf = Lower pharyngeal, pdp = Upper pharyngeal (pdp), Pf = Frontal plaque. Pgt = Pterygiaphore, pmx = Premaxilla, qua = Quadrate, rd = dorsal spine (ray), rl = lateral spine (ray), rn = Spine (ray), ve = vertebra, vo = vomer.

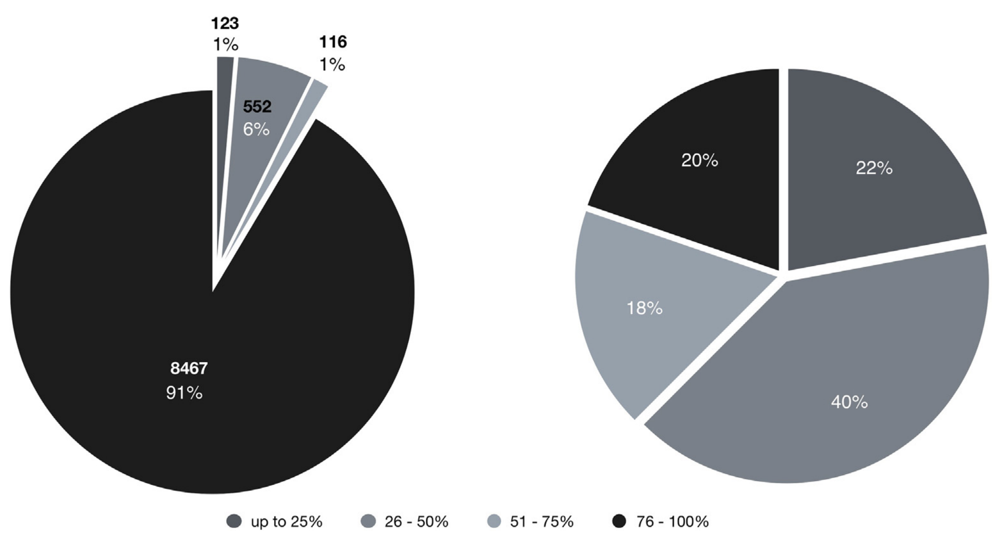

Fig. 4. Otolith (left) and fishbone (right) completeness.

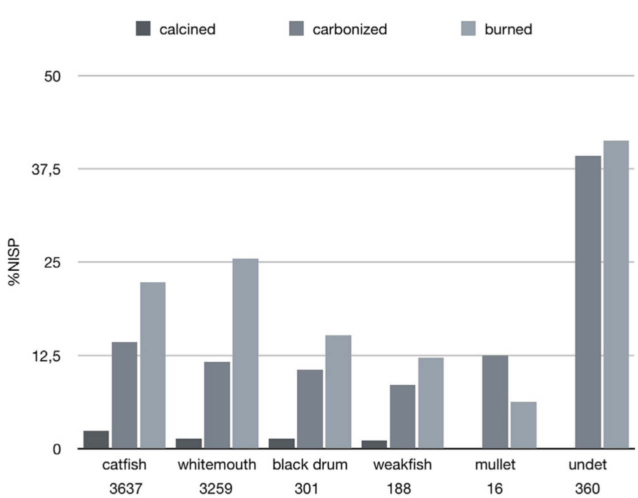

Fig. 5. Thermal Alteration of Otoliths (axis corresponds to %NISP, number indicates frequencies of elements by taxa).

4.4. Weathering

Weathering is not a common occurrence in most of the site's fish bone materials: only 1% presents some sort of alteration. On the other hand, approximately 39% (or 3647 specimens) of otoliths are weathered. Most funerary layers exhibit higher evidence of alteration by post-depositional factors. Also, weathering affected most of the bone and shell assemblage from loci 3 and 6. Otoliths and bones respond differently to processes due to the fact that their composition is dissimilar. On the other hand, the same weathering processes that affect shell valves also cause the deterioration of the otoliths' calcium carbonate. The loss of the aragonite makes these elements more susceptible to breakage (Pierce and Boyle, 1991) and in some cases disintegration, as seen in Jabuticabeira II.

The most usually weathered specimens belong to catfish and whitemouth croaker, with weathering being present in 47% and 41% of otoliths, respectively (Fig. 6). Black drum (26%) and weakfish (22%) have lower frequencies of weathering. Weakfish are not frequently recovered in the samples, but black drums are present in approximately 90% of them, so recurrence does not explain their lower percentages of

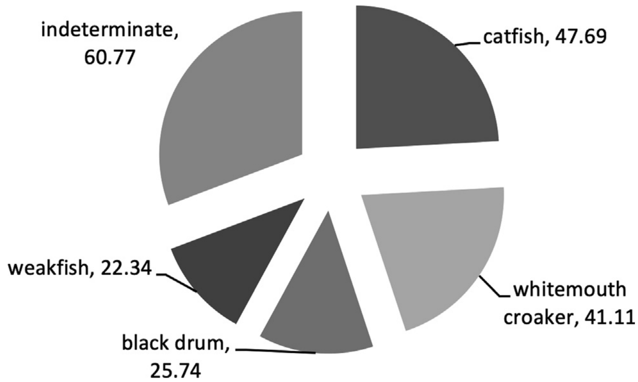

Fig. 6. Percentage of weathering according to taxon.

alteration. Both were subjected to the same processes that caused the weathering of almost half of the catfish and croaker otoliths. This lower occurrence of weathering may be attributable to the thickness of the elements; black drum and weakfish otoliths are thin and more prone to fragmentation and could be rendered unidentifiable or completely dissolved when heavily weathered, thus decreasing their identification and final quantification.

4.5. Size estimates

Elements from shell layers (n = 122) and from a random selection of funerary features, including funerary lenses, hearths, and burial pits (n = 370), were analyzed. The length values of whitemouth croaker and catfish were then used to estimate fish weight. T-tests based on size estimates indicated that there are significant differences between the shell and funerary deposits (Table 3). These results concur with the previous hypothesis that larger fish were included during the funerary rituals (Klokler, 2001).

While mass capture would be expected in order to feed great quantities of people during a feast, I believe that larger specimens were selectively caught as grave offerings, probably using a different technology. According to measurements exposed in table 3, the minimum weight estimates for both taxa vary very little in shell and funerary layers but, conversely, the maximum weights increase markedly in the latter. During the excavation of the funerary layer 2.15.13, several large fish in anatomical position were recognized, and I still posit they were probably deposited in the funerary area as food offerings, their occurrence clearly indicating the selection of larger specimens for this specific function.

Nevertheless, sample size could be a factor in the results. In funerary features, larger fish specimens occur, but their inclusion could be due to the larger number of measurable otoliths from these samples, which could facilitate the incorporation of unusual sizes. Due to the small assemblage of otoliths recovered from shell layers, very few could be measured. The sample size differences between assemblages from funerary and shell layers could be a factor and should be addressed in the future with the recovery of larger samples.

Table 3
Ranges, Mean, Median, and Standard deviation for fish weight estimates.

	Whitemouth croaker (weight in grams)	Catfish (weight in grams)
Shell layers	17.21–765.10	3.30–292.57
	Mean – 148.44	Mean – 74.90
	Median – 71.70	Median – 46.08
	Standard Deviation – 172.44	Standard Deviation – 74.71
Funerary layers	18.56–1251.32	5.19–696.58
	Mean – 189.19	Mean – 94.39
	Median – 83.85	Median – 52.63
	Standard Deviation – 225.72	Standard Deviation – 119.43

Table 4
Basic information about the burials in Locus II with large quantities of otoliths.

Location	Burial	Sex and Age	Total	NMI
Locus 2 - Trench 15	32	Indeterminate – 21–35	308	157
Layer 2.15.13	34	Female – 21–35	511	253
Layer 2.15.13	36	Male/Indeterminate – 21–35/0	198	119
Layer 2.15.13	40	Female – Adult	116	69
Layer 2.15.13	41	Male/Indeterminate – Adult/less than1	194	111
Locus 6	115	Indeterminate/indeterminate – Adult/ < 1	238	73
Locus 6	119	Indeterminate/Adult	235	79

Dr. Levy Figuti has led a team of students that measured otoliths from large samples recovered from a trench (number 18) at the site. Their study demonstrated that fish with a broad range of weights were included in Jabuticabeira II's assemblage, encompassing small to large fish, although the vast majority are small specimens weighing less than 200 g (Levy Figuti, personal communication 2015). The length estimates indicate that most whitemouth individuals were juveniles that had not reached reproductive age (under 200 mm total length). These results are similar to ours and the expansion of sampling coupled with the combination of both length and weight estimates will shed more light on fishing practices of shell mound groups, among other topics.

4.6. Associations

Some burial pits at Jabuticabeira II have, among their components, impressive quantities of otoliths. Seven burials (32, 34, 36, 40, 41, 115, and 119) included over 100 recovered otoliths (Table 4). In nine other burials I could not ascertain the association of numerous otoliths. Two excavation areas, located at loci 2 and 6, are the only contexts where the excavation methods permitted total recovery of the features' contents. Burial 32 was recovered from Trench 15, with all accompaniments successfully retrieved. Four other burials included in this study belong to the same funerary area (2.15.13), located spatially close to Burial 32 but temporally later. Due to its position in the mound, burial 42 probably belongs to the same funerary area (2.15.13) as most of the burials used in this study. Burials 115 and 119 are located within the same layer at Locus 6 and their pit contents were retrieved.

One individual (34), a female between the ages of 21 to 35 was buried with over 500 otoliths deposited either within the grave confines or in a small concentration above it. The MNI of the otoliths recovered from these features corresponds to 253 fish; within the confines of the burial pit the MNI approaches 130. The pit was just big enough to accommodate the tightly flexed individual, so it is safe to assume that these elements were deposited separately from the fish neurocrania. This situation implies a deliberate deposition of these elements and not a random accumulation of remains consumed during the feast, subsequently laid next to the deceased.

5. Discussion

5.1. Otoliths: Incidental remains or selected elements?

For most of the history of shell mound archaeology in Brazil, shell valves and fish bones were seen as indicators of the diet of shell mound builders. The ubiquity of otoliths in shell mounds was always connected to the presence of other fish remains and celebrated as a means of species identification and quantification by zooarchaeologists. However, there has been a change in perspective in shell mound archaeology that now identifies individual sites as graveyards and their construction as following a series of ritual activities. This has been accompanied by a shift in the focus of zooarchaeological analyses, which incorporates other realms of the human-animal relationship besides the economy. This study proposes that otoliths were not simply refuse remains of fish processing and consumption but had special significance for Archaic period shell mounding populations that inhabited the coast.

The taxonomic identification based on otoliths closely follows the identification based on fishbones, with a slight variation regarding the importance of catfish (*G. barbus* and *G. genidens*) due to the ease with which elements from siluriformes' skeleton are recognized. Undoubtedly these taxa had great importance to shell mounding groups and were fished regularly. In Jabuticabeira II, otoliths are the second most common fish element identified in the site, even though there are elements that occur in higher numbers within individual fish skeletons, such as ribs, spines, frontal plaques, that are expected to be recovered in larger numbers from deposits. The sagittae otoliths are only present in pairs.

If processing was a factor affecting their presence at the site, high frequencies of other cranial elements would be expected. However, fish postcranial elements occur in larger quantities than cranial elements at Jabuticabeira II (Table 2). The quantities of elements suggest that otoliths were processed in a distinct way from other fish remains, which facilitated their presence and/or preservation. Some authors believe that differential processing and deposition are usual indicators of materials that are regarded as distinct, sacred (Kansa and Campbell, 2002). I concur and believe that at Jabuticabeira II feasting refuse also had distinct "life histories".

Clearly, fish occupied a special place in shell mound groups' daily lives and little by little, researchers observe that their importance went beyond the economic realm. Firstly, research demonstrated that fish remains were used as construction materials in shell mound sites, in very similar ways as shellfish valves, in some instances creating "fish mounds" (Klokler, 2001, 2008, 2014a; Nishida, 2007; Villagrán, 2014; Villagrán et al., 2010). Secondly, whole fish skeletons deposited near graves in Jabuticabeira II (as well as other shell mounds), suggest their use as offerings. Thirdly, catfish and whitemouth croakers are the most common food served in funerary feasts and appear in higher number in mortuary contexts.

Multiple lines of evidence indicate that croakers and catfish were selectively being targeted for capture and use during funerary occasions. Their size, and weight, suggest fishing took place in estuarine areas with the use of nets, or traps. Also, analyses of contents of some graves in Jabuticabeira II suggest that otoliths may have been extracted from the fish neurocranium and deposited in different funerary features. The reason can be associated with the belief that these elements possess some characteristics that were particularly appreciated by fisher-gatherer groups. In Brazil, at least three other shell mounds offer some evidence of the distant past importance of otoliths.

5.2. Insights from other sites

Selecting some sites where sampling included recovery of all faunal remains, we can discern some cases similar to Jabuticabeira II. At Espinheiros II site, located further north in Santa Catarina state, research by Levy Figuti quantified 51,638 otoliths, totaling 47% of the vertebrate assemblage (report on file). Faunal remains were wet sieved using 3 mm mesh and all vertebrate materials retained were collected. The proportion of otoliths in relation to other remains arouses suspicions of deliberate collection and deposition in even higher numbers than Jabuticabeira II. Unfortunately, the report does not include the provenience of the samples so it was not possible to identify the exact context of the findings.

Information from sites located approximately some 600 km north of Jabuticabeira, in São Paulo state, seems to reinforce the idea that fisher-gatherer groups intentionally selected and deposited otoliths (Fig. 2). At Piaçaguera site, a shell midden, 120,279 elements were recovered from excavations in an area of 79 m2 (volume excavated = 93 m3) (Garcia, 1972). Garcia affirms that in some parts of the site there are concentrations of *Cathorops spixii* (Madamango sea catfish) otoliths (1972:103). Borges, who recently analyzed a portion of the faunal assemblage from Piaçaguera, highlighted that more than 95% of the fish elements were otoliths (C. Borges, 2015). Tenório site, another midden in the same area had 65,968 otoliths in 194 m^3 (Garcia, 1972). The most common species' otoliths recovered was from *Larimus breviceps*. According to the author, unlike Piaçaguera, the distribution of otoliths in Tenório seem balanced among the deposits[3]. All materials from both sites were water sieved using 3 and 5 mm meshes and materials considered diagnostic were collected (C. Borges, 2015; Garcia, 1972). Recovery methods could have influenced the higher quantities of otoliths found at the middens due to the easiness of otolith identification. On the other hand, analogous frequencies of bones and otoliths were not seen in other shell sites excavated at the period using similar recovery strategies, which could indicate that the latter elements were, in fact, more commonly present at Piaçaguera and Tenório. In her analysis of Piaçaguera, Caroline Borges affirms that even though the site's more acidic matrix could have affected the osseous elements, she could not rule out that the frequencies of otoliths could be due to processing or "accumulation" practices (2015: 303).

Further north – around 300 km from the Tenório and Piaçaguera shell middens –a different situation is uncovered. At the sites located in Rio de Janeiro state (Fig. 2), otolith numbers are very low in comparison with the more southern sites, despite the existence of matrices with similar composition that should guarantee good preservation of these elements. At Sampaio I site, large-scale sampling recovered less than 300 otoliths (Pinto, 20099), while in Guapi, only 28 otoliths were recovered (D. Borges, 2015). Within the Rio de Janeiro area, groups do not seem interested in the distinct collection, recovery, and/or deposition of otoliths.

Nevertheless, the quantities of otoliths in certain sites, as seen in shell mounds located in São Paulo, or in certain funerary deposits as observed in Santa Catarina, lead us to believe that their presence is not solely dependent on their proportion within the fish skeletons, processing or due to taphonomic influences. These elements appear to have had a significance beyond the subsistence realm. A more detailed investigation of other sites and fine-grained provenience data could help identify patterns of deposition and shed light on the possible role or roles of fish otoliths.

As discussed previously, there is clear evidence that otoliths have a special meaning for some ancient and traditional groups alike, in different parts of the world, and in some cases they are used for medicinal purposes to cure a myriad of ailments. The shape, smoothness and color of otoliths, for example, could have initially drawn the attention of prehistoric groups to these elements, and they could have been seen as factors in ritual, divinatory or medicinal realms for these groups as well.

Research using archaeofauna from Brazilian shell mounds has been deconstructing long-held traditional beliefs in the last 20 years. Studies demonstrated that large shell mounds were built following a design (Bianchinni, 2015; Gaspar, 2000; Klokler, 2001; Nishida, 2007): some sites were strictly funerary and built with feasting remains (Fish et al., 2000; Klokler, 2001, 2008, 2014a). Our research is one of the few that identified large-scale feasts promoted by fisher-hunter-gatherers and moreover, with the use of non-exotic animals (Klokler, 2008). The current results reinforce the idea that shell mound groups served specific fish taxa in funerary feasts and otoliths were selected for special deposition in these ritual contexts.

[3] Only recently were the field diaries pertaining to both sites made available, so at the moment more precise information about the specimens and their provenience cannot be pinpointed.

6. Fishing for lucky-stones

Given the recognition - in several texts and ethnographical works – of the magical and healing powers of otoliths, one can argue that shell mound communities could identify similar particularities in these fish elements. Healers, shamans or other individuals with access to the supernatural could be interred surrounded by these powerful "lucky stones", their tools of trade. In any case, elements charged with power would be managed, manipulated and/or deposited with great care, following special or careful treatment.

Recent research, particularly with the development of the social zooarchaeology perspective, demonstrate the extremely rich relationships between animals and humans, however fish resources have often been ignored while most of the literature focused more deeply on mammals or birds. Within Brazilian archaeology, fish have been mostly relegated to their role as part of the diet of shell mound builders, without exploring other aspects of fish – human interactions outside this realm, thus ignoring a long tradition of their importance in zootherapy. Analyses of Jabuticabeira II's assemblage suggest that otoliths were viewed and handled distinctively from the rest of the ichthyological remains, thus highlighting their differential role.

Some examples of studies within this perspective, and that focus on maritime societies, include research by Betts et al. (2012) focused on Late Archaic - Late Woodland ceremonial and mortuary contexts from the Maritime Peninsula (located in the region between US and Canada) where shark teeth deposits are considered more than adornments or offerings but rather as emblems of a maritime way of life and icons relating to supernatural powers of the animals. Fiore and Zangrando in their 2006 article brought a comprehensive study on subsistence and ceremonial activities involving fish taxa in Tierra del Fuego. The authors show the importance of using multiple lines of evidence in order to explain presence and absence of certain species in the assemblage and how avoidances can be due to the symbolic sphere.

David et al. (2005) document changes in ritual processes at about 500–400 years ago, expressed by arrangements of Bu shells (large edible marine gastropods – *Syrinx aruanus*) by Torres Strait Islanders. The authors, performing an "Archaeology of spirit worlds", detect important shifts brought after contact with Spanish seafarers.

Overton and Hamilakis feel that most social zooarchaeology practitioners still operate within an anthropocentric approach and advocate for the recognition of animals' agency and alternative ontologies (2013: 114). Their work, focusing on the entanglement between humans and whooper swans, uses as an example two assemblages from the Danish Mesolithic and demonstrates (among other points) how fertile it is to study animal ethology closely so as to better understand the interactions between humans and animals, from a standpoint that is not solely economic and that understands the relations between them prior to the capture and killing.

In Brazil, the scenario in shell mound archaeology began to change with research that focused on the use of shellfish and fish as construction materials, feast food and funerary offerings (Figuti and Klokler, 1996; Klokler, 2008, 2017; Villagrán, 2014; Klokler, 2001; Klokler, 2014a; Nishida, 2007; Villagrán et al., 2010). As other maritime societies, shell mound builders probably had a special place reserved for aquatic animals and their resources, as suggested by the existence of zooliths, and particular portions – such as otoliths - could be viewed as encompassing spiritual powers. The greater presence of otoliths in mortuary hearths, burial pits and differential processing at Jabuticabeira II supports the belief that for some communities they had a particular use. At this point, I cannot unequivocally verify repetition of trends presented here in other sites but assemblages from prior research can be reanalyzed to allow comparisons, since this is an avenue of study worth pursuing in more detail.

As revealed by a review of the literature, human societies have been using otoliths for thousands of years, particularly maritime societies. A similar scenario can be distinguished in Brazilian shell mounds. The higher degree of heat alteration, the presence in quantities in ritual contexts such as hearths, burial pits and funerary areas in Jabuticabeira II and overrepresentation of these elements (especially in relation to other fish elements) in some sites, support the hypotheses that fisher-gatherers groups in southern Brazil had non-dietary uses for otoliths.

At first, we surmised that otoliths were deposited in graves of successful fishers. Common materials associated with fishing and commonly used by archaeologists as indicators of occupation, such as fishhooks and net weights, are rarely found within pits. Two of the individuals identified in this study were interred with bone points (burial 34 – 3 points and burial 36 – only one) which could indicate connection with fishing activities. The elements could signify the plentiful fishing activities performed by particularly talented deceased individuals. Otoliths, then, would signal the individual's prowess while also being offerings during the funerary ritual for the continuation of successful fishing activities.

Otoliths could also have been used during fishing, as a device that attracted schools of fish, like the hunting charms discussed by McNiven (2010). Hunting charms are well known to anthropologists and archaeologists alike. Such artifacts can be made out of wood, rock and bone (McNiven, 2010; Ringhofer, 2010; Russell, 2011); in many cases they personify characteristics of the prey, and can also be mediators between prey and hunters. McNiven (2010) describes the use of dugong ear bones by Torres Strait islanders to symbolically control the dugongs' hearing by either removing the auditory sensory of the animals or assisting communication with them. His analyses of Torres Strait dugong ear bones show similarities, with respect to the special treatment these elements received, with the otoliths in some Brazilian shell mounds.

Otoliths could also be seen as the most important fish body part controlling hearing and communication since, to many fishers, ear stones are responsible for the 'croaking' sounds of some fish species. Even Aristotle mentions that drums have an acute hearing and make grunting noises due to otoliths (Balme, 1991). In this way, otoliths could have acted as fishing charms. Fishers using them could then block the hearing or grunting of prey, suppressing their communication and facilitating capture. Or maybe otoliths helped fishers to communicate with schools, and were used during the capture of large quantities of food for funerary events.

Adverse weather conditions such as treacherous seas, strong currents, high winds are situations that seafarers might encounter in their voyages, irrespective of duration, and they are all dangers inherent in the coastal life that shell mound builders led. Past sailors might have relied upon otoliths as amulets to protect them from hazards of the sea. Or, they could have been carried as a tool to predict the sea's behavior as Pliny and Rackham (1938) and Duffin (2007) described.

Finally, otoliths could have been associated with people considered as healers. The use of otoliths as medicinal elements is ancient and widespread, as seen in the zootherapy literature. Maybe individuals that possessed knowledge about diseases and their treatment were interred with elements used as medicine, or considered powerful in treating some ailments. The increased deposition of otoliths in hearths could also be related to their magical power. Burning otoliths could be part of the mortuary ritual for these groups.

7. Final remarks

Delving farther into ethnographic and ethnohistorical literature is an essential step in understanding how traditional fishing communities relate to fish ear bones, and how they are processed, used and discarded. An expansion of the investigation into otoliths can provide more clues as to the richness of uses of faunal remains by human communities, and broaden our understanding of past human populations. It also can demonstrate the importance of faunal studies and how animal remains help archaeologists examine social organization, ritual, health and other areas usually underrepresented in zooarchaeological studies.

The use of otoliths for seasonality studies should be increased in shell mound research in Brazil following the successful trend in other countries, as discussed by Disspain et al. (2016). The mobility of these populations is poorly understood, due to the use of indirect evidence, so a more accurate approach using ring growth could be fundamental in settling the debate regarding settlement patterns of shell mound groups. Otolith use for sclerochronology should be considered if the croaker and catfish otoliths prove to be sufficiently sensitive to capture seasonal temperature changes. Thus, archaeologists could have more refined chronologies for the coastal occupations and site construction, which have so far proved difficult to achieve solely with radiocarbon dates.

CRediT authorship contribution statement

Daniela Klokler: Conceptualization, Methodology, Data curation, Writing - original draft, Funding acquisition.

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

The author would like to thank the teams of the projects “Sambaqui e Paisagem” and “Sambaquis Médios, Grandes e Monumentais” and their coordinators: Paulo DeBlasis, Paulo Giannini, MaDu Gaspar, and Sheila Mendonça de Souza. Also Levy Figuti for our many conversations about fish and their otoliths. Erendira Morales made suggestions that improved the manuscript. I specially thank two anonymous reviewers who greatly contributed with suggestions. Finally, Suzanne Fish and Ximena Villagrán for encouraging me to publish it.

Funding

This work was supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES grant 1501-02-0, National Science Foundation doctoral dissertation grant (SBR-0652177) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq grant 409428/2013-2).

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jaa.2020.101167.

References

Adams, Leverett A., 1940. Some characteristic otoliths of American Ostariophysi. J. Morphol. 66, 497–519.
Alves, Romulo, Humberto, A., 2011. The faunal drugstore: animal-based remedies used in traditional medicines in Latin America. J. Ethnobiol. Ethnomed. 7, 9.
Alves, Romulo, Rosa, Ierece, 2005. Why study the use of animal products in traditional medicines? J. Ethnobiol. Ethnomed. 1, 1–5.
Alves, Romulo, Rosa, Ierece, Santana, Gindomar, 2007. The role of animal-derived remedies as complementary medicine in Brazil. Bioscience 57, 949–955.
Andrus, Fred T., Crowe, Douglas E., 2002. Alteration of otolith aragonite: effects of prehistoric cooking methods on otolith chemistry. J. Archaeol. Sci. 29, 291–299.
Andrus, Fred T., Sandweiss, Daniel, Reitz, Elizabeth, 2008. Climate Change and Archaeology: The Holocene History of El Niño on the Coast of Peru. In: Scarry, Margaret, Scudder, Sylvia (Eds.), Elizabeth Reitz, C. Case Studies in Environmental Archaeology, New York, Springer, pp. 143–158.
Wheeler, A, 1978. Problems of the identification and interpretation of archaeological fish remains. In: Brothwell, D, Thomas, K, Clutton-Brock, J (Eds.), Research Problems in Zooarchaeology. Occasional Papers of the Institute of Archaeology 3 Institute of Archaeology, pp. 69–75.
Balme, D.M., 1991. Aristotle. History of Animals, Books VII-X, Cambridge, Harvard University Press.
Bandeira, Dione, 1992. Mudança na estratégia de subsistência – o sítio arqueológico Enseada I – um estudo de caso. Unpublished Master’s Thesis, Universidade Federal de Santa Catarina, Florianópolis.
Bastos, G.C.C., 1990. Morfologia de otólitos de algumas espécies de Perciformes (Teleostei) da costa sudeste-sul do Brasil. Unpublished Master’s Thesis. Instituto Oceanográfico, Universidade de São Paulo, São Paulo.
Betts, Matthew, Blair, Susan, Black, David, 2012. Perspectivism, mortuary symbolism, and human-shark relationships on the maritime Peninsula. Am. Antiquity 77 (4), 621–645.
Bianchini, Gina, 2015. Por entre corpos e conchas: prática social e arquitetura de um sambaqui. Unpublished PhD Dissertation. Museu Nacional, Universidade Federal do Rio de Janeiro, Rio de Janeiro.
Bonnerjea, B., 1931. Some present day superstitions of the white population of the Middle West, U.S.A. Man 31, 224–225.
Borges, Caroline, 2015. Analyse archéozoologique de l’exploitation des animaux vertébrés par les populations de pêcheurs-chasseurs-cueilleurs des sambaquis de la Baixada Santista, Brésil, entre 5000 et 2000 BP. Unpublished PhD Dissertation. Museum National D’Histoire Naturelle, Paris.
Borges, Diogo, 2015. Prepare o terreno, vou construir: Estudo do processo de formação do sambaqui do Guapi. Unpublished Master’s Thesis, Museu Nacional, Universidade Federal do Rio de Janeiro, Rio de Janeiro.
Calippo, F.R., 2000. Análise da ocorrência de otólitos de bagres da Família Ariidae (Teleostei), Micropogonias furnieri e Pogonias cromis (Teleostei: Scianidae) em sítios arqueológicos da restinga da Laguna dos Patos, Rio Grande do Sul, Brasil. Unpublished BA thesis. Universidade Federal do Rio Grande, Rio Grande.
Campana, Steven, 2005. Otolith science entering the 21st century. Mar. Freshwater Res. 56, 485–495.
Casteel, Richard W., 1976. Fish Remains in Archaeology and Paleo-Environmental Studies. Academic Press, New York.
Chim, E. N., 2013. Análise dos otólitos provenientes do sítio RS-LS-11 - Rio Grande/RS. Unpublished BA thesis. Universidade Federal do Rio Grande, Rio Grande.
Colonese, Andre C., Collins, M., Lucquin, A., Eustace, M., Hancock, Y., de Almeida Rocha Ponzoni, R., Craig, O.E., 2014. Long-term resilience of late Holocene coastal subsistence system in southeastern South America. PLoS ONE 9(4), e93854.
Colley, Sarah, 1990. The Analysis and Interpretation of Archaeological Fish Remains. In: Schiffer, Michael (Ed.), Archaeological Method and Theory. 2. University of Arizona Press, Tucson, pp. 207–252.
David, Bruno, Crouch, Joe, Zoppi, Ugo, 2005. Historicizing the spiritual: Bu shell arrangements on the Island of Badu, Torres Strait. Cambridge Archaeol. J. 15 (1), 71–91.
Dawson, Warren R., 1932. Studies in Egyptian Medical Texts. J. Egyptian Archaeol. 18, 150–154.
DeBlasis, Paulo, Fish, Suzanne K., Gaspar, Maria Dulce, Fish, Paul R., Afonso, Marisa C., Eggers, Sabine, Figuti, Levy, Klokler, Daniela, Pilles, Peter J., Sanches-Carpenter, Guadalupe, Worthington, Anne, 1999. Projeto Arqueológico Camacho (Padrões de Assentamento e Formação de Sambaquis em Santa Catarina). As Campanhas de 1998 e 1999. São Paulo, Unpublished report (FAPESP 98/8114-3).
DeBlasis, Paulo, Kneip, Andreas, Scheel-Ybert, Rita, Giannini, Paulo, Gaspar, Maria Dulce, 2007. Sambaquis e Paisagem: Dinâmica Natural e Arqueologia Regional no Litoral Sul do Brasil. Arqueologia Sudamericana/Arqueologia Sul-americana 3, 29–61.
De Masi, Marco, 1999. Prehistoric Hunter-gatherer Mobility on the Southern Brazilian Coast: Santa Catarina Island. Unpublished PhD Dissertation (Anthropology). Stanford University, Stanford.
DeJesus Silva, R.T., 2018. Lancem as redes: a pesca no sambaqui Mato Alto I – SC. Unpublished BA thesis (Archaeology). Universidade Federal de Sergipe, Laranjeiras.
Disspain, M., Ulm, Sean, Gillanders, B., 2016. Otoliths in archaeology: methods, applications and future prospects. J. Archaeol. Sci.: Reports 6, 623–632.
Doucet, J., 2012. Oysters and Catfish: Resource Exploitation at Rollins Shell Ring, Ft. George Island, Florida. Unpublished Master’s Thesis, LSU.
Duffin, Christopher, 2007. Fish otoliths and folklore: a survey. Folklore 118, 78–90.
Figuti, Levy, 1993. O Homem Pré-histórico, o Molusco e o Sambaqui: Considerações Sobre a Subsistência dos Povos Sambaquianos. Revista do Museu de Arqueologia e Etnologia 3, 67–80.
Figuti, Levy, Klokler, Daniela, 1996. Resultados Preliminares dos Vestígios Zooarqueológicos do Sambaqui Espinheiros II (Joinville, SC). Revista do Museu de Arqueologia e Etnologia 6, 169–187.
Fiore, Danae, Zangrando, Atilio F.J., 2006. Painted fish, eaten fish: Artistic and archaeofaunal representations in Tierra del Fuego, Southern South America. J. Anthropol. Archaeol. 25, 371–389.
Fish, Suzanne, DeBlasis, Paulo, Gaspar, Maria Dulce, Fish, Paul, 2000. Eventos Incrementais na Construção de Sambaquis, Litoral Sul do Estado de Santa Catarina. Revista do Museu de Arqueologia e Etnologia 10, 69–87.
Fossile, Thiago, Ferreira, J., Bandeira, D., Figuti, L., Dias-da-Silva, S., Hausmann, N., Robson, Harry, Orton, D., Colonese, A., 2019. Pre-Columbian fisheries catch reconstruction for a subtropical estuary in South America. Fish Fish. https://doi.org/10.1111/faf.12401.
Garcia, Caio, 1972. Estudo comparativo das fontes de alimentação de duas populações pré-históricas do litoral paulista, São Paulo, SP. Unpublished PhD thesis. Universidade de São Paulo.
Gaspar, Ma.Du., 2000. Sambaqui: Arqueologia do Litoral Brasileiro. Jorge Zahar Editor. Rio de Janeiro.
Ham, Leonard C., 1982. Seasonality, Shell Midden Layers, and Coast Salish Subsistence Activities at the Crescent Beach Site, DgRr. Unpublished PhD Dissertation.
Hildburgh, W., 1913. Further Notes on Spanish Amulets. Folklore 24 (1), 63–74.
Kansa, Sarah W., Campbell, Stuart, 2002. Feasting with the Dead? A Ritual Bone Deposit at Domuztepe, South Eastern Turkey (c.5550 cal B.C.). In: Sharyn O’Day, Van Neer, W., Ervynck, A., (Eds.), Behavior Behind Bones: The Zooarchaeology of Ritual,

Religion, Status and Identity, Oxbow Books, Oxford, pp 2–13.
Kefous, K.C., 1977. We Have a Fish with Ears, and Wonder if it is Valuable. Unpublished BA Thesis. Australian National University, Canberra.
Klokler, Daniela, 2001. Construindo ou Deixando um Sambaqui? Análise de Sedimentos. Região de Laguna - SC. Unpublished Master's Thesis, Museu de Arqueologia e Etnologia, Universidade de São Paulo, São Paulo.
Klokler, Daniela, 2008. Food for Body and Soul: Mortuary Ritual in Shell Mounds (Laguna-Brazil). Unpublished PhD dissertation. (Anthropology), University of Arizona, Tucson.
Klokler, Daniela, 2014a. A Ritually Constructed Shell Mound: Feasting at the Jabuticabeira II Site. In: Roksandic, M., Mendonça de Souza, S., Eggers, S., Burcell, M., Klokler, D. (Eds.), The Cultural Dynamics of Shell Middens and Shell Mounds: A Worldwide Perspective, University of New Mexico Press, pp. 151-162.
Klokler, Daniela, 2016a. Otólitos, para que te quero? Revista de Arqueologia 29 (1), 3–17.
Klokler, Daniela, 2016b. Animal para toda obra: fauna ritual em sambaquis. Revista Habitus 14 (1), 21–34.
Klokler, Daniela, 2017. Zooarchaeology of Brazilian Shell Mounds. In: Albarella, U., Russ, H., Vickers, K., Viner-Daniels, S. (Eds.), Handbook of Zooarchaeoloy. Oxford University Press.
Kunz, George F., 1915. The magic of jewels and charms. J.B. Lippincott Company, London.
Lev, Efraim, 2006. Healing with animals in the Levant from the 10th to the 18th century. J. Ethnobiol. Ethnomed. 2, 11.
Lima, Tânia, 1991. Dos mariscos aos peixes: um estudo zooarqueológico de mudança de subsistência na pré-história do Rio de Janeiro. Unpublished PhD Dissertation, F.F.L.C. H. Universidade de São Paulo. São Paulo.
López Amador, J. Juan, 2003. Un amuleto de posible origen protohistórico. Revista de Historia de El Puerto 31, 11–22.
López Amador, J.J., Ruiz Gil, J.A., 2010. Las ofrendas del santuario púnico-gaditano de La Algaida (Sanlúcar de Barrameda). In: Mata Almonte, E. (Ed.), Cuaternario y Arqueología: Homenaje a Francisco Giles Pacheco, pp. 271–281.
Lyman, L., 1994. Vertebrate Taphonomy. Cambridge University Press, Cambridge.
McNiven, Ian, 2010. Navigating the human-animal divide: marine mammal hunters and rituals of sensory allurement. World Archaeol. 42 (2), 215–230.
Munk, Kristen, Smikrud, Kathy M., 2002. Relationships of Otolith Size to Fish Size and Otolith Ages for Yelloweye Sebastes ruberrimus and Quillback S. maliger Rockfishes. Alaska Department of Fish and Game Division of Commercial Fisheries Mark, Tag, and Age Lab – Age Determination Unit Juneau, Alaska.
Nishida, Paula, 2007. A coisa ficou preta: estudo do processo de formação da terra preta do sítio arqueológico Jabuticabeira II. Unpublished PhD Dissertation, Museu de Arqueologia e Etnologia, Universidade de São Paulo, São Paulo.
Miller, Holli, Sykes, Naomi, 2016. Zootherapy in Archaeology: The Case of the Fallow Deer (Dama dama dama). Journal of Ethnobiology 36 (2), 257–276.
Overton, Nick, Hamilakis, Yannis, 2013. A manifesto for a social zooarchaeology. Swans and other beings in the Mesolithic. Archaeol. Dialogues 20 (2), 111–136.
Peacock, Evan, Gabitov, Rinat, Frisch, Jonathan, Hadden, Carla, Carlock, Bradley, Henderson, Kate, 2016. LA-ICP-MS chemical analysis of archaeological otoliths as a tool for seasonality and site catchment studies. J. Archaeol. Sci. 65, 11–19.
Pezo-Lanfranco, L., Eggers, S., Petronilho, C., Toso, A., Bandeira, D., Von Tersch, M., Santos, A., Costa, B., Meyer, R., Colonese, A., 2018. Middle Holocene plant cultivation on the Atlantic Forest coast of Brazil? Royal Soc. Open Sci. 5, 180432.
Pierce, G.J., Boyle, P.R., 1991. A review of methods for diet analysis in piscivorous marine mammals. Oceanogr. Mar. Biol. Annu. Rev. 29, 409–486.
Pliny, Rackham, H., 1938. Natural History. Harvard University Press, Cambridge.
Reitz, E., Wing, E., 1999. Zooarchaeology. Cambridge University Press, Cambridge.
Reitz, Elizabeth J., Quitmyer, Ivy R., Stephen Hale, H., Scudder, Sylvia J., Wing, Elizabeth S., 1987. Application of allometry to zooarchaeology. Am. Antiquity 52, 304–317.
Ringhofer, Lisa, 2010. Fishing, Foraging and Farming in the Bolivian Amazon: On a Local Society in Transition. Springer, New York.
Ross, Robert M., Johnson, James H., Adams, Connie M., 2005. Use of fish-otolith-length regressions to infer size of double-crested cormorant prey fish from recovered Otoliths in Lake Ontario. Northeastern Nat. 12 (2), 133–140.
Ruiz, Lorena, 2012. Etnoictiología y aspectos pesqueros de los grupos humanos que habitan el sector Islas Caracas-La Morena, Parque Nacional Mochima, estado Sucre, Venezuela. Unpublished BA Thesis. Cumaná.
Russell, Matthew, 2011. Encounters at tamál-húye: An Archaeology of Intercultural Engagement in Sixteenth-Century Northern California. Unpublished PhD Dissertation, University of California, Berkeley.
Russell, Nerita, 2012. Social Zooarchaeology. Humans and Animals in Prehistory. Cambridge University Press, Cambridge.
Souza, Laura M., 1984. O Diabo e a Terra de Santa Cruz: Feitiçaria e Religiosidade Popular no Brasil Colonial. Companhia das Letras, São Paulo.
Treacy, Crawford, 1981. Retrieval of Otoliths and Statoliths from Gastrointestinal Tracks and Scats of Marine Mammals. J. Wildlife Manage. 45, 990-993.
Villagrán, X.S., 2014. A redefinition of waste: deconstructing shell and fish mound formation among coastal groups of Southern Brazil. J. Anthropol. Archaeol. 36, 211–227.
Villagrán, X.S., Klokler, D., Nishida, P., Gaspar, M., DeBlasis, P., 2010. Lecturas estratigráficas: Arquitectura funerária y depositación de resíduos en el sambaquí Jabuticabeira II. Latin Am. Antiquity 21, 195–227.
Ihering, Von, Hermann, 1895. A civilisação prehistorica do Brazil meridional. Revista do Museu Paulista 1, 33–159.
Waselkov, G., 1987. Shellfish gathering and shell-midden archaeology. Adv. Archaeol. Method Theory 10, 93–209.