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Integrating zooarchaeology in the conservation of coastal-marine ecosystems in Brazil

Thiago Fossile[a,*], Jessica Ferreira[b], Dione da Rocha Bandeira[c,d], Sérgio Dias-da-Silva[a], André Carlo Colonese[e]

[a] Programa de Pós-graduação em Biodiversidade Animal, Universidade Federal de Santa Maria, Av. Roraima, 1000, Camobi, Santa Maria, 97105-900, Rio Grande do Sul, Brazil
[b] Departamento de Ciências Biológicas - Meio Ambiente e Biodiversidade, Universidade da Região de Joinville, Rua Paulo Malschitzki 10, Zona Industrial Norte, 89219-710, Joinville, Santa Catarina, Brazil
[c] Museu Arqueológico de Sambaqui de Joinville, Estr. Dona Francisca 600, Centro, 89201-220, Joinville, Santa Catarina, Brazil
[d] Universidade da Região de Joinville, Mestrado em Patrimônio Cultural e Sociedade, Rua Paulo Malschitzki 10, Zona Industrial Norte, 89219-710, Joinville, Santa Catarina, Brazil
[e] BioArCh, Department of Archaeology, University of York, York, YO10 5DD, United Kingdom

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ABSTRACT

Sambaquis are archaeological shell mounds and middens formed by pre-Columbian populations inhabiting the Atlantic Forest coast of Brazil between the Middle and Late Holocene. Beyond their recognized cultural values, sambaquis are valuable biological archives for tracking changes in past biodiversity and informing modern conservation studies and management. In this contribution we reviewed the published record of faunal remains from archaeological sites located in Babitonga Bay, in the state of Santa Catarina, southern Brazil. Through a literature review covering 110 sites, we assembled a comprehensive survey of terrestrial and marine taxa exploited by human groups in this area between *ca.* 5500 and 370 years ago. A total of 244 species were recorded, of which 14 are currently endangered and 12 are no longer present in Babitonga Bay. This zooarchaeological synthesis provides snapshots of past biodiversity, adding a novel contribution to current debates around the conservation biology of one of the world's most threatened tropical biomes.

1. Introduction

1.1. *Bridging conservation biology and archaeology in the Atlantic Forest coast of Brazil*

The Atlantic Forest of Brazil is a hotspot of world biodiversity and one of the most threatened ecosystems on the planet, in which approximately 740 species of vertebrates and 8,000 species of vascular plants are endemic (Pinto et al., 2006; Colombo and Joly, 2010; Costa et al., 2017). This heterogeneous rainforest extends into tropical and subtropical regions, from the northeast coast of the state of Ceará to the coast of Rio Grande do Sul, and encompasses contrasting physiographic zones, rainfall regimes and phytogeographic units that contribute to an immense biodiversity and biological productivity, mainly in estuaries and mangrove ecosystems (Pinto et al., 2006; Cremer, 2006; Costa et al., 2017). More than 60% of the Brazilian population lives in or near the Atlantic Forest, which implies that social development, biological conservation and management of natural resources are intertwined subjects of continuous debate (Scarano and Ceotto, 2015). Historical exploitation of natural resources and population growth have caused considerable environmental impacts resulting in severe degradation, reduction, and even loss of important biomes (Mittermeier et al., 2004; Pinto et al., 2006) to the extent that only 7.3% of pre-European vegetation is estimated to currently remain (Morellato and Haddad, 2000; Costa et al., 2017). As a consequence, of the 2,059 species listed as currently endangered in Brazil, 49% are found in the Atlantic Forest (SISBio - portaldabiodiversidade.icmbio.gov.br/portal/). This has led to biological surveys and conservation ecology increasingly acting as the driving forces behind scientific research in the Atlantic Forest, setting the agenda of conservation policy in the region (Paglia et al., 2002; Pinto et al., 2006; Campanili and Schaffer, 2010; Norris et al., 2012; Galetti et al., 2017).

Regional and national checklists have been created as tools to identify areas of interest for conserving biodiversity (Key Biodiversity

* Corresponding author.
E-mail address: thifossile@gmail.com (T. Fossile).

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Areas) (Passos and Magalhães, 2011; Silva et al., 2016) and charismatic (or flagship) species of public interest (Silva et al., 2016), while others have proposed community-based, multilevel conservation and management efforts (Berkes, 2007). While these strategies are based on biological information covering only the last few decades, the Atlantic Forest has supported human populations for at least the last 8000 years (Lima et al., 2004). In fact, recent studies suggest that human impacts on Atlantic Forest biodiversity had begun long before European colonization and the subsequent urbanisation of the region (Dean, 1997; Lopes et al., 2016).

In recent years, studies have demonstrated that archaeological and historical information provide valuable insights into conservation issues (Richards and Rago, 1999; Lyman, 2006; Wolverton and Lyman, 2012; Hofman et al., 2015; Lyman, 2015; Szabó, 2015; Engelhard et al., 2016) and offer the only currently available records of past biodiversity in some regions (Newbold, 2010; Alagona et al., 2012). Despite the fact that this approach is now gaining global recognition (Erlandson and Rick, 2008; Jackson and Jacquet, 2011; Braje et al., 2017), so far South America has received little attention (e.g. Castilho, 2008; Few and Tortorici, 2013). This also applies to the Atlantic Forest coast of Brazil, which preserves exceptional archaeological evidence of past human-environment interaction in the form of *sambaquis*, which literally means "mountain of shells" in the Tupi language. Despite the increasing number of archaeological studies in the Atlantic Forest, there has been little attempt to connect the zooarchaeological research with contemporary debates in conservation biology in this region (Souza et al., 2003, 2016; Lopes et al., 2016; Silva et al., 2017).

The sambaquis are cultural shell mounds and middens dating from *ca*. 8000 to 1000 years ago, which are composed of large quantities of animal remains (Gaspar, 1998; Wagner et al., 2011). Many of these sites contain numerous human burials, suggesting they were likely more than just middens, and expressed long standing political (territorial) and ideological values (DeBlasis et al., 1998; Gaspar et al., 2008; Klokler, 2017). They represent the first tangible evidence of anthropogenic transformation of the Atlantic Forest coast (Villagran et al., 2011; Klokler, 2016). More than a thousand sites have been recorded along the Brazilian coast, but this is only a fraction of the original number as many have been totally destroyed in the last five hundred years through modern coastal development. These sites provide unique snapshots of past biodiversity (Lopes et al., 2016; Souza et al., 2016; Coe et al., 2017; Mendes et al., 2018) which can certainly contribute to the ongoing debates on modern anthropogenic disturbance to evolutionary ecological patterns, and ecosystem functioning and services in this region.

Here we review the literature on the zooarchaeology of sambaquis in order to provide a comprehensive taxonomic census encompassing several sites in Babitonga Bay, southern Brazil (Fig. 1A and B). We analysed the taxonomic compositions in the context of current national regulations for biodiversity protection and management, aiming to gather long-term information on biodiversity in the region while fostering the relevance of zooarchaeology to discussions on ecological baselines and related conservation issues in the Atlantic Forest.

1.2. Sambaquis of Babitonga Bay: unexplored and threatened biological archives

Among the 2000 sambaquis recorded along the Brazilian coast (Lopes et al., 2016), approximately 170 are located in Babitonga Bay, one of the regions with the highest concentration of these sites in Brazil (Okumura and Eggers, 2005; Bandeira, 2015). The sambaqui groups relied heavily on fishing, shellfish gathering, and hunting land mammals (Gaspar, 1998) as attested by the remarkable quantities of faunal remains in these sites. Several lines of evidence also indicate that plants played an important role in dietary and other aspects of daily life Wesolowski and Neves, 2002; Peixe et al., 2007). Ceramic artefacts were introduced into this coastal area by groups moving from the southern Brazilian highlands around 1500 years ago (associated with Taquara/Itarare tradition; Bandeira, 2015), yet faunal remains suggest that the human exploitation of local fish and terrestrial mammals continued relatively unchanged. The long-term interval of sambaqui occupation in Babitonga Bay is marked by important environmental changes, such as oscillations in relative sea level and in vegetation composition (Behling and Negrelle, 2001; Angulo et al., 2006), which may have affected subsistence strategies and the way faunal remains are represented in sambaquis.

Currently, the sambaquis of Babitonga Bay are under heavy economic and population pressure (Fig. 2A–C). The high biological productivity and strategic location of the estuary has bolstered distinct economic activities, from fisheries to industrial centers, including two ports and six other seaport projects (SEPUD, 2017; Gerhardinger et al., 2017, 2018). Population pressure has increased in the last decades, and currently the cities located around the bay comprise the highest population density of the state of Santa Catarina (Gerhardinger et al., 2017). While several conservation and archaeological efforts have been implemented locally in order to mitigate these impacts, many have either been ineffective or introduced too late to prevent the destruction of numerous archaeological sites. Moreover, an increase of 41% in deforestation of the Atlantic Forest in Santa Catarina state in only the last two years (SOS Mata Atlântica and INPE, 2017) directly expanded the list of threatened and endangered species. Today, a considerable number of sambaquis from Babitonga Bay have been destroyed, as the exploitation of shells for the lime industry was only banned in the mid-1960s (Fossile and Bandeira, 2013; Maciel and Bandeira, 2015).

2. Material and methods

2.1. The faunal record of sambaquis at Babitonga Bay

We accessed thirty-one sources of information dating from 1951 to 2018 reporting faunal remains from 110 sambaquis, representing approximately 65% of the sites recorded to date in this region (Fig. 1B; SI1). This comprehensive review included different types of analyses ranging from standardized archaeological surveys on well-defined excavated areas to random collections lacking detailed contextual information (SI2), and unravelled significant faunal variability.

Given the qualitative and quantitative variation observed in the bibliographic sources, we classified them as follows:

1. Qualitative-quantitative: sources with detailed taxonomic identification, and absolute and relative abundance of taxa (e.g. number of remains, number of individuals).
2. Semi-quantitative: sources reporting the number of identified species only.
3. Qualitative: sources that only report taxa identified *in-situ*, with apparently no support from reference collections.

Qualitative-quantitative and semi-quantitative sources ($n = 22$) usually provide faunal information at the species level derived from comparative analysis with reference collections and therefore provide more accurate taxonomic identifications.

These sources allowed us to generate a comprehensive list of taxa from 110 sambaquis, of which 44 were radiocarbon dated between 5,480 ± 30 (Sambaqui Praia Grande VI) and 375 ± 40 (Sambaqui Bupeva II) years before present (BP). Some of the youngest sites contained ceramic artefacts associated with the Taquara/Itarare tradition (Bandeira, 2015). Whenever possible, we provide the taxonomic information at the species level, but for some sites only genus, and often families, were available.

2.2. Species composition, distribution and status

The modern distribution of archaeological species in Babitonga Bay

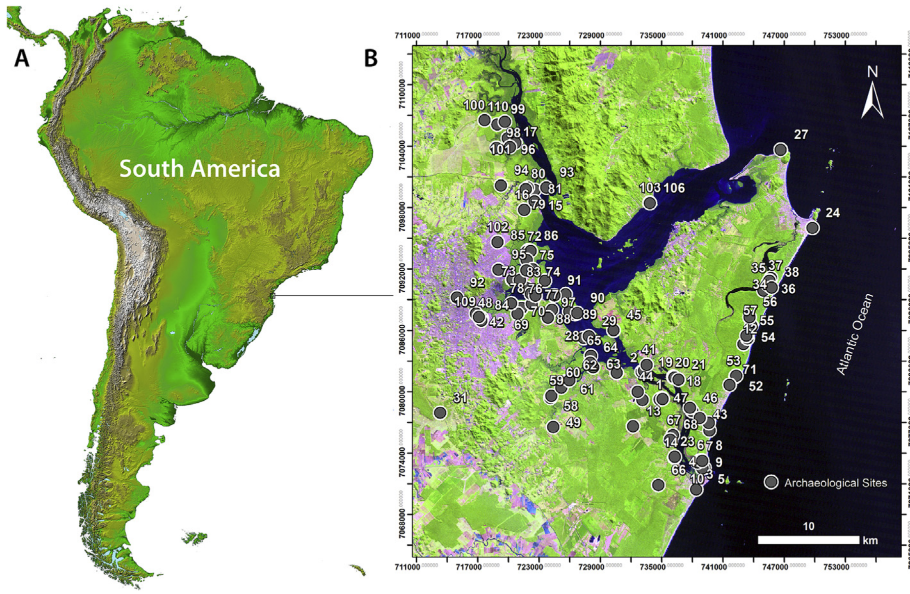

Fig. 1. (A) Study area in South America and (B) the location of sambaqui sites discussed in the text (see also SI1).

Fig. 2. (A) The sambaqui of Rio Comprido, excavated in the 1970s, has partially survived the urban development in Joinville; (B) the sambaqui of Morro do Ouro has been partially excavated in the last decades and it is now a municipal park; (C) sites such as the sambaqui of Cubatão I, excavated between 2007 and 2009, are threatened by fluvial activity and changes in land use practices; (D) an example of fish bone from Cubatão I (*Epinephelus* spp.). Shell and fish bones are the most abundant biological remains resulting from thousands of years of food refuse and funerary feasts. Pictures A and B were kindly provided by the *Museu Arqueológico de Sambaqui de Joinville*.

was assessed based upon recent regional checklists (Cherem et al., 2004; Cremer, 2006; Passos and Magalhães, 2011; Agudo-Padron, 2014; Brazil, 2014a, 2014b; Gerhardinger et al., in press). Their conservation status was evaluated according to the categories and criteria of the IUCN Red List of Threatened Species and through the decrees 444/2014 (Brazil, 2014a) and 445/2014 (Brazil, 2014b) of Brazil's Ministry of the Environment (*Ministério do Meio Ambiente* - MMA). Both IUCN and MMA use the same categories and criteria for assessing endangered species, including population decline (past, present and/or predicted), restricted geographical distribution, fragmentation, decline or fluctuations, population size and quantitative analysis of extinction risk. However, some differences between IUCN and MMA categories arise due to the status and species evaluation in Brazilian territory.

3. Results and discussion

3.1. The current status of faunal remains from sambaqui sites

A total of 244 species were identified, belonging to seven major taxonomic groups: Annelida (1), Mollusca (Bivalvia, 67; Gastropoda, 59), Arthropoda (Crustacea: Malacostraca, 2; Hexanauplia, 2) and Chordata (Vertebrata: Elasmobranchii, 14; Actinopterygii, 57; Reptilia, 4; Ave, 3; and Mammalia, 35) (SI3). The results reveal a high diversity of taxa exploited by sambaqui populations, although species richness is likely underestimated, as, for instance, the most frequently reported taxa belong to marine molluscs, including *Anomalocardia flexuosa* (carib pointed venus) (95%), *Phacoides pectinatus* (thick lucine) (55%), *Crassostrea rhizophorae* (native oyster) (43%), *Ostrea* sp. (oyster) (39%), *Phrontis vibex* (bruised nassa) (53%), and *Neritina virginea* (virgin nerite) (33%). This is largely due to the nature of sambaqui deposits which are predominantly composed of sediments and shells, as well as the fact that mollusc shells tend to preserve better than mammal, fish and bird bone remains. Moreover, reference collections for purposes of comparison of terrestrial faunal remains, as well as local taxonomists of such organisms, are rare, and terrestrial specimens may also include cryptic species (Ceballos and Ehrlich, 2009) which make accurate identification difficult using only skeletal remains.

It is also worth noting that *Anomalocardia flexuosa*, *Phacoides pectinatus* and Ostreidae were possibly used as building materials in sambaquis (Gaspar, 1998), and as such they must have been abundantly distributed in Holocene coastal environments (Cancelli et al., 2017). Intertidal and subtidal molluscs are also easily exploitable as their acquisition does not pose a substantial risk when compared to some large mammals and fish. While *Anomalocardia flexuosa* and *Phacoides pectinatus* are not included in red lists, they are currently targeted as food sources by both humans (notably by artisanal fisheries) and other animals (Squella et al., 2015), so a decline in numbers has been reported due to overexploitation and dredging of coastal bays and estuaries along the Brazilian coast (Sônia-da-Silva et al., 2000; Squella et al., 2015). Worth noting is the occurrence of *Perna perna* (brown mussel) in two sambaquis (Bandeira, 1992, 2004), a species previously considered invasive in South America (Gernet and Birckolz, 2011; Souza et al., 2003, 2011), but recently confirmed to be native to this region (Pierri et al., 2016).

Several fish and terrestrial mammals frequently reported in sambaquis of this region are also currently abundant in the study area

(Cherem et al., 2004; Gerhardinger et al., in press). These include *Trichiurus lepturus* (Atlantic cutlassfish), *Conodon nobilis*, (barred grunt), *Micropogonias furnieri* (whitemouth croaker), *Stellifer* spp. (drums or croakers), *Cynoscion leiarchus* (smooth weakfish), *Genidens barbus* (white sea catfish), *Lagocephalus laevigatus* (smooth puffer), *Cavia aperea* (Brazilian guinea pig) and *Dasyprocta* sp. (agouti) (Bandeira, 1992, 2004; Fossile, 2013). Two exotic species were identified, *Rattus norvegicus* (brown rat) and *Subulina octona* (miniature awlsnail), both possibly reflecting post depositional contamination due to European colonization and urban development.

According to Cherem et al. (2004), Passos and Magalhães (2011), Agudo-Padron (2014) and Gerhardinger et al. (in press), 12 species reported in 14 sambaquis (13% of sites) have no current record in Babitonga Bay (SI3). These include one fish species, *Bagre bagre* (coco sea catfish), and 11 mollusc species, including *Atrina rigida* (stiff penshell), *Brachidontes darwinianus* (mussel), *Bulbus striatus* (sea snail), *Magallana ariakensis* (suminoe oyster), *Chione subrostrata* (cross-barred venus), *Colina macrostoma* (sea snail), *Conus regius* (crown cone), *Odontostomus paulistus* (land snail), *Phrontis antillarum* (Antilles nassa), *Phrontis polygonata* (sea snail), and *Vitrinella filifera* (threaded vitrinella). All the aforementioned molluscs are absent from the coast of Santa Catarina nowadays, while *B. striatus*, *C. macrostoma* and *M. ariakensis* are absent in all malacofauna databases from Brazil (Rios, 1994; World Register of Marine Species). According to Amaral and Simone (2014), the distribution of *M. ariakensis* in unclear and the species could actually refer to *Crassostrea rhizophorae*. The presence of these species in the sambaquis and their current absence in the regional checklist appears to support the ongoing process of defaunation in the Atlantic Forest (Dirzo et al., 2014; Galetti et al., 2017), with several species and/or populations known to be declining in abundance or disappearing entirely (Dirzo et al., 2014).

According to the IUCN Red List and/or the MMA decrees 444/2014 and 445/2014, at least 14 species recovered in eight sambaquis (7% of the sites) are currently threatened, within the categories of Vulnerable (VU), Endangered (EN), and Critically Endangered (CR) (SI3). These include *Panthera onca* (jaguar), *Puma concolor* (cougar), *Ozotoceros bezoarticus* (Pampas deer), *Tayassu pecari* (white-lipped peccary), *Tapirus terrestris* (lowland tapir), *Alouatta guariba* (brown howler), *Sotalia guianensis* (Guiana dolphin), *Genidens barbus*, *Pomatomus saltatrix* (bluefish), *Hyporthodus niveatus* (snowy grouper), *Isurus oxyrinchus* (shortfin mako shark), *Carcharodon carcharias* (great white shark), *Carcharias taurus* (sand tiger shark), and *Alopias vulpinus* (common thresher shark). In addition, teeth attributed to *Carcharhinus isodon* (finetooth shark) were found in sambaquis Itacoara and Bupeva II (Bandeira, 2004; SI3), and the species is classified as Regionally Extinct (RE) for the Brazilian coast (Brazil, 2016a, 2016b). With the exception of *P. onca,* all of the aforementioned species were reported in publications where the authors were either specialists in the taxonomic analysis of faunal remains or had consulted such taxonomists, therefore their identifications are believed to be accurate.

Panthera onca was recorded only in the sambaqui of Rio Pinheiros II by Tiburtius et al. (1954), unfortunately without a secure stratigraphic context. *P. onca* is a flagship species considered Near Threatened (NT) (IUCN, 2017) and Vulnerable (VU) (Brazil, 2014a) that occurs in all Brazilian biomes, with the exception of the Pampa Biome, where it has gone extinct (Morato et al., 2013). Hunting, along with loss and fragmentation of habitat associated with agricultural expansion, mining, hydropower development, and road networks are its main threats (Morato et al., 2013). *Ozotoceros bezoarticus* entered the IUCN category of Near Threatened (NT) in 2002, while it gained the status of Vulnerable (VU) by MMA in 2014. In the last 15 years, populations of this species have declined due to habitat degradation, hunting, and disease. *P. onca* and *O. bezoarticus* are not currently found in this region (IUCN, 2017; Cherem et al., 2004).

Tapirus terrestris, Tayassu pecari, Alopias vulpinus, *Carcharias taurus, Carcharodon carcharias, Hyporthodus niveatus, Isurus oxyrinchus*, and *Pomatomus saltatrix* have all been classified as Vulnerable (VU) by the IUCN (2017). Based on MMA decrees 444/2015 (Brazil, 2014a) and 445/2014 (Brazil, 2014b), *C. taurus* is classified as Critically Endangered (CR) because its populations have been drastically reduced by commercial and artisanal fishing. *T. terrestris* and *T. pecari*, typically found in the Atlantic Forest, are classified as Endangered (EN) and CR, respectively, due to predatory hunting, habitat fragmentation, and increased urbanisation (Médici et al., 2012; Keuroghlian et al., 2012). *A. vulpinus* was never abundantly recorded on the Brazilian coast, whereas *C. carcharias* was considered abundant around the 16th century, but both it and *H. niveatu* have declined over the last few years due to overfishing (Brazil, 2016a).

Sotalia guianensis is currently under Vulnerable (VU) conservation status (Brazil, 2014a). Present in Babitonga Bay, populations of *S. guianensis* are threatened by accidental catches, loss of habitat, acoustic pollution and water contamination (Cremer et al., 2009). Its occurrence in the sambaqui of Forte Marechal Luz, along with other cetaceans in 18 sites (16% of the record) around the bay, has been associated with the occasional exploitation and collection of stranded animals or carcasses. There is no evidence of systematic captures (Tiburtius, 1996; Castilho, 2008; Castilho and Simões-Lopes, 2001), suggesting that sambaqui groups from Babitonga Bay had minimal impact on local cetacean populations.

Alouatta guariba, Puma concolor, Genidens barbus, and *Carcharhinus isodon* are classified as Least Concern (LC) by the IUCN. However, according to MMA decrees 444/2014 (Brazil, 2014a) and 445/2014 (Brazil, 2014b), the first two species are now Critically Endangered (CR) and Vulnerable (VU), respectively, due to habitat fragmentation, roadkill incidents, and hunting (Neves et al., 2015; Azevedo et al., 2013). *G. barbus* is a long-lived species with a low reproduction rate, highly sensitive to human impact, and classified as Endangered (EN). *C. isodon* has a vulnerable life cycle and entered the category of Regionally Extinct (RE) (Brazil, 2016a). *Galeocerdo cuvier* (tiger shark)*, Prionace glauca* (blue shark)*, Thalassarche melanophris* (black-browed albatross) and *Spheniscus magellanicus* (Magellanic penguin) are currently affected by overexploitation and habitat degradation, and classified as Near Threatened (NT) by the IUCN (2017) and Brazil (2014a,b). All of these species are currently recorded in Babitonga Bay (IUCN, 2017; Gerhardinger et al., in press).

3.2. Integrating archaeology into conservation biology in the Atlantic Forest

Due to mutualistic interactions between forest components (e.g. fauna, vegetation, cycle of nutrients) the consequences of biodiversity loss and population decline on ecosystem function are complex and nonlinear (Dirzo et al., 2014; Pires et al., 2014). Human disturbances are major factors in this process, and have transformed tropical ecosystems long before historical times (Roberts et al., 2017), thus a temporal perspective beyond historical records is highly desirable (Lyman, 2015). Archaeology can provide valuable contributions to conservation debates in the Atlantic Forest by offering just such a perspective. The review of the literature presented above was not aimed at elucidating a diachronic narrative of human-environment interaction in Babitonga Bay through time, but rather at highlighting the potential of archaeology to critically assess the conservation status of a number of species with the longstanding temporal dimensions that are increasingly required for conservation efforts. The results reveal that pre-Columbian coastal populations in this region interacted with a wide range of terrestrial and marine organisms between *ca.* 5500 and 370 years ago, some of which are currently either in decline or no longer reported in this area of the Atlantic Forest.

Babitonga Bay has been considered a strategic region for the creation of the first Wildlife Reserve in Brazil (2007) and more recently of a Marine Protected Area (Brazil, 2012; Gerhardinger et al., 2017), yet modern faunal information is limited for the region (Vilar et al., 2011). Several of the marine species that are presently exploited by small-scale and industrial fisheries are relatively abundant in the sambaquis of Babitonga Bay (Fig. 2D). Their remains can be systematically recovered from well-dated archaeological deposits and analysed in order to explore the impact of centennial to millennial scale changes in cultural practices, changes in climate and environmental conditions on species diversity, distribution, size and abundance, and on trophic interactions and population dynamics. This information can potentially complement and integrate historical baselines spanning the last few decades (Gerhardinger et al., 2006; Vilar et al., 2011; Bender et al., 2014; Pinheiro et al., 2015) to guide decision making processes in conservation efforts.

However, it is important to point out that we detected problems with the available archaeological record, notably the lack of robust taxonomic and taphonomic analyses of faunal remains, which introduce some limitations to its crude applicability to conservation actions. These limitations can be mitigated by establishing common protocols for sampling and data analysis that also address taphonomic processes in tropical areas, as well as by expanding the methodology and the research portfolio to integrate biomolecular techniques, such as archaeogenomics, proteomics, and stable isotope analysis of faunal remains (McKechnie et al., 2014; Hofman et al., 2015; McKechnie and Moss, 2016; West et al., 2017).

Archaeology is a valuable source of information for tracking long-term changes in forest ecosystems and biological diversity in the Neotropics (Stahl, 1996). The time has come for the discipline to realize this potential (van der Leeuw and Redman, 2002), and for us to explore a niche in conservation biology and management initiatives in the Atlantic Forest. This process requires the development of transdisciplinary research collaborations between archaeologists, conservation biologists and stakeholders, where operational principles, research questions, aims, methods and desirable outcomes are jointly decided and monitored through cooperation (Meyer and Crumley, 2011). The training of graduate and postgraduate students in South American archaeology should also reflect upon the relevance of the discipline to the current environment and conservation agenda.

4. Conclusion

Our review of the literature on the zooarchaeology of sambaquis resulted in a comprehensive census of terrestrial and marine taxa exploited by human groups in Babitonga Bay, southern Brazil, between *ca.* 5500 and 300 years ago. The increased demand for a multidisciplinary and temporal perspective in conservation debates offers the opportunity for the archaeology of the Neotropics to interact with and actively contribute to conservation actions, thereby enhancing the relevance of the discipline to environmental issues at local, regional and national levels. This could in turn enhance the ecological visibility of the archaeological sites, offering additional leverage for preservation and transdisciplinary significance. After all, sites such as the sambaquis of Babitonga Bay offer unique and often otherwise inaccessible glimpses of past biodiversity in some of the most diverse and threatened tropical biomes on the planet.

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Appendix A. Supplementary data

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