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Archaeological history of Middle Holocene environmental change from fish proxies at the Monte Castelo archaeological shell mound, Southwestern Amazonia

Gabriela Prestes-Carneiro,[1,2,3] Philippe Béarez,[1]
Francisco Pugliese,[2] Myrtle Pearl Shock,[2,3]
Carlos Augusto Zimpel,[2,4] Marc Pouilly[5] and Eduardo Góes Neves[2]

Abstract

Monte Castelo, an archeological shell mound located on the southwestern periphery of the Amazon basin, is an artificial forest island occupied from the Middle to late-Holocene, and it contains one of the longest, continuous sequences of human occupation anywhere in the basin. Analysis of fish remains investigates fluctuations in the fish communities that are markers of changes in the paleoenvironment. The 8112 taxonomically identified remains document diagnostic taxa that are drought-tolerant (armoured catfishes, swamp-eels and tiger fishes) and from swampy environments, indicating probable occupation during low-waters periods. The results from Monte Castelo contrasts with the use of shell mounds as refuges from high-water season floods, a dominant hypothesis. A considerable shift in the nature of the fish spectrum occurred around 4000 BP with increased diversity; the number of taxa jumps from 18 to 48. The Middle Holocene occupations, from 6000 to 4000 BP, reflect long-term stability in drought-tolerant taxa collaborating with paleoecological evidence of dryer conditions. The post 4000 BP introduction of small-sized cichlids and characins suggests an initial exploitation of flooded forests. Archeological fish remains corroborate paleoenvironmental records of increased precipitation between the Middle and Late-Holocene. The probable replacement of some savanna areas by forest vegetation, and the accompanying alteration of aquatic landscapes, is documented through the presence/absence of certain taxa in Monte Castelo's occupations. This suggests new economic strategies and the exploitation of new ecological niches, as the fish remains correspond to approximately 80% of the vertebrate fauna throughout the archeological sequence.

Keywords

Amazon, paleoenvironment, shell mound, zooarchaeology

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Introduction

Holocene reconstructions of region-scale climatic and paleoenvironmental change have recently been redefined for lowland South America (Baker, 2015; Mayle et al., 2000). Archeological sites from the Early and Middle Holocene are scattered across the lowlands. Subsistence strategies of human groups in coastal regions demonstrate the importance of fishing and shellfish collection with changes alongside climate and sea level (Figuti et al., 2013; Gaspar et al., 2008; Reitz 2001). In interior regions hunting and gathering is frequently the predominant strategy with some prey changes associated with environmental fluctuations (Borrero et al., 1998; Kipnis, 1998; Gutiérrez and Martínez, 2008; Vialou et al., 2017). In Amazonia, paleoenvironmental evidence for geographically localized changes, on scale with human occupations, is sparse alongside the possible articulations of these changes with human strategies of resource exploration.

Southwestern Amazonia is a biogeographical zone bordered to the southeast by the pre-Cambrian Brazilian shield and to the southwest by the Andes (Figure 1). Its main drainage is the Upper Madeira River and its four major tributaries: the Madre de Dios, Beni, Mamoré and Guaporé (called *Itenez* in Bolivia) rivers. The fish communities are extremely diverse, coming from both clear and black waters of the pre-Cambrian shield and from the turbid and sediment-rich waters of the pre-Andean plains. Such terrestrial and aquatic interconnectivity probably also favored transit,

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[1] Archéozoologie, archéobotanique: sociétés, pratiques et environnements (UMR 7209), CNRS. Muséum national d'histoire naturelle, France
[2] Laboratório de Arqueologia dos Trópicos (Arqueotrop). Museu de Arqueologia e Etnologia, Universidade de São Paulo, Brazil
[3] Anthropology and Archaeology Program, Institute of Social Sciences, Federal University of Western Para (UFOPA), Santarém, Brazil
[4] Departamento de Arqueologia (DARQ) da Universidade Federal de Rondônia (UNIR), Brazil
[5] Institut de Recherche pour le Développement (IRD), UMR BOREA (MNHN, CNRS, IRD, SU, UNICAEN, UA), Paris, France. Ecologie des Hydrosystèmes Fluviaux (UMR 5023) Université Lyon 1, France

Corresponding author:
Gabriela Prestes-Carneiro, Anthropology and Archaeology Program, Institute of Social Sciences, Federal University of Western Para (UFOPA), Av. Mendonça Furtado, n° 2946 – Fátima CEP 68040-470, Santarém – Pará, 68035-110, Brazil.
Email: gabi_prestes@hotmail.com

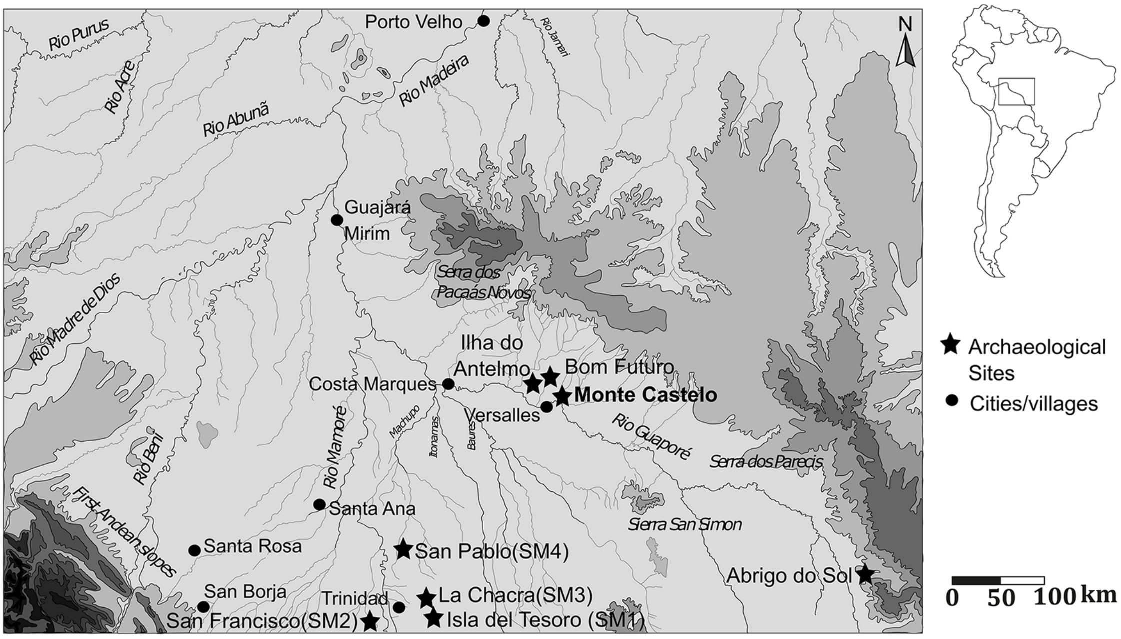


Figure 1. Map of southwestern Amazonia showing the location of Monte Castelo (Rondônia State, Brazil) on the frontier between the pre-Andean plains to the west and the higher elevation of the Brazilian Shield to the east. Sites contemporaneous to Monte Castelo are included (Basemap from the American Defense Mapping Agency).

exchanges, and relationships between different cultural groups from neighboring regions such as the Central Brazilian Plateau, the Eastern Amazon, the upper Paraguay River, the Bolivian Llanos de Mojos, and the Andes.

The archeology of Early and Middle Holocene occupations in this zone, and more broadly Amazonia, is not yet well understood, with few sites reported or explored. Increasing attention has been given to this period during the last decade, yet little is known about the productive strategies of these early inhabitants. Evidence of human presence in the Amazonian forest dates back to the Late Pleistocene to Early Holocene transition, 12,600 BP. The Cerro Azul rock shelter located in the Serranía La Lindosa in Colombia is the only site where a zooarchaeological study has been conducted and this suggests diverse economic activities from a broad spectrum of fish, reptiles, and small mammals (Morcote-Ríos et al., 2020). Other archeological sites from the Early Holocene include the Pedra Pintada rock shelter situated near the confluence of the Amazon and Tapajos Rivers in Brazil (Roosevelt et al., 1996) and Peña Roja, an open-air site, on a terrace of the Caqueta River in Colombia (Gnecco and Mora, 1997). In Southwestern Amazonia, the earliest evidence is from the Abrigo do Sol rock shelter, in the Guapore River Basin on the border of the Brazilian Shield where vegetation was open and climate drier. The occupations are characterized by chert and quartz flakes associated with extinct megafauna in sandy layers 7 m deep and dated to between 14,000 and 6000 cal. yrs BP (Figure 1) (Miller, 1987). Nearby, but across the Parecis range, Santa Elina rockshelter contexts have yielded dates going back to the Late Pleistocene, at ca. 22,000 yrs BP (Vialou et al., 2017).

Greater variability is observed in Middle Holocene (8000–2500 BP acc. Walker et al., 2018) occupational contexts. Along the Jamari River, a tributary of the Madeira River, a lithic industry dating from 8000 to 6000 BP has been recovered in open-air sites (Miller, 1992; Mongeló, 2013). From ca. 5500 BP, Amazonian Dark Earths (ADEs), started forming at the Teotônio site, near Santo Antonio waterfalls on the Upper Madeira River (Miller, 1992; Watling et al. 2018; Zimpel Neto, 2009). Later on, different ceramic complexes dating to 4000 BP, if not earlier, are found at Teotônio, artificial forest islands on the north bank of the Guaporé River (Bacabal phase) and on the Middle Ji-Paraná River (Miller, 2009; Zimpel Neto, 2009; Zimpel and Pugliese, 2016).

In the Amazon, shell mounds are part of the Middle Holocene variability of the archeological record, as they start to be built around 8000 yrs BP near Santarém, Brazil (Taperinha site) and 6600 yrs BP in the mangroves of the equatorial Amazonian coastline (Bacanga site) (Bandeira, 2011; Bandeira et al., 2016; Roosevelt et al., 1991, 1995; Pugliese et al., 2018). From 6000 to 4000 yrs BP, shell mounds were also common in fluvial-estuarine areas of the Guiana coast and the estuary of the Amazon River, where more than 43 sites have been identified (Lopes, 2018; Simões, 1981; Silveira et al., 2011). Southwestern Amazonia is another area where sites have large concentrations of shell and where dates go back to the Early and Middle Holocene (Capriles et al., 2019; Lombardo et al., 2013, 2020; Pugliese et al., 2017, 2018). Many of these sites indicate a landscape transformation as they are artificial forest islands in seasonally inundated savannas. Monte Castelo is one such site.

The archeological deposits at Monte Castelo that resulted in this transformation are different combinations of stratigraphically patterned sediment and shell strata. The shell mound stands above flood season high water levels and thus can support plant communities that are not flood-resistant. Denevan (1966: 70) was the first to describe the artificial forest islands in Amazonian landscapes and distinguished them from the late-Holocene artificial mounds called *lomas*. According to Denevan, the "early" forest islands are wholly artificial and contain horizons of pottery sherds associated with snail shells. They are described as round or oval in form, about 1–2 m high, and 10–50 m in diameter and they are separated from each other by several miles. These artificial islands have been reported in four main micro-regions: (1) north of Santa Cruz, Bolivia, (2) west of Santa Ana, Bolivia, (3) on along the Mamoré River, Bolivia (Isla del Tesoro/SM1, San Francisco/SM2, La Chacra/SM3, San Pablo/SM4), and (4) the eastern bank of the Guaporé River, Brazil (Monte Castelo, Bom Futuro, and Ilha do Antelmo) (see Figure 1) (Capriles et al., 2019; Denevan, 1966; Lombardo et al., 2013; Miller, 2009). To date, four of these artificial forest islands have been excavated, Isla del Tesoro/SM1, La Chacra/SM3, San Pablo/SM4 (Capriles et al., 2019; Lombardo et al., 2013, 2020) and Monte Castelo (Miller, 2009, 2013; Pugliese et al., 2018). A set of evidence (presence of sterols, anthropogenic black carbon and human-accumulated faunal remains) attests to the human occupation of Isla del Tesoro since 10,600 cal BP (Lombardo et al., 2013). At Monte Castelo, radiocarbon dates published by Miller (2009) demonstrate that the site was occupied between 8000 and 700 yrs BP, but more secure contexts date from 6000 yrs BP. At both sites, the stratigraphy shows that these mounds were occupied and re-occupied during different periods of the Holocene. Since the excavations undertaken are still preliminary, we are just starting to know more about the cultural groups who constructed and settled these sites.

Monte Castelo occupations continue during the late-Holocene. This period beginning in 2500 BP is marked by a great variability of archeological cultures across Southwestern Amazonia that promoted changes on the landscape (Almeida, 2013; Walker, 2008) including geometric excavated ditches, also known as geoglyphs, dated to 2150 yrs BP in the interfluvial zone of the Upper Purús and Madeira Rivers (Saunaluoma, 2012). Constructed earthen platforms (lomas) start flourishing around 1750 BP near Trinidad, Bolivia, contemporaneous with the first evidence for agricultural raised fields nearby around San Borja (Dougherty and Calandra, 1984; Erickson and Michel, 1991). Late-Holocene occupations are encountered across the Bolivian Llanos de Mojos, and on the north eastern bank of the Guaporé River, with a complex range of architectural forms and artefactual industries. The great variability in ceramic industries reflects the diversity of groups occupying southwestern Amazonian for over a millennia. The multiple influences on ceramic styles and the trade of ceramic forms and stone blades between groups from the south and north banks of the Guaporé River attest to networks of migration and exchange that are far from being fully understood (Jaimes Betancourt and Prümers, 2013; Lima, 2012; Zuse, 2014).

The history of human occupation in the Amazon along the Holocene is constructed within an environment that experiences contemporary changes, including in temperature, precipitation, plant and animal communities, and other aspects of ecological function (Carson et al., 2014; Latrubesse et al., 2000). The driving forces underlying ecological fluctuations, especially regarding human-environment relationships, have been a source of debate during the last few years (Clement et al., 2015; McMichael et al., 2017; Watling et al., 2017). Many archeological and palaeoenvironmental records such as sediment loads, phytoliths, charcoal, and pollen have been used as potential markers of the evolution of ancient environments (Burbridge et al., 2004; Lombardo et al., 2012; Mayle and Iriarte, 2014, Plotzki et al., 2015). The different roles that natural and cultural forces had in the shaping and transformation of the landscapes have yet to be assessed, especially for the Middle Holocene.

Amazonian faunal distribution, utilization, and possible changes by human exploration have been discussed in relationship to how humans occupy and use the forest (Carneiro, 1970; Gross, 1975; Lathrap, 1968; Meggers, 1954). While the existence of shell mounds has suggested different resource availability, this is the first look into how fauna register human-environment relationships for the Holocene in the Amazon. Across the world faunal assemblages have been used alongside archeobotanical and geomorphological data to record environmental changes (Casteel, 1976; Reitz and Wing, 1999; Rofes et al., 2015). Presence/absence of taxa, fluctuations in taxa diversity, and introduction of new species in faunal assemblages can be potential bioindicators of climatic-driven events, such as the Pleistocene-Holocene transition (Bailon et al., 2015; Miotti and Salemme, 1999; Vigne, 1992; Tonni et al., 1999). The use of fish remains as bioindicators has some limitations: 1) not all species or communities can serve as successful bioindicators; 2) some species are very tolerant of environmental changes; 3) it is difficult to ensure that the observed communities reflect real regional fluctuations in climatic conditions rather than local-scale changes in hydrology; 4) many fish species are migratory and cannot be assigned to a specific location; and 5) archeological animal assemblages are biased by human fishing selectivity or trade. Thus, while assemblages recovered in archeological sites can provide relevant information on the surrounding ancient environments, they cannot be taken as perfect representations (Flantua et al., 2016; Grayson, 1981; Holt and Miller, 2011; Machado-Allison, 1990).

Although micromammals and herpetofauna are the most commonly used taxa in paleoenvironmental studies, poikilotherms, organisms whose internal temperature varies according to the external conditions, such as fish, are considered to be good indicators of environmental fluctuations (Casteel, 1976). To date, paleoenvironmental studies based on fish communities have been carried out in Europe and on the Pacific coast of South America (Capriles et al., 2014; Casteel et al., 1977; Reitz and Wing, 1999). In Amazonia, the paleoenvironmental record of fish remains has never been studied.

Evaluating long-term fish spectra in the neotropical South American lowlands can be a difficult task since the conservation of organic matter is rare and because the Holocene history from archeological sites presents chronological gaps and discontinuities. Furthermore, there are very few sites with remains from between 7000 and 3000 yrs BP, a gap that has been called “the Holocene hiatus” (Araujo et al., 2005; Neves, 2012). The Monte Castelo archeological site, excavated in four seasons from 2014 to 2020, offers data for this period. It is composed of an exceptionally preserved sequence of 21 stratigraphic strata that span the Holocene, with secure radiocarbon dates from 6000 to 700 yrs BP (Miller, 2009; Pugliese et al., 2018). Organic remains are well preserved throughout the sequence and fish remains constitute the large majority of recovered vertebrate fauna (about 80%), followed by reptiles. As asserted by many paleoecologists (Burbridge et al., 2004; Mayle et al., 2000), rainforest-savanna boundaries of southwestern Amazon are highly responsive to environmental change and, therefore, are “key areas” for the study of the long-term evolution of landscapes. The location of Monte Castelo on the current southernmost border of the Amazonian rainforest poses and permits the consideration of numerous questions: When did the fish spectrum fluctuate and in what ways? Were fish communities at Monte Castelo affected by the paleoenvironmental changes that occurred during the Holocene? Alongside paleoenvironmental transformations, what other variables influenced species distribution? Due to multiple, sequential occupations of Monte Castelo, species distribution might record human species selection and the evolution of fishing practices. We studied more than 8112 identified fish remains recovered at Monte Castelo, combining species identification and assemblage diversity analysis, in order to understand both ecological conditions and human exploitation of aquatic resources including long-term fishing strategies and their changes through the Holocene.

Environmental setting

The Guaporé River, flowing east to northwest into the Mamoré River, divides two drainage zones, on the right margin are clearwaters coming from the Brazilian Shield and on the left whitewaters draining the pre-Andean alluvial plains (Goulding, 1981). The Brazilian Shield is formed by Tertiary rocks, predominantly granite and basalt, that successive weathering and erosion shaped into hills and plateaus that descend from the south to the north, varying between 300 and 100 m covered in lateritic soil (Figure 1). To the south, the pre-Andean plains, also called the Chaco-Benian plains, are flat expanses of accumulated Quaternary alluvial deposits (gravel, sand, clays and silt), below 300 m. Therefore, fed by tributaries of both lithologies, the Guaporé river is a place of exchange in fish fauna where 619 species have been identified (Jégu et al., 2012; Maldonado and Goitia, 2012).

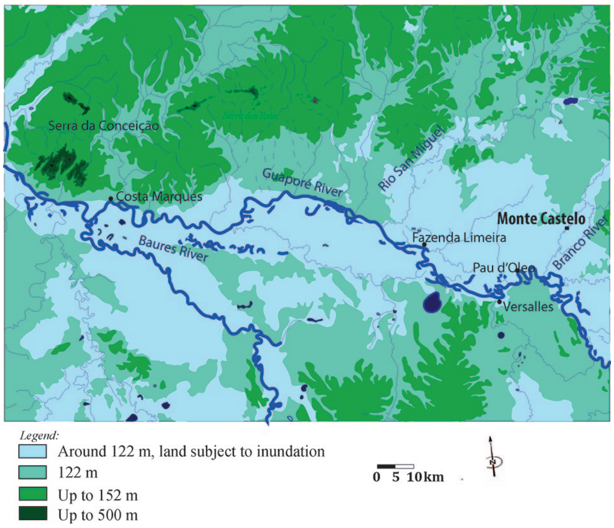


Figure 2. Monte Castelo and the extensive flooded area formed during the flood pulse of the Guaporé River as shown by elevation (Basemap from the American Defense Mapping Agency).

Vegetation along the Middle Guaporé River Basin is highly variable. Seasonally flooded savannas are covered by short semi-deciduous trees (<8 m), grasses, sedges, and forbs. These extensive open areas are dotted with patches of vegetation from the evergreen rainforest and forest islands covered by palm trees (De Freitas et al., 2001; Mayle et al., 2007).

Seasonality plays a primary role in the configuration of aquatic environments and distribution of organisms in the Middle Guaporé River Basin. The flood season, from December through June, and the dry season, from June through November, mark the local hydrological cycle. When rains start in November, water quickly overflows the banks of the Guaporé and its tributaries, forming extensive wetlands (Figure 2). The rapid inundation can be explained by the Guaporé river's shallow bed (Torrente-Vilara and Doria, 2012). The floods extend across 60,000 km^2 (about 20% of the basin) reaching Baures to the southwest and the Paraguay-La Plata River system to the southeast forming an aquatic corridor (Goulding, 1981; Roche and Jauregui, 1988; Ovando-Leyton, 2012). The receding of the flood water is slower in the Guaporé than in many parts of the main Amazon River floodplain, as it is associated with and dependent upon the water levels in the Mamoré River that flows from the Andes. Thus, wetland areas are flooded for at least 6 months of the year (Torrente-Vilara and Doria, 2012).

The annual flood drives a complete transformation of the landscape and large communities of fishes participate in lateral migrations from the major river channel across extensive aquatic territories, where they find shelter, reproduce and feed on insects, fruits, and seeds falling from the forest cover (Goulding, 1981; Junk et al., 1989). As the water recedes fish return to the streams and rivers or are confined in shallow depressions of standing water where marsh and swamp vegetation grow (Figure 3). These general, regional patterns are diverse at the local and microenvironmental scale.

In the proximity of Monte Castelo four main categories of aquatic environments have been determined on the basis of variables that include: depth, origin, and type of water, abundance of aquatic vegetation, speed of water flow, and isolation and exchange of animal communities (Figure 4):

Swamps: Flat areas and shallow depressions characterized by retained stagnant and turbid waters that are isolated for half of the year and connected during the rainy season, when flood waters overtake them.

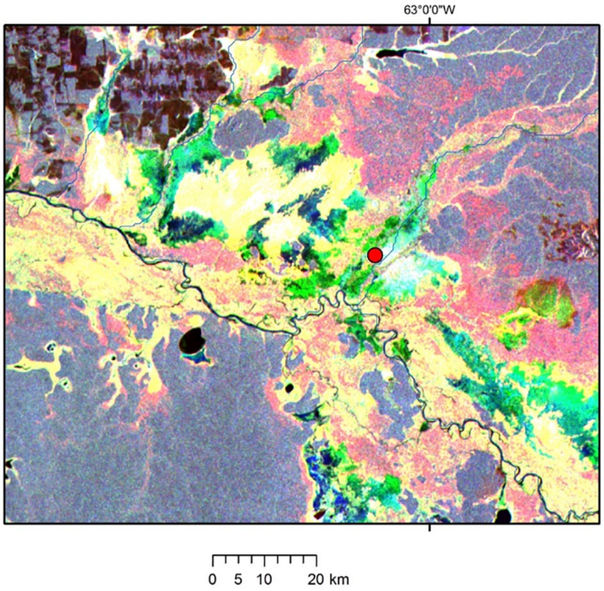


Figure 3. Vegetation composition and flooding extent from radar images (ALOS-PALSAR) obtained in March, June, and September 2007. Never flooded forest (gray tones), dense and sparse floodable forest (white – yellow and red tones), and floodable savanna (green – blue). Map drafted by Alex Ovando Leyton.

Open waters: Lakes, creeks, and streams that contain lentic or slow flowing waters year-round. These waterways are adjacent to the Guaporé River including the Branco river, which flows around 300 m from the site, and have depths between 2 m and 5 m.

Flooded forests: Locally known as *igapós*, the flooded forests are corridors along the rivers that are inundated by the lateral, seasonal overflow of rivers or lakes (Junk et al., 1989). During the aquatic phase the slow-flowing waters are, generally, shallower than the open waters and covered by trees adapted to inundation. Conditions in flooded forests are characterized by lower water temperatures and increased transparency.

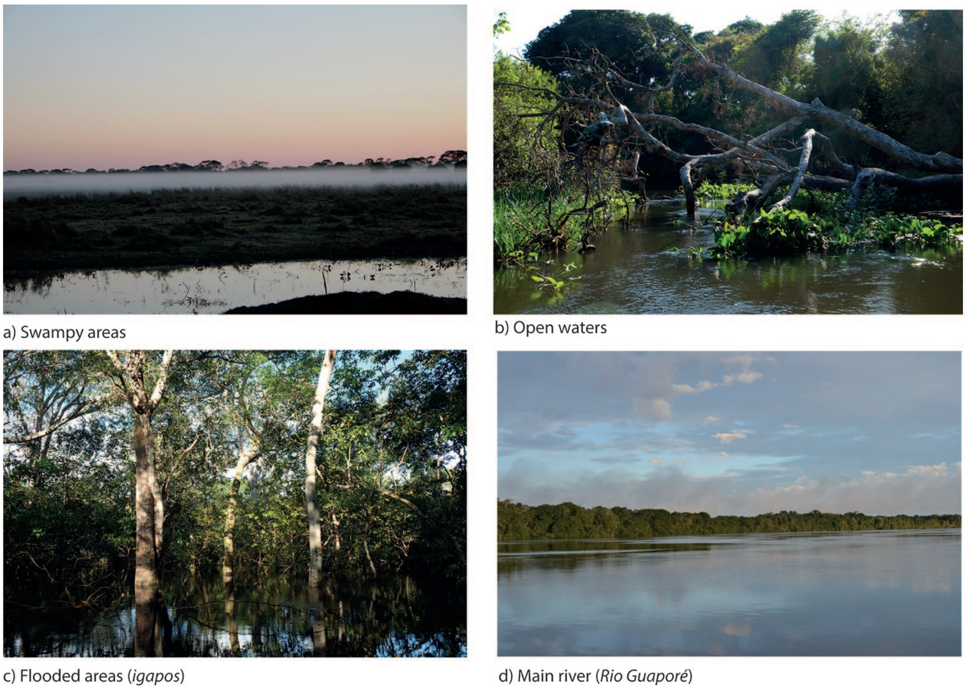
Major river: The flood cycle of the area around Monte Castelo is regulated by the closest river, the Guaporé, that flows about 8 km from the site. The Guaporé is slow-flowing and the water depth in its main channel varies annually between 8 m and 3.2 m (Torrente-Vilara and Doria, 2012).

Each aquatic environment supports fish communities adapted to specific conditions of oxygen concentration, water flow velocity, depth, and transparency (Pouilly et al., 2004a; Pouilly and Camacho, 2012; Rodriguez and Lewis, 1997).

Monte Castelo stratigraphy

The Monte Castelo shellmound currently measures 120 m in length and 6,5 m high. From June to November the wetlands surrounding Monte Castelo are almost completely dry (Figure 5). During the flood season, however, the site is an island completely surrounded by water. Former archeological excavations were carried out in the beginning of the 1980's by Eurico Miller, who undertook a 2 × 2 excavation at the highest point of the shell mound and some smaller test pits. The site was not studied again until 2013. Recent fieldwork sought to expand Miller's previous excavations in order to identify intact deposits. Excavation followed a ten-centimeter artificial levels within identified cultural strata.

By 2016, a 630 cm-deep profile was exposed, composed of 21 strata (labeled A to U from surface to depth) reaching the sterile surface over which the initial mound was built (Figure 6).



a) Swampy areas b) Open waters

c) Flooded areas (*igapos*) d) Main river (*Rio Guaporé*)

Figure 4. The main categories of aquatic environments in the area surrounding Monte Castelo.

Figure 5. A dry season, October, view of the site of Monte Castelo as a forest island, center surrounded by wetlands. The course of the Branco River is obscured within a strip of trees at the top of the image (photo by Carlos Zimpel).

Preliminary descriptions of the strata are given in Supplemental Table 1, available online (Preliminary description of the strata) (Pugliese et al., 2018). The present article bases its analysis on the stratigraphy (Supplemental Figure 1, available online Monte Castelo stratigraphy) and chronology (Supplemental Section 1, available online Monte Castelo chronology, Supplemental Table 2, available online Monte Castelo radiocarbon dates). Greater detail of the changes in material culture and deposit matrix are presented in the supplementary material (Supplemental Figure 2, available online Monte Castelo matrix).

Materials and methods

In order to sample fish remains, sediment consisted of duplicated 11 L sediment collections from each of the 21 specific strata (named from A to U). Following the different depths of the strata, larger number of collections were processed for thicker strata; the specific number of liters per stratum is given in Supplemental Table 1, available online Preliminary description of the strata. Samples were water-screened using a stack of sieves of decreasing mesh size (2, 1, and 0.5 mm) and materials were taken to the lab for sorting. Fish remains were separated from material coarser than 2 mm. Bone remains from strata H, I, and J were covered by concretions of burnt, crushed shells, making their identification impossible. Therefore, the remains from these strata were soaked for two hours in a solution of formic acid diluted in water to 8%.

The osteological and taxonomic identification of the fish remains was undertaken with the aid of a comparative collection of about 120 modern fish specimens collected from the Amazon Basin and housed at the Muséum National d'Histoire Naturelle (MNHN, Paris). About 70 of the individuals in the comparative collection were captured in aquatic environments near Monte Castelo and the environments around the Guaporé River and prepared in conjunction with this study. Cranial and post-cranial archeological remains were quantified by Number of Identified Specimens (NISP) and Minimum Number of Individuals (MNI). MNI was calculated on the basis of the single, best represented anatomical element, often cranial elements (e.g. dentary, premaxilla).

Fish taxa were grouped according to their distribution in the four principal aquatic environments of the study area: (1) swamps, (2) open waters, (3) flooded forests, and (4) major river. These environmental groupings were based on ecological data provided by Machado-Allison (1990), Pouilly et al. (2004a), Pouilly and Rodriguez (2004b) and Sarmiento and Barrera (2003).

The identifications of most catfish were based on the analysis of pectoral fins, and indeterminate specimens were classified as sp. 1, sp. 2, etc.

Facing the complexity of a chronologically extensive and diverse fish assemblage, we elaborated a pollen-like frequency diagram (Figure 7). The percentage frequencies of taxa were represented using ACACIA software. This diagram can be a tool to evaluate the distribution and appearance of fish groups throughout the stratigraphy and provide information as to which aquatic environments were exploited. Richness and Diversity index calculations are in Supplemental Section 2, available online (Diversity index calculation).

Results

The fish spectrum

The archeological assemblage includes nearly 35,287 fish remains, 8112 of which were identified either to the family, genus, or species level (about 22% of the total assemblage). From

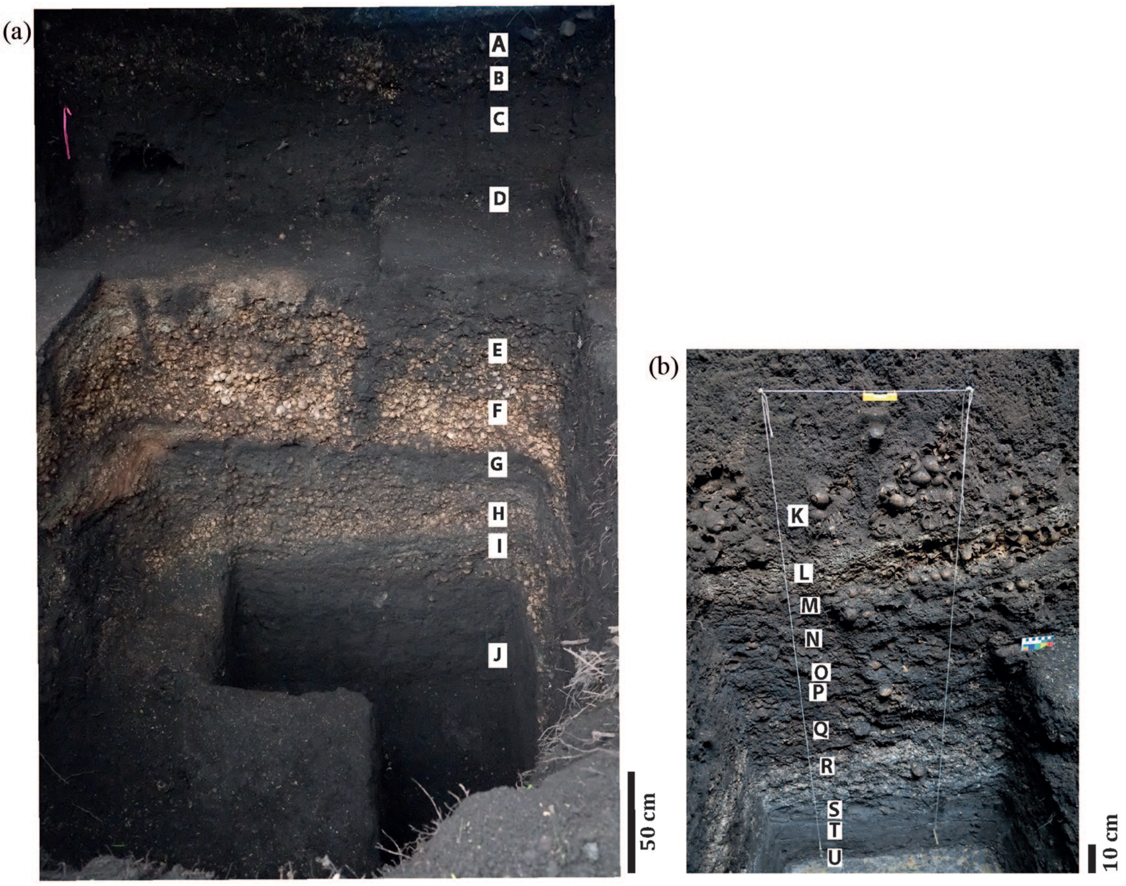


Figure 6. The stratigraphic profile at Monte Castelo is seen in three sections with strata A-D a meter beyond strata E-J due to the stepped excavation of the north face (a) and strata K-U on the west face of the restricted excavation area (b). Gastropod shells, whole or in crushed layers, are the dominant visual feature (photos by Middle Guaporé Project).

stratum A to stratum U, fish constitute the large majority of the faunal spectrum. Other vertebrates like aquatic turtles, caimans, snakes, lizards, amphibians, cervids, small rodents, and armadillos were present in lower abundances.

The use of 2mm mesh sieving allowed for the recovery of small sized species such as Characids or Cichlids (with live weights of approximately 20 g) and permitted the identification of a highly diverse fish spectrum that includes 38 genera belonging to 7 orders and 16 families presented in Supplemental Table 3, available online Number of Identified Specimens (NISP) and Minimum Number of individuals (MNI).

Although highly fragmented, the bones are well preserved compared to those from most Amazonian archeological contexts. In stratum U, the deepest cultural level excavated, bone material is highly mineralized. Throughout the deposits, less than one percent of the bones were burnt. An external portion of dorsal spine of *Anadoras wedelli* recovered in stratum P (520–544 cm depth) presents charring that indicates that the body of the fish had been entirely roasted before consumption (Figure 7.33).

Frequencies in faunal assemblages can be strongly influenced by a certain number of biases:

1) Bone conservation. As a result of age, sediment weight, chemical infiltrations, and many other factors, the deepest strata tend to present less well preserved bones than the uppermost strata. It is to be expected, therefore, that small-sized species would be underrepresented in deeper strata. This bias, however, does not appear to affect Monte Castelo, where small-sized fishes have been recovered in strata at depths of 630 cm (Figure 7.41).
2) Functionality of the stratum and density of faunal remains. Form, composition, and materials recovered in different strata at Monte Castelo are records of different activities that took place at the site. It is to be expected that construction strata would present a lower density of faunal remains than occupation strata. Thus, low bone concentrations and seemingly correlated low taxonomic diversity in strata H, F, and J corroborate the hypothesis that these are construction related (Pugliese, 2018) (Figure 8).
3) Sample size. The larger the sample, the greater the number of identified species (Grayson, 1981). This sample-size problem is illustrated by Figure 9a. There is a positive correlation between the number of taxa and the sample size (total NISP) at Monte Castelo ($r = 0.8517$), indicating that one cannot directly compare collections of different sizes. In an attempt to understand species accumulation and the rate at which new taxa are found, we used the rarefaction curve. As the curve flattens to the right, a reasonable number of samples have been taken to represent total taxonomic diversity. A steep slope, in contrast, indicates that a portion of the species diversity remains to be discovered. For strata at Monte Castelo, the great majority of the curves tend to flatten when the minimum number of individuals reaches 70 and can, therefore, be compared (Figure 9b). In strata P and G however, further samples are necessary (Grayson, 1981; Lyman, 2008).

Dominant taxa. Samples from Monte Castelo provide an extensive list of fish taxa, seven of which are consistently and frequently represented throughout the stratigraphy: armored catfishes (Callichthyidae or *tamoata/buchere*), small sized thorny fish

Figure 7. Selected fish bones recovered from Monte Castelo grouped by strata. STRATUM A: (1 and 2) *Synbranchus marmoratus* ectopterygoid and dentary, (3 and 4) Potamotrygonidae stingray vertebra and dermal denticle, (5–7) *Lepidosiren paradoxa* dermal ethmoid, prearticular, and parasphenoid, (8) *Ossancora* sp. parietal-supraoccipital, (9) and (50) *Pseudoplatystoma* sp. complex vertebra and pectoral fin, (48) *Anadoras* sp. pectoral fin; STRATUM B: (10 and 11) *Synbranchus madeirae* dentary and otolith, (12) and (44) Loricariidae vertebra and pectoral fin, (13) Characidae sp. 3 dentary, (14) Doradidae indeterminate, (43) Heptapteridae pectoral fin; STRATUM C: (15) *Cichlasoma* sp. maxilla, (16) Potamotrygonidae stingray vertebra; STRATUM D: (17) *Crenicichla* sp. maxilla, (18) *Astronotus* sp. pharyngeal, (19) *Platydoras* sp. parietal-supraoccipital, (20 and 21) *Pseudoplatystoma* sp. vertebra and pre-maxilla, (22) *Trachelyopterus* sp. mesethmoid (23) *Ossancora* sp. mesethmoid, (24) *Rhamdia* sp. mesethmoid; (45) cf. *Corydoras* sp. pectoral fin (46) cf. *Pimelodella* sp. pectoral fin, (47) cf. *Agamyxis* sp. pectoral fin; STRATUM E: (25 and 26) *Cichla* sp. vertebra and articular; STRATUM F: (42) *Anadoras* sp. pectoral fin; STRATUM J: (27 and 28) Serrasalmidae basioccipital and teeth, (29) Callychthyidae supraoccipital (49) Doradoidea sp. 8 pectoral fin; STRATUM L: (30) *Cichla* sp. otolith; STRATUM M: (31) *Ossancora* sp. cleithrum (32) *Rhamdia* sp. supraoccipital; STRATUM P: (33) Doradoidea dorsal fin presenting burn mark, (34) Anostomidae vertebra; STRATUM Q: (35) *Cichla* sp. dentary; STRATUM S: (36) *Lepidosiren paradoxa* pterygoid; STRATUM T: (37) *Astronotus* sp. dentary, (38) *Pseudoplatystoma* sp. vertebra; STRATUM U: (39 and 40) *Synbranchus* sp. dentary and vertebra, (41) Doradoidea cleithrum.

(Doradidae-Auchenipteridae), swamp-eels (*Synbranchus*), tiger fish (*Hoplias malabaricus* or *traíra/bentón*), tucunaré (*Cichla*), acará (*Astronotus)* and lungfish *(Lepidosiren paradoxa*).

Armored catfishes (Callichthyidae) are small to medium sized catfish and the bodies of fish in this group are encased in a series of bone plates that were also frequently recovered. Even though these elements cannot be identified to genus level, the recovered pectoral spines and cranial bones indicate that they probably belonged to the species *Hoplosternum littorale*, locally named *buchere* or *tamoatá* (Figure 7.29). Well distributed throughout the occupation, armored catfishes tend to gain importance in the uppermost strata from ~4000 to 700 BP (strata D to A) (Figure 8). *H. littorale* is one of the most common species inhabiting small creeks, ponds, and shallow waters of the Madeira basin (Britto,

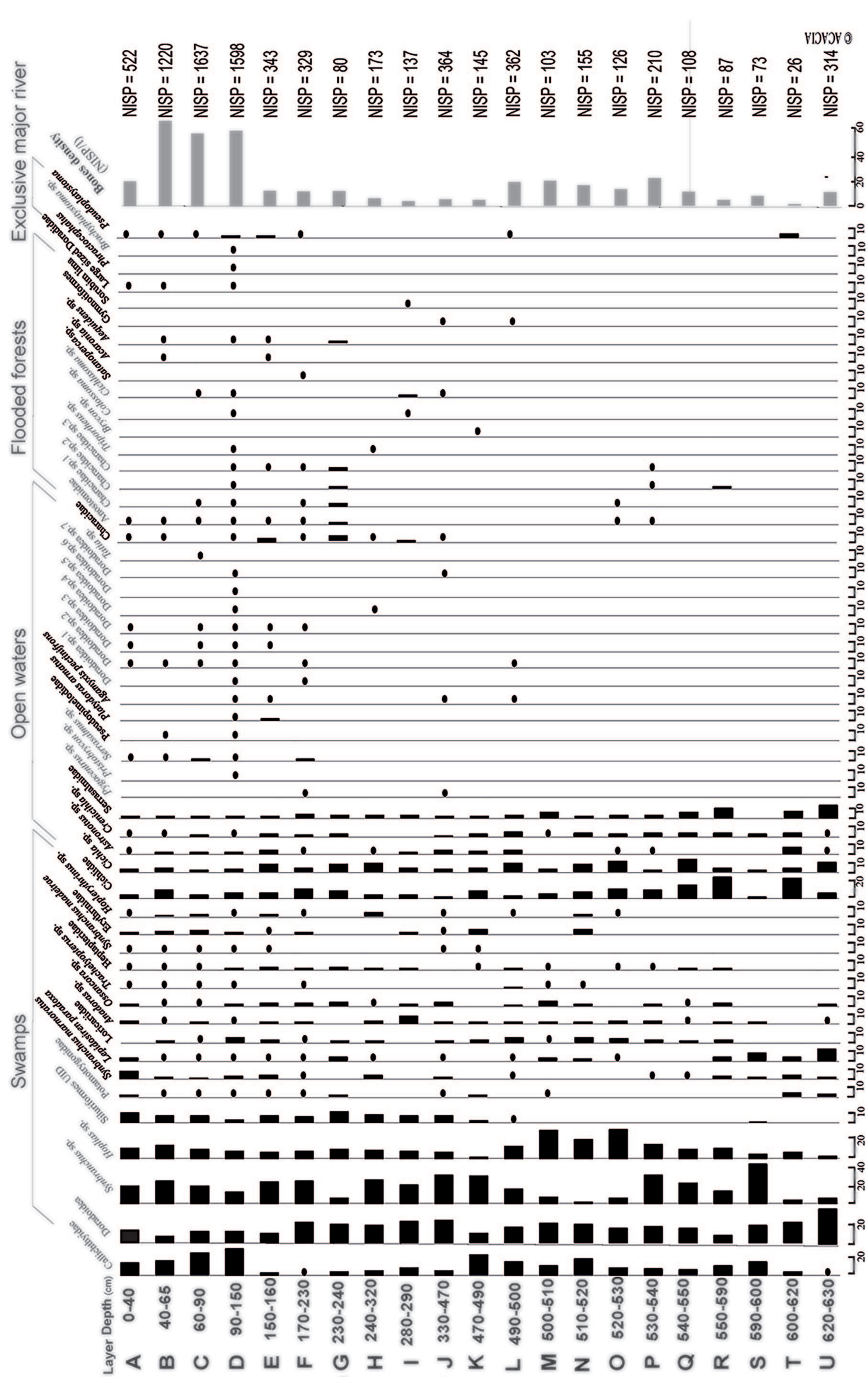


Figure 8. Percentage NISP of each fish taxon by strata. The vertical axis is ordered by depth in the deposit and is therefore roughly related to time. The taxon placement on the horizontal axis is organized by aquatic environment. Radiocarbon dates are calibrated. The category unidentified catfish ("Siluriformes UID") should be interpreted with caution since this group can inhabit the most diverse aquatic environments.

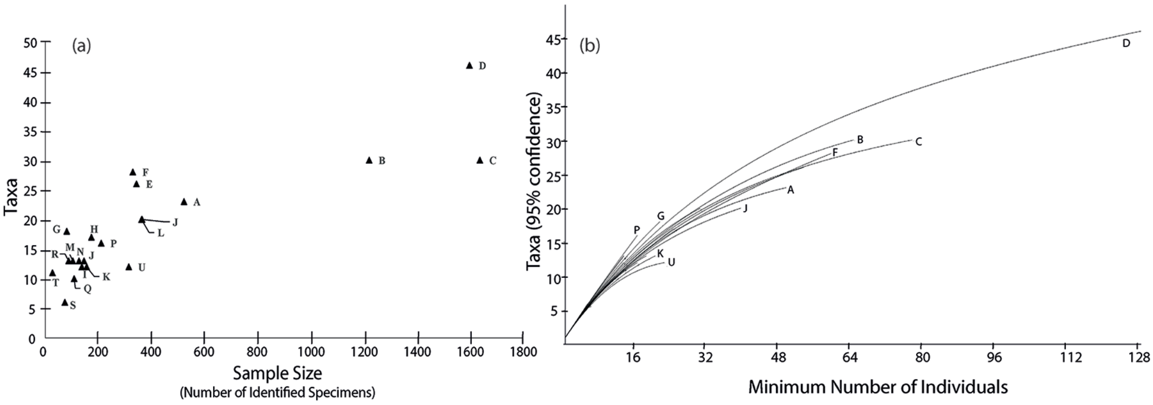


Figure 9. Evaluation of the effect of sample size on identified species. (a) A higher number of taxa were recovered with larger samples. (b) Rarefaction curves for each strata estimate the rate at which new species are found. The curves that become flatter to the right indicate that most new species have been found with the number of individuals analyzed.

2013). Armored catfishes are commonly consumed by modern local communities and are targeted by subsistence and commercial fisheries.

In the Monte Castelo sequence, we observed a great number of pectoral fins belonging to small-sized catfish known as "thorny fish" or "talking catfishes," that are grouped in the super-family Doradoidea (Auchenipteridae and Doradidae) (Figure 7.42, 47–49). Since this group is extremely diverse, taxonomic identification to the species level was limited (Birindelli, 2014). In Monte Castelo, we were able to identify two groups of doradids, the first includes medium-sized species (~50 cm), *Oxydoras niger* and *Pterodoras granulosus*, and the second is comprised of small-sized fish, specifically *Anadoras wedelli* (15 cm) and *Ossancora* cf. *punctata* (10 cm). The great majority of indeterminate Doradoidea are 10–15 cm fish probably belonging to these two latter species. The frequency of this group seems to be constant along the stratigraphy. In the deepest stratum (U) (~6000 BP), this group represents about 40% of the NISP. *Anadoras wedelli* and *Ossancora* cf. *punctata* generally inhabit shallow waterways (Birindelli and Pérez, 2011; Yunoki et al., 2013). Even though talking catfishes are scarcely commercialized today, they are important protein sources among Amazonian communities that dwell along the rivers (Akama and Ribeiro, 2013; Cabalzar, 2005). Other indeterminate catfish (Siluriformes UID) include an extensive range of small sized catfishes (Heptapteridae, Pimelodidae and other Doradoidea).

South American swamp-eels (*muçum*) figure as the third-most represented taxa. Both species that exist in the Madeira River Basin, *Synbranchus marmoratus* and *S. madeirae*, were recovered at the Monte Castelo site. Today the common length of synbranchids is 50 cm, but some individuals reach 150 cm. In Monte Castelo, percentage frequencies of swamp-eels appear to be constant from the deeper to the uppermost strata, representing between 20% and 30% of the fish spectrum. Most of the remains were only identified to genus level since only a few cranial elements allow one to distinguish between the two species. However, the remains permit the observation that *S. marmoratus* is the dominant species. Swamp-eels are able to withstand very poorly oxygenated environments, surviving in buried channels during the dry season (Figure 7.1, 2, 10, 11, and 39, 40). These fish are absent from modern commercial fisheries.

The taxon that represents from 5% to 15% of the assemblage is the tiger fish (*Hoplias malabaricus)*, a medium-sized characiform fish (65 cm maximum length) known for its sharp teeth. Tiger fish inhabit shallow and lentic waters. The fifth most well-represented fish are the cichlids, mainly *Cichla* sp. (*tucunaré*), *Astronotus* sp. (*acará*) and *Crenicichla* sp. (*peixe-sabão*). *Cichla* spp., also known as peacock bass, are among the largest Cichlidae in the Amazon Basin, reaching 75 cm in length and weighing up to 12 kg. The two latter genera are smaller, reaching no more than 30 cm in length. These three taxa share a preference for inhabiting open, slow-flowing water bodies (Figure 7.25–26, 30, and 35).

Rare taxa. Observing the fish spectrum recovered at Monte Castelo (Figure 8), there are a number of taxa that are less abundant in terms of the number of identified remains but are long-standing throughout the sequence. These taxa include stingrays (Myliobatiformes), lungfish (*Lepidosiren paradoxa*), different groups of pirañas (Serrasalmidae) and sucker-mouth catfishes (Loricariidae). Stingrays, pirañas, and the majority of suckermouth catfishes inhabit slow-flowing, open waters. Suckermouth catfishes are also associated with tree trunks and woody litter (Sarmiento and Barrera, 2003).

Tigerstriped catfish (*Pseudoplatystoma* sp., locally named *surubí*) is another taxon that has been recovered from the deeper to uppermost strata. Even though we were not able to identify the species, it is known that this fish can weigh up to 25 kg and measure 120 cm in length. The archeological specimens have been

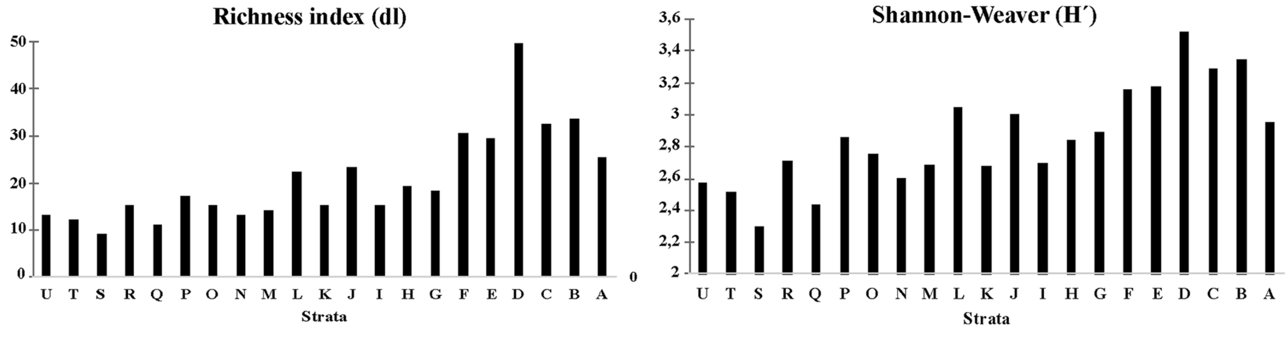


Figure 10. Changes in the Richness (dl) and Diversity (H') indices through time at Monte Castelo.

estimated to range in size from one to 10 kg. The principal habitat of this fish is the major river (Figure 7.9, 20, 21, and 38).

Long-term fluctuations at Monte Castelo

Richness (dl) and diversity (H') indices increase slightly over time (Figure 10 and Supplemental Section 2, available online Diversity index calculation). Since richness is based predominantly on the number of taxa, the elevated value for stratum D may be due, in part, to the greater sample size. From observation of the fluctuations in taxonomic richness and diversity, we propose two intervals of time whose strata express similar characteristics. The first interval goes from ~6000 to ~4400 BP (strata U to G), and the second from ~4300 to ~700 BP (strata F to A)

During the interval of ~6000 to ~4400 BP the richness index is fairly constant, varying between 9 and 25, and diversity (H') varies from 2,4 to 3,0. Starting in ~4300 BP (stratum F), there is an increase in both richness and diversity and a peak is observed in stratum D (~4000 BP), with the greatest number of recovered taxa (48).

These results suggest that an increasing number and variety of taxa were exploited by the population at Monte Castelo over the Holocene, although the natural fish diversity is projected to have remained constant. In deeper strata, there is a smoothed (or equalized) distribution of taxa and a low total number of taxa (low richness). On the contrary, entering the upper strata, the distribution is characterized by dominant with other unique taxa occurring in low proportions, a result reflected in the richness index and Shannon-Weaver diversity.

Discussion

The Monte Castelo fish spectrum and its evolution in light of contemporary paleoenvironmental fluctuations in Western Amazonia

Today, Monte Castelo is a flood-free island that is surrounded by water at least 6 months of the year. If the mound was used exclusively as a refuge from flood waters, it would be expected that fish taxa be typical of flooded forests and savannas. To the contrary, our results show that the spectrum is dominated by a set of small-sized catfish (Callichthyidae), swamp-eels, tiger fishes, and lungfish. These are typical burrowing drought-tolerant taxa that inhabit swampy areas and dry environments. The absence of species from flooded forests in strata dated from ~6000 to 4300 BP (strata U to F) lead us to suppose that environmental conditions and/or fishing practices could have been slightly different during the earlier occupations of Monte Castelo.

Pollen, charcoal, phytolith, and soil carbon isotope studies have been used in different parts of Southwestern Amazonia to reconstruct Holocene temperatures, atmospheric CO_2 concentrations, and precipitation. Pollen records recovered from Laguna Bella Vista and Laguna Chaplin (Noel Kempff National Park, Bolivia), located about 200 km south of Monte Castelo, were studied by Mayle et al. (2000). The author demonstrated that from ~9000 to 2000 cal. yrs BP, the landscape was dominated by open, seasonally flooded savannas and semi-deciduous dry forests. The analysis of atmospheric carbon dioxide concentrations corroborates the pollen data, showing that before 3000 BP the length of the dry season was longer than during the late-Holocene. Lower precipitation, associated with increased water-stress, favored the development of drought-adapted plant taxa (Mayle et al., 2004). That the Early and Middle Holocene were relatively dryer in reference to the late-Holocene has also been proposed for other regions of the Southwestern Amazon (Bird et al., 2011; Bush et al., 2007, 2016; Carson et al., 2014; De Freitas et al., 2001).

The best representation of drought-tolerant fish species and of those typically found in swampy areas in the deeper archeological strata (from ~6000 to 4300 BP) could be related to a longer dry season at Monte Castelo. The modern swampy areas are formed at the beginning of the dry season following receding flood waters. At the peak of the dry season, many swamps and ponds are reduced and others dry out. The remaining areas of confined water are separated by expanses of open terrain that is covered by, predominantly dry, plant matter from grasses, sedges, rushes, and forbs. The standing water bodies are shallow, have low levels of dissolved oxygen, high concentration of colloids that diminish light penetration, and water temperatures reaching 38–40°C. Only a few groups of fish, that possess specific physiological and morphological characteristics, are able to withstand such conditions (Machado-Allison, 1990). These taxa include the swamp-eels, callichthyids, lungfish, tigerstriped catfish and some sucker-mouth catfishes (*Hypostomus plecostomus* and *Pterygoplichthys* spp.). The shallow waters of dry wetland landscapes can also be the home to some small doradids (*Ossancora* spp. and *Anadoras* spp.) (Yunoki et al., 2013). Hence, the spectra of taxa from fishing activities are markers of paleoenvironmental conditions during the Middle Holocene, as well as of the practices of exploitation in swampy and standing waters.

Proportionally less important than taxa of swampy environments, open-water fish such as *Cichla* sp. (*tucunaré*), *Astronotus* sp. *(acara)* and Serrasalmidae (*pirañas*) are also well represented in the deeper strata of Monte Castelo. Open water bodies are the small and medium sized streams, rivers (such as the Rio Branco), creeks, and lakes that maintain permanent water circulation and where fluctuations in temperature are less pronounced than in the swampy areas. Although a great number of fish are dependent on water circulation, many can adapt to the lentic conditions brought about by the dry season (Machado-Allison, 1990). Due to the occurrence of such species by ca. 6000 BP, it appears that open waters were also commonly exploited aquatic environments.

The environmental changes in southwestern Amazonia date to the transition from the Middle to the late-Holocene with precipitation levels progressively increasing from about 4000 to 3000 cal. yrs BP. This initiates the southward expansion of the Amazonian moist evergreen forests that reach the study area ~2000 BP (Mayle et al., 2004). In a similar fashion, a study of carbon isotopes in stable organic matter of soil samples collected along a N-S transect connecting the cities of Humaitá and Porto Velho, along the Madeira River, also shows forest advance toward the south, as a consequence of increasingly wetter conditions in the region about 3000 cal. yrs BP (De Freitas et al., 2001). Increased precipitation from 3800 BP documented at Lake Titicaca implies a changed hydrological regime, under which flooded riverine forest environments expanded (Cross, 2000).

In the interval between 2000 and 700 BP, the paleoecological sequences for the Amazon show little variation in vegetation, with consistent humid evergreen rainforests (Carson et al., 2014; Flantua et al., 2016). At Monte Castelo, the corresponding strata (A and B) dated from ~2800 to 700 BP, are characterized by a reduction in the number of taxa compared to stratum D (~4000 BP). However, fish groups from both swampy environments and flooded areas indicate the continued use of both habitats for fishing.

An increase in flooded savannas and forests around 4000 BP?

Changes in environmental factors during the Middle Holocene are represented in the increased number of taxa that utilize flooded forests. From strata U to M (from ~6000 to 5000 BP), the number of taxa was relatively stable, ranging between 10 and 17. This subsequently increased from 22 in stratum L to 27 in stratum F and to 48 in stratum D (but, one caveat to this data is the possibility that diversity was effected due to NISP sample size). Considering that taxa were added to the assemblage, which groups of fish appear and which ecological niches do they represent?

By chronological order, the first group are Characiformes, which includes Anostomidae (*aracu*), *Triportheus* sp. (*sardinha*), *Brycon* sp. (*matrinxã/yatoarana*), *Colossoma* sp. (*tambaqui/pacu*), and a set of small (~20 g) Characiformes (sp.1, 2, and 3) that we were not able to identify given the great diversity of this group (see Figure 7.13). The presence of medium to large size characins at Monte Castelo can be indicative of the exploitation of flooded forests, since, according to Goulding (1981), a large portion of the characins of the Madeira River Basin are schooling and laterally migratory species. Feeding mainly on fruits and seeds, they spread out into the flooded forest during high water season (Goulding, 1981).

While the most commonly recovered cichlids in the bottom strata of Monte Castelo (*Cichla* sp., *Astronotus* sp. and *Crenicichla* sp.) are middle to large sized fishes, from stratum J (5180 ± 130 cal yrs BP) we observed the inclusion of more small-sized Cichlids such as *Cichlasoma* sp., *Satanoperca* sp., *Acaronia* sp. and *Aequidens* sp. whose body lengths vary from 8 to 17 cm (Figure 7.15 and 7.17). Cichlidae is a large family of fish with more than 60 species distributed across the Madeira River Basin. They may inhabit different aquatic environments, however, the four latter taxa are commonly found among the aquatic vegetation of slow-flowing waters in flooded forests and grasslands or along river shores (Sarmiento and Barrera, 2003).

Larger fishes, with the exception of the tiger-striped catfish, do not appear at deeper strata of Monte Castelo. From ~4000 BP, in stratum D, however, in addition to the tiger-striped catfish, two other large fishes were recovered: redtail catfish or *pirarara* (*Phractocephalus hemioliopterus*) and goliath catfish or *filhote (Brachyplatystoma* sp.). Redtail catfish can reach 1.3 m in length and weight up to 44 kg and *Brachyplatystoma* is a genus that includes the largest catfishes of the Amazon basin, those that can reach 3 m and 200 kg (Sarmiento et al., 2014). Despite this potential for sizeable individuals, those encountered archeologically in Monte Castelo have estimated weights ranging only from 8 to 10 kg. While these large catfishes generally inhabit the bottom of the river main channel, redtail catfish can also colonize flooded forests and grasslands during the high waters where they feed on fruits and seeds (Sarmiento and Barrera, 2003).

A third group, the thorny catfishes (Doradoidea), have been recovered throughout the stratigraphic sequence. From ~4300 BP (stratum F) we observe increased diversity of new fish species with pectoral spines belonging to *Platydoras armatus, Agamyxis pectinifrons, Tatia* spp. and seven other forms named Doradoidea sp. 1 to sp. 7. The majority of the archeological individuals were recovered in strata D and B and have lengths no larger than 10 cm. Some of the smaller individuals measured no more than 5 cm long (cf. Pseudopimelodidae/bumblebee catfishes). The current diversity of doradids in the Madeira River Basin includes at least 17 species of auchenipterids and 41 species of doradids (Akama and Ribeiro, 2013; Birindelli and Pérez, 2011; Shibatta, 2013). Therefore, to better identify these groups of taxa an extensive reference collection and the establishment of anatomical criteria will be necessary. It can be postulated that the majority of these small catfish inhabit hollowed-out tree trunks and the aquatic vegetation submerged in the flooded areas and river banks.

These general trends in changes in the paleoenvironmental records can be consistent with the shift of the fish communities observed from stratum H in Monte Castelo, which dates to the Middle Holocene, from ~5000 to 4000 BP. If the rainy season got longer with increased precipitation, rainfall could have led to an increase in water volume that would favor the dispersal of fish into the flooded forests. Evidence of this change is present in Monte Castelo with the emergence of a suite of small characids and cichlids typical of flooded forests. The mixing of stagnant waters with the overflow waters allows for nutrient exchanges among phyto- and zooplankton, insects, larvae, crustaceans, and mollusks. Furthermore, at least three fish taxa recovered at Monte Castelo (*Brycon* sp., *Triportheus* sp., and *Colossoma* sp.) are directly dependent on the flooded forests (Goulding, 1981). The exploitation of this environment is also supported by the increase in ichthyofaunal diversity, principally by species poorly adapted to extreme arid conditions. The predominantly small size of archeological individuals corroborates the function of these areas as “nurseries” of small-sized and juvenile fish (Junk et al., 1989; Machado-Allison, 1990).

Arrival of the Bacabal ceramic phase

Contemporaneous with the expansion of fishing to more diverse environmental settings, 4000 BP marks the appearance of an elaborate ceramic industry named the *Bacabal* phase (Miller, 2009). This style of ceramics, with decorated incised zone-hatched motifs, was recovered in quantity in strata B, C, and D (from ~4000 to 2000 BP) of Monte Castelo (Pugliese et al., 2018). To date, these ceramics have also been recovered in sites such as Bom Futuro and Ilha do Antelmo, on the right margin of the Upper Guaporé River (Zimpel Neto and Pugliese, 2016). The known sites are usually located on elevated terraces within the Guaporé floodplain that are covered by *Attalea phalerata (urucuri)* palm trees. The origins of the Bacabal ceramics are still debated. The zone-hatched zigzag bands on pottery have some similarities with the Valdivia ceramics, from the Pacific Coast of Ecuador that are dated to ca. 5780 BP. These similarities led Miller (2013) to propose that Bacabal ceramics could be an indicator of the migration of groups from the Pacific coast to Southwestern Amazon.

The archeological record suggests major changes in the fish spectrum around 4000 yrs BP that go beyond paleoenvironmental factors. Heightened diversity of the spectrum, in taxa and fish size, suggests the development of more types of fishing strategies. The inclusion of large catfish, such as the redtail catfish (*Phractocephalus hemioliopterus*) and goliath catfish (*Brachyplatystoma* sp.) demonstrates that fishing locations expanded into the flooded forests and major river, suggestive of flood-season procurement. The utilization of an increased range of aquatic habitats implies the development or utilization of fishing techniques adapted to such local environments. Remains from both dry and flood season fish species could be a result of year-round occupation. The botanical remains indicate that the population was using squash, maize, and rice the cultivation of which can be indicative of longer periods of occupation (Hilbert et al., 2017).

Four thousand yrs BP also marks a change in one of the plant foods, the wild rice *Oryza* sp., for which one domestication syndrome, increased grain size, is documented in Monte Castelo from phytolith sizes (Hilbert et al., 2017). Accepting that morphological changes and plant domestication can occur under management aside from agriculture, changes in the hydrological regime potentially amplified the geographic area appropriate for *in situ* plant management.

Characterizing strategies: Fishing or gathering fish?

Why are small, thorny, bone-covered, talking catfish so important at Monte Castelo? These catfish are commonly found in aquatic vegetation of shallow waters and can be captured by hand or by shaking out hollowed tree trunks (Machado-Allison, 1990) (Figure 3).

Environmentally, the aquatic vegetation that surrounds these tree trunks tends to be wild rice (*Oryza* spp.), cutters, *taboas* (*Rhynchospora* spp.), and *periperiaçu* (*Typha* spp.). These are potential feeding environments for apple snails (*Pomacea* spp.) (Alves et al., 2006). Due to elevated concentrations of calcium, phosphorus, and amino acids, apple snails can constitute important source of protein for human populations (Vasconcelos, 1956).

Like the talking catfishes, these snails and the wild rice were consistently exploited aquatic resources of Monte Castelo occupations (Hilbert et al., 2017). Apple snails feed on algae, bryophytes, and other microorganisms within the vegetation. They inhabit the margins of rivers, streams, and lakes and the quiet water swamp environments similar to those where the talking catfishes are found. The life cycle of these gastropods is regulated by the flood pulse. As the water recedes, they burrow and wait until the next rainy season to return to active feeding and reproduction, or die. Due to this cycle, they can be used as potential indicators of seasonality in resource exploitation (Watanabe et al., 2015). Even though the species identification of apple snails will refine our understanding of their ecological habitats, the apple snails and talking fishes may have been captured simultaneously as it is probable that they inhabited similar locations.

Furthermore, talking catfishes and apple snails share the possibility of being fished or captured by hand. Similar to talking catfishes, many other taxa recovered at Monte Castelo can be fished with bare hands. An additional resource in parts of this "common" ecological distribution are the sucker-mouth catfishes (Loricariidae) and *Crenicichla* sp. (Cichlidae) that also inhabit hollow tree trunks in areas adjacent to the Guaporé River.

An additional capture option is that of digging for apple snails, swamp-eels, and lungfish, which is possible during the dry season when they have burrowed into the channels of swampy areas to wait out the dry period and emerge during the next rainy season (Johansen and Lenfant, 1967; Bicudo and Johansen, 1979; Watanabe et al., 2015). Until recently, little attention was given to the importance of eel-like fishes in archeological sites, including in South America. Our understanding has improved with the discovery that swamp-eels were a key resource at archeological sites in the Llanos de Mojos, during at least, the first millennium AD (Béarez and Prümers, 2005; Prestes-Carneiro and Béarez, 2017; Prestes-Carneiro et al., 2019; Von den Driesch and Hutterer, 2012)

The presence of tucunaré, acará, and pirañas, throughout the Monte Castelo sequence, is indicative of the use of other fishing techniques (arrows, nets, harpoons, spears, etc.). Here we avoid the conceptual discussion about boundaries between gathering and fishing, yet the resources used at Monte Castelo indicate that "hand" fishing or "gathering of fish" had an important place among fishing practices. The practice of fishing by hand does not preclude the use of other fishing techniques that are documented in other remains. The recovery of a bone projectile point in stratum Q (~6000 BP) indicates that elaborate tools were employed since the beginning of the occupation of the site.

Conclusion

Monte Castelo is one of the rare archeological sites in the Amazon that registers successive human occupation for 6000 years, including from the "Holocene hiatus" ca. 4500 yr BP when evidence of human occupation is scarce (Araujo et al., 2005; Neves, 2012). Further, diverse taphonomic processes have contributed to poor preservation of bone remains at most other archeological sites across the lowlands. These factors contribute to a limited vision of economic diversity for the Early and Middle Holocene, where practices have been characterized as hunting and gathering. The example of aquatic resource exploration at Taperinha has been portrayed as an exception to a standard practice across the interior, but Monte Castelo and Cerro Azul's recent data indicate that it may not be an outlier. Monte Castelo brings new data to demonstrate greater cultural diversity in patterns of faunal use. Fish remains represent approximately 80% of the vertebrate fauna, indicating that not only was fish consumption a key element in human diet along with reptiles, mammals and mollusks, but that the population was exploiting the aquatic environment. A similar critique of gathering is suggested by the remains of squash, maiz, and rice that are cultivated species. In light of these elements, a strict association of Early and Middle Holocene resource acquisition with hunting and gathering should be reconsidered.

Alongside the study of Indigenous practices, local paleoenvironmental conditions were recorded in the Monte Castelo fish assemblage. Fish assemblages from 6000 to 4000 yrs BP present consistent regularity in the occurrence of drought-resistant taxa such as swamp-eels, armored catfishes, lungfish, and tiger fish. The predominance of drought-resistant taxa correlates with paleoenvironmental reconstructions for low levels of precipitation and long dry seasons from the Early to Middle Holocene. These resources indicate dry-season occupation and likely fish harvesting in swampy areas. The dominance of these taxa questions the idea that shell mounds were the locations of flood-season occupation (Capriles et al., 2019). At Monte Castelo, in addition to the drought-resistant taxa, the presence of smaller quantities of tucunaré, piranãs, and small thorny fishes indicate harvesting in open, lentic waters (streams and lakes). Today, the permanent water sources are the Branco River (~300 m from the site) and the Guaporé River (~8 km from the site).

Around 4000 BP, a suite of fish taxa from the flooded forests appears in the archeological record. Small characids and cichlids from this microenvironment are responsible for the increase in fish diversity to 48 taxa, rather than a change from one set of fauna to another. The human occupants of Monte Castelo may have amplified fishing to include the flooded forest landscape (*igapós*). The presence of both dry and flood season fish species suggests longer-term occupation that is corroborated by the botanical remains of squash, maize, and rice that were cultivated at Monte Castelo. Paleoenvironmental changes show the progressive introduction of wetter conditions from 4000 cal. yrs BP that probably extended the flood season, and potentially the flood-regime. The faunal assemblage with flooded forest fish species seems to be a local record of climate driven landscape change.

These contemporaneous paleoenvironmental, economic, and cultural changes that are demonstrated in the archeological remains from ~ 4000 yr BP (stratum D) reinforce the likelihood that Bacabal ceramics are a marker of the arrival of a new cultural group, rather than a local adoption of introduced ceramic technologies (Pugliese et al., 2018; Zimpel Neto and Pugliese, 2016). It is difficult to assert that these were year-round settlements, however Monte Castelo is a persistent place that was used for millennia, as has been suggested for other early Holocene Amazonia occupations (Shock and Moraes, 2019).

The drought-tolerant fish taxa that dominate Monte Castelo occupations in all periods, such as thorny and armored catfishes (Doradoidea and Callichthyidae), Heptapteridae, and Pseudopimelodidae, are rarely mentioned in today's commercial fishery. The presence of these species implies extensive knowledge of their behavior and the ecological niches they occupy. These small-sized fish inhabit submerged hollowed tree trunks frequently associated with aquatic grasses. Apple snails live in the same niche, as well as burrowing in the mud. We suggest that "fishing by hand" could have been carried out in conjunction with the collection of apple snails.

The intersection of changes in human behavior and the local environment are preserved in Monte Castelo. Animal and plant communities respond to environmental disturbances or the presence of stressors (precipitation, temperatures, and hydrology) and constitute, therefore, important sources of information about the evolution of paleo-landscapes. However, no single taxon can adequately indicate every type of disturbance in all environments, and fish remains are only one part of the puzzle. Similarly, the presence or absence of any specific taxon in an archeological site is related to human selectivity and the choice of fishing habitats, elements that are not predictable (Holt and Miller, 2011). The long-term sequences of data from neighboring shell mounds and forest islands will be critical to document the changes in human-environment relationships in Southwestern Amazonia throughout the Holocene.

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ORCID iDs

Gabriela Prestes-Carneiro https://orcid.org/0000-0003-2958-5797
Philippe Béarez https://orcid.org/0000-0003-0397-2393

Supplemental material

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References

Akama A and Ribeiro FRV (2013) Auchenipteridae. In: Queiroz LJ, Torrente-Vilara G, Ohara WM et al. (eds) *Peixes Do Rio Madeira 3*. São Paulo: Santo Antônio Energia, pp. 172–205.

Almeida FO (2013) *A tradição policroma no Alto Rio Madeira*. PhD Thesis, Universidade de São Paulo, Brazil.

Alves T, Lima P, Lima SFB et al. (2006) Growth of *Pomacea lineata* and *Pomacea bridgesi* in different stock densities. *Thalassas* 22(1): 55–64.

Araujo AG, Neves WA, Piló LB et al. (2005) Holocene dryness and human occupation in Brazil during the "Archaic Gap." *Quaternary Research* 64(3): 298–307.

Bailon S, Bochaton C and Lenoble A (2015) New data on Pleistocene and Holocene herpetofauna of Marie Galante (Blanchard Cave, Guadeloupe Islands, French West Indies): Insular faunal turnover and human impact. *Quaternary Science Reviews* 128: 127–137.

Baker PA and Fritz SC (2015) Nature and causes of Quaternary climate variation of tropical South America. *Quaternary Science Reviews* 124: 31–47.

Bandeira AM (2011) O povoamento da América visto a partir dos sambaquis do litoral equatorial amazônico do Brasil. *Fumdhamentos* 7: 431–468.

Bandeira AM, Chahud A, Ferreira ICP et al. (2016) Mobilidade, subsistência e apropriação do ambiente: Contribuições da zooarqueologia sobre o sambaqui do Bacanga, São Luís, Maranhão. *Boletim do Museu Paraense Emílio Goeldi Ciências Humanas* 11(2): 467–480.

Béarez P and Prümers H (2005) Prehispanic fishing at Loma Mendoza, Llanos de Moxos, Bolivia. In: Plogmann H (ed.) *The Role of Fish in Ancient Time. Proceedings of the 13th Meeting of the ICAZ Fish Remains Working Group in October 4th - 9th, Basel/Augst 2005*. Rahden/Westfalen: Verlag Marie Leidorf, pp 3–10.

Bicudo PW and Johansen K (1979) Respiratory gas exchange in the air-breathing fish, Synbranchus marmoratus. *Environmental Biology of Fishes* 4(1): 55–64.

Bird BW, Abbott MB, Vuille M et al. (2011) A 2,300-year-long annually resolved record of the South American summer monsoon from the Peruvian Andes. *Proceedings of the National Academy of Sciences* 108(21): 8583–8588.

Birindelli JL (2014) Phylogenetic relationships of the South American Doradoidea (Ostariophysi: Siluriformes). *Neotropical Ichthyology* 12(3): 451–564.

Birindelli JL and Pérez MHS (2011) *Ossancora*, new genus of thorny catfish (Teleostei: Siluriformes: Doradidae) with description of one new species. *Proceedings of the Academy of Natural Sciences of Philadelphia* 161(1): 117–152.

Britto MR (2013) Callichthyidae. In: Queiroz LJ, Torrente-Vilara G, Ohara WM et al. (eds) *Peixes Do Rio Madeira 2*. São Paulo: Santo Antônio Energia, pp. 180–195.

Borrero LA, Zárate M, Miotti L et al. (1998) The Pleistocene–Holocene transition and human occupations in the southern cone of South America. *Quaternary International* 49–50: 191–199.

Burbridge RE, Mayle FE and Killeen TJ (2004) Fifty-thousand-year vegetation and climate history of Noel Kempff Mercado National Park, Bolivian Amazon. *Quaternary Research* 61(2): 215–230.

Bush MB, Correa-Metrio A, McMichael CH et al. (2016) A 6900-year history of landscape modification by humans in lowland Amazonia. *Quaternary Science Reviews* 141: 52–64.

Bush MB, Silman MR and Listopad C (2007) A regional study of Holocene climate change and human occupation in Peruvian Amazonia. *Journal of Biogeography* 34(8): 1342–1356.

Cabalzar A (2005) *Peixe e gente no Alto Rio Tiquié: conhecimentos Tukano e Tuyuka: Ictiologia, Etnologia*. São Paulo: Instituto Socioambiental.

Capriles JM, Lombardo U, Maley B et al. (2019) Persistent early to Middle Holocene tropical foraging in southwestern Amazonia. *Science Advances* 5(4): eaav5449.

Capriles JM, Moore KM, Domic AI et al. (2014) Fishing and environmental change during the emergence of social complexity in the Lake Titicaca Basin. *Journal of Anthropological Archaeology* 34: 66–77.

Carneiro RL (1970) The transition from hunting to horticulture in the Amazon Basin. In: *Proceedings of the Eighth International Congress of Anthropological and Ethnological Sciences*. Tokyo: Science Council of Japan, pp. 144–148.

Carson JF, Whitney BS, Mayle FE et al. (2014) Environmental impact of geometric earthwork construction in pre-Columbian Amazonia. *Proceedings of the National Academy of Sciences* 111(29): 10497–10502.

Casteel RW (1976) *Fish Remains in Archaeology and Paleo-Environmental Studies*. New York: Academic Press.

Casteel RW, Adam DP and Sims JD (1977) Late-Pleistocene and Holocene remains of *Hysterocarpus traski* (Tule Perch) from

Clear Lake, California, and inferred Holocene temperature fluctuations. *Quaternary Research* 7(1): 133–143.

Clement CR, Denevan WM, Heckenberger MJ et al. (2015) The domestication of Amazonia before European conquest. *Proceedings of the Royal Society B: Biological Sciences* 282(1812): 20150813.

Cross SL, Baker PA, Seltzer GO et al. (2000) A new estimate of the Holocene lowstand level of Lake Titicaca, central Andes, and implications for tropical palaeohydrology. *The Holocene* 10(1): 21–32.

De Freitas HA, Pessenda LCR, Aravena R et al. (2001) Late Quaternary vegetation dynamics in the southern Amazon basin inferred from carbon isotopes in soil organic matter. *Quaternary Research* 55(1): 39–46.

Denevan WM (1966) *The Aboriginal Cultural Geography of the Llanos de Mojos Bolivia*. Berkley: University of California Press.

Dougherty B and Calandra H (1984) Prehispanic human settlement in the Llanos de Moxos, Bolivia. *Quaternary of South America and Antarctic Peninsula* 2: 163–199.

Erickson JE and Michel M (1991) Estudio preliminar de los sistemas agrícolas precolombinos en el Departamento del Beni, Bolivia: informe de los trabajos de campo efectuados durante el mes de julio de 1990. Report, Documentos Internos del Instituto Nacional de Arqueología de Bolivia, La Paz.

Figuti L, Plens CR and DeBlasis P (2013) Small sambaquis and big chronologies: shellmound building and hunter-gatherers in Neotropical highlands. *Radiocarbon* 55(3): 1215–1221.

Flantua SGA, Hooghiemstra H, Vuille M et al. (2016) Climate variability and human impact in South America during the last 2000 years: Synthesis and perspectives from pollen records. *Climate of the Past* 12(2): 483–523.

Gaspar MD, DeBlasis P, Fish SK et al. (2008) Sambaqui (shell mound) societies of coastal Brazil. In: Silverman H and Isbell W (eds) *The Handbook of South American Archaeology*. New York: Springer, pp. 319–335.

Gnecco C and Mora S (1997) Late Pleistocene/Early Holocene tropical forest occupations at San Isidro and Pena Roja, Colombia. *Antiquity* 71(273): 683–690.

Goulding M (1981) *Man and Fisheries on an Amazon Frontier, Developments in Hydrobiology*. Hingham: Dr. W. Junk Publishers.

Gutiérrez MA and Martínez GA (2008) Trends in the faunal human exploitation during the Late Pleistocene and Early Holocene in the Pampean region (Argentina). *Quaternary International* 191(1): 53–68.

Grayson DK (1981) A critical view of the use of archaeological vertebrates in paleoenvironmental reconstruction. *Journal of Ethnobiology* 1(1): 28–38.

Gross DR (1975) Protein capture and cultural development in the Amazon Basin. *American Anthropologist* 77(3): 526–549.

Kipnis R (1998) Early hunter-gatherers in the Americas: Perspectives from central Brazil. *Antiquity* 72(277): 581–592.

Hilbert L, Neves EG, Pugliese F et al. (2017) Evidence for mid-Holocene rice domestication in the Americas. *Nature Ecology & Evolution* 1(11): 1693–1698.

Holt EA and Miller SW (2011) Bioindicators: Using organisms to measure environmental impacts. *Nature Education Knowledge* 3(10): 8.

Jaimes Betancourt C and Prümers H (2013) La fase Jasiaquiri - una ocupación de los siglos IV-VI en la provincia Iténez, Llanos de Mojos, Bolivia. In: Alconini S and Jaimes Betancourt C (eds) *En El Corazón de América Del Sur 3: Arqueología de Las Tierras Bajas de Bolivia y Zonas Limítrofes*. Santa Cruz de la Sierra: Imprenta, pp. 17–40.

Jégu M, Queiroz LJ, Terrazas JC et al. (2012) Catálogo de los peces de la cuenca Iténez (Bolivia y Brasil). In: Van Damme P, Maldonado M, Pouilly M et al. (eds) *Aguas Del Iténez o Guaporé: Recursos Hidrobiológicos de Un Patrimonio Binacional (Bolivia y Brasil)*. Cochabamba: Editorial INIA, pp. 111–156.

Johansen K and Lenfant C (1967) Respiratory function in the South American lungfish, *Lepidosiren paradoxa*. *Journal of Experimental Biology* 46: 205–218.

Junk WJ, Bayley PB and Sparks RE (1989) The flood pulse concept in river-floodplain systems. In: Dodge DP (ed.) *Proceedings of the International Large River Symposium*. Canadian Special Publication of Fisheries and Aquatic Sciences 106(1): 110–127.

Lathrap DW (1968) The “Hunting” economics of the Tropical Forest Zone of South America: An attempt at Historical perspective. In: Lee R and Devore I (eds) *Man the Hunter*. Chicago: Aldine Transaction, pp. 23–29.

Latrubesse EM, Rossi A and Franzinelli E (2000) Geomorphology of the Pacaás Novos Range, southwestern Amazonia, Brazil: One example on the importance of geomorphological evidences to the reconstruction of Quaternary Paleoenvironmental scenarios in Amazonia. *Revista Brasileira de Geociências* 30(3): 517–521.

Lima LFE (2012) A cerâmica Capão do Canga: Uma nova indústria cerâmica na Bacia do alto rio Guaporé, Mato Grosso, Brasil. *Amazônica-Revista de Antropologia* 4(1): 186–220.

Lombardo U, Iriarte J, Hilbert L et al. (2020) Early Holocene crop cultivation and landscape modification in Amazonia. *Nature* 581(7807): 190–193.

Lombardo U, May J-H and Veit H (2012) Mid-to late-Holocene fluvial activity behind pre-Columbian social complexity in the southwestern Amazon basin. *The Holocene* 22(9): 1035–1045.

Lombardo U, Szabo K, Capriles JM et al. (2013) Early and middle Holocene hunter-gatherer occupations in Western Amazonia: The hidden shell middens. *Plos One* 8(8): e72746.

Lopes P, Gaspar M and Gomes DMC (2018) O Sambaqui Porto da Mina e a cerâmica utilizada como material construtivo: um estudo de caso. *Revista de Arqueologia* 31(1): 52–72.

Lyman RL (2008) *Quantitative Paleozoology*. Cambridge: Cambridge University Press.

Machado-Allison A (1990) Ecologia de los peces de las areas inundables de los llanos de Venezuela. *Revista Interciencia Grandes Rios Suramericanos* 15: 411–423.

Maldonado M and Goitia EA (2012) La cuenca del rio Itenez en Bolivia: descripción ecológica. In: Van Damme PA, Maldonado M, Pouilly M et al. (eds) *Aguas Del Iténez o Guaporé: Recursos Hidrobiológicos de Un Patrimonio Binacional (Bolivia y Brasil)*. Cochabamba: Editorial INIA, pp. 5–25.

Mayle FE and Iriarte J (2014) Integrated palaeoecology and archaeology–a powerful approach for understanding pre-Columbian Amazonia. *Journal of Archaeological Science* 51: 54–64.

Mayle FE, Beerling DJ, Gosling WD et al. (2004) Responses of Amazonian ecosystems to climatic and atmospheric carbon dioxide changes since the last glacial maximum. *Philosophical Transactions of the Royal Society B: Biological Sciences* 359(1443): 499–514.

Mayle FE, Burbridge R and Killeen TJ (2000) Millennial-scale dynamics of southern Amazonian rain forests. *Science* 290(5500): 2291–2294.

Mayle FE, Langstroth RP, Fisher RA et al. (2007) Long-term forest–savannah dynamics in the Bolivian Amazon: Implications for conservation. *Philosophical Transactions of the Royal Society B: Biological Sciences* 362(1478): 291–307.

McMichael CN, Matthews-Bird F, Farfan-Rios W et al. (2017) Ancient human disturbances may be skewing our understanding of Amazonian forests. *Proceedings of the National Academy of Sciences* 114(3): 522–527.

Meggers BJ (1954) Environmental limitation on the development of culture. *American anthropologist* 6(5): 801–824

Miller ET (1987) Pesquisas arqueológicas paleoindígenas no Brasil Ocidental. *Estudios Atacameños* 8: 37–61.

Miller ET (1992) Adaptação agrícola pré-histórica no alto rio Madeira. In: Meggers BJ (ed.) *Prehistoria Sudamericana; Nuevas Perspectivas. Segundo Simposio Comemorando el Quinto Centenario, National Museum of Natural History, Smithsonian Institution, Washington, D.C., Oct. 1988*. Santiago: Ed. Universitaria, pp. 219–232.

Miller ET (2009) A Cultura Cerâmica do Tronco Tupí no alto Ji-Paraná, Rondônia, Brasil: algumas reflexões teóricas, hipotéticas e conclusivas. *Revista Brasileira de Linguística Antropológica* 1(1): 35–136.

Miller ET (2013) Algumas culturas ceramistas, do Noroeste do Pantanal do Guaporé à encosta e altiplano Sudoeste do Chapadão dos Parecis. Origem, Difusão/Migração e Adaptação do Noroeste da América do Sul ao Brasil. *Revista Brasileira de Linguística Antropológica* 5(2): 335–383.

Miotti L and Salemme M (1999) Biodiversity, taxonomic richness and specialists-generalists during late Pleistocene/ early Holocene times in Pampa and Patagonia (Argentina, southern South America). *Quaternary International* 53: 53–68.

Mongeló G (2013) *O formativo e os modos de produção: ocupações pré-ceramistas no Alto Rio Madeira-RO*. PhD Thesis, Universidade de São Paulo, Brazil.

Morcote-Ríos G, Aceituno FJ, Iriarte J et al. (2020) Colonisation and early peopling of the Colombian Amazon during the Late Pleistocene and the Early Holocene: New evidence from La Serranía La Lindosa. *Quaternary International*. Epub ahead of print 28 May 2020. DOI: 10.1016/j.quaint.2020.04.026.

Neves EG (2012) El Formativo que nunca terminó: la larga historia de estabilidad en las ocupaciones humanas de la Amazonía central. *Boletín de arqueología PuCP* 11: 117–142.

Ovando-Leyton A (2012) Deforestation and flood dynamics in the Itenez Basin as landscape indicators for mercury pollution. In: Van Damme PA, Maldonado M, Pouilly M et al. (eds) *Aguas Del Iténez o Guaporé: Recursos Hidrológicos de Un Patrimonio Binacional (Bolivia y Brasil)*. Cochabamba: INIA, pp. 57–78.

Plotzki A, May JH, Preusser F et al. (2015) Geomorphology and evolution of the late Pleistocene to Holocene fluvial system in the south-eastern Llanos de Moxos, Bolivian Amazon. *Catena* 127: 102–115.

Pouilly M and Camacho J (2012) Distribución de peces en la cuenca del río Iténez. In: Van Damme P, Maldonado M, Pouilly M et al. (eds) *Aguas Del Iténez o Guaporé: Recursos Hidrológicos de Un Patrimonio Binacional (Bolivia y Brasil)*. Cochabamba: INIA, pp. 157–172.

Pouilly M, Lino F and Yunoki T (2004a) Peces de las lagunas. In: Pouilly M, Beck SG, Moraes R et al. (eds) *Diversidad Biológica En La Llanura de Inundación Del Río Mamoré: Importancia Ecológica de La Dinámica Fluvial*. Santa Cruz de la Sierra: Centro de Ecologia Simón, pp. 323–350.

Pouilly M and Rodríguez MA (2004b) Determinism of fish assemblage structure in neotropical floodplain lakes: Influence of internal and landscape lake conditions. In: Welcomme RL and Petr T (eds) *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries. Food and Agriculture Organization and Mekong River Commission*. Bankok: FAO Regional Office for Asia and the Pacific, pp. 243–265.

Pouilly M, Lino F and Yunoki T (2004a) Peces de las lagunas. In: Pouilly M, Beck SG, Moraes R et al. (eds) *Diversidad Biológica En La Llanura de Inundación Del Río Mamoré: Importancia Ecológica de La Dinámica Fluvial*. Santa Cruz de la Sierra: Centro de Ecologia Simón, pp. 323–350.

Prestes-Carneiro G and Béarez P (2017) Swamp-eel (*Synbranchus* spp.) fishing in Amazonia from pre-Columbian to present times. *Journal of Ethnobiology* 37(3): 380–397.

Prestes-Carneiro G, Béarez P, Shock MP et al. (2019) Pre-Hispanic fishing practices in interfluvial Amazonia: Zooarchaeological evidence from managed landscapes on the Llanos de Mojos savanna. *Plos One* 14(5): e0214638.

Pugliese FA, Zimpel Neto CA and Neves EG (2017) Los concheros de la Amazonía y la historia indígena profunda de América del Sur. In: Rostain S and Jaimes Betancourt C (eds) *Las Siete Maravillas de La Amazonía Precolombina*. La Paz: Plural, pp. 27–46.

Pugliese FJ (2018) *A história indígena profunda do sambaqui Monte Castelo*. PhD Thesis. São Paulo, Brazil: University of São Paulo.

Pugliese FJ, Zimpel Neto CA and Neves EG (2018) What do Amazonian Shellmounds tell us about the long-term indigenous history of South America? In: Smith C (ed.) *Environmental Archaeology: Encyclopedia of Global Archaeology*. New York: Springer, pp. 1–25.

Reitz EJ (2001) Fishing in Peru between 10 000 and 3750 BP. *International Journal of Osteoarchaeology* 11(1–2): 163–171.

Reitz EJ and Wing ES (1999) *Zooarchaeology*. Cambridge: Cambridge University Press.

Roche M-A and Jauregui CF (1988) Water resources, salinity and salt yields of the rivers of the Bolivian Amazon. *Journal of Hydrology* 101(1–4): 305–331.

Rodriguez MA and Lewis WM (1997) Structure of fish assemblages along environmental gradients in floodplain lakes of the Orinoco River. *Ecological Monographs* 67(1): 109–128.

Rofes J, Garcia-Ibaibarriaga N, Aguirre M et al. (2015) Combining small-vertebrate, marine and stable-isotope data to reconstruct past environments. *Scientific Reports* 5(1): 14219.

Roosevelt A (1995) Early pottery in the Amazon: Twenty years of scholarly obscurity. In: Barnet WK and Hoope J (eds) *The Emergence of Pottery: Technology and Innovation in Ancient Societies*. Washington, DC: Smithsonian Institution Press, pp. 115–131.

Roosevelt AC, da Costa ML, Machado CL et al. (1996) Paleoindian cave dwellers in the Amazon: The peopling of the Americas. *Science* 272(5260): 373–384.

Roosevelt AC, Housley RA, Imazio da Silveira M et al. (1991) Eighth millennium pottery from a prehistoric shell midden in the Brazilian Amazon. *Science* 254(5038): 1621–1624.

Sarmiento J and Barrera S (2003) Peces. In: Ibish PL (ed.) *Biodiversidad: La Riqueza de Bolivia*. Santa Cruz de la Sierra: Editorial FAN, pp. 126–133.

Sarmiento J, Bigorne R, Carvajal-Vallejos F et al. (2014) *Peces de Bolivia*. La Paz: Plural.

Saunaluoma S (2012) Geometric earthworks in the state of Acre, Brazil: Excavations at the Fazenda Atlântica and Quinaua sites. *Latin American Antiquity* 23(4): 565–583.

Shibatta OA (2013) Pseudopimelodidae. In: Queiroz LJ, Torrente-Vilara G, Ohara WM et al. (eds) *Peixes Do Rio Madeira 2*. São Paulo: Santo Antônio Energia, pp. 339–346.

Shock MP and Moraes CP (2019) A floresta é o domus: A importância das evidências arqueobotânicas e arqueológicas das ocupações humanas amazônicas na transição Pleistoceno/ Holoceno. *Boletim do Museu Paraense Emílio Goeldi. Ciências Humanas* 14(2): 263–289.

Silveira MID, Oliveira ERD, Kern DC et al. (2011) O sítio Jabuti, em Bragança, Pará, no cenário arqueológico do litoral amazônico. *Boletim do Museu Paraense Emílio Goeldi. Ciências Humanas* 6(2): 335–345.

Simões MF (1981) Coletores-pescadores ceramistas do litoral do Salgado (Pará). *Boletim do Museu Paraense Emilio Goeldi. Antropologia* 78: 1–26.

Tonni EP, Cione AL and Figini AJ (1999) Predominance of arid climates indicated by mammals in the pampas of Argentina during the Late Pleistocene and Holocene. *Palaeogeography, Palaeoclimatology, Palaeoecology* 147(3–4): 257–281.

Torrente-Vilara G and Doria CRC (2012) Categorização e duração dos períodos hidrológicos do Rio Guaporé. In: Van Damme P, Maldonado M, Pouilly M et al. (eds) *Aguas Del Iténez o Guaporé: Recursos Hidrológicos de Un Patrimonio Binacional (Bolivia y Brasil)*. Cochabamba: INIA, pp. 29–37.

Vasconcelos B (1956) *Contribuição ao estudo químico-bromatológico do Aruá*. PhD Thesis, Faculdade de Medicina Universidade Federal de Pernambuco, Brazil.

Vialou D, Benabdelhadi M, Feathers J et al. (2017) Peopling South America's centre: The late Pleistocene site of Santa Elina. *Antiquity* 91(358): 865–884.

Vigne JD (1992) Zooarchaeology and the biogeographical history of the mammals of Corsica and Sardinia since the last ice age. *Mammal Review* 22(2): 87–96.

Von den Driesch A and Hutterer R (2012) Mazamas, Patos criollos y anguilas de lodo. Restos de subsistencia del asentamiento precolombino "Loma Salvatierra", Llanos de Mojos, Bolivia. *Zeitschrift für Archäologie Außereuropäischer Kulturen* 4: 341–367.

Walker JH (2008) The Llanos de Mojos. In: Silverman H and Isbell W (eds) *The Handbook of South American Archaeology*. New York: Springer, pp. 927–939.

Walker M, Head MJ, Berkelhammer M et al. (2018) Formal ratification of the subdivision of the Holocene Series/Epoch (Quaternary System/Period): Two new Global Boundary Stratotype Sections and Points (GSSPs) and three new stages/subseries. *Episodes* 41(4): 213–223.

Watanabe TT, Hattori GY and Sant'Anna BS (2015) Activity, substrate selection, and effect of a simulated Amazon flood regime on the behavior of the apple snail *Pomacea bridgesii. Marine and Freshwater Research* 66(9): 815–821.

Watling J, Iriarte J, Mayle FE et al. (2017) Impact of pre-Columbian "geoglyph" builders on Amazonian forests. *Proceedings of the National Academy of Sciences of the Unites States of America* 114(8): 1868–1873.

Watling J, Shock MP, Mongeló GZ et al. (2018) Direct archaeological evidence for Southwestern Amazonia as an early plant domestication and food production centre. *Plos One* 13(7): e0199868.

Yunoki T, Cholima BR, Moreno JP et al. (2013) Cambio estacional de la estructura de comunidades ictícolas en relación a la conectividad y cobertura vegetal en pozas artificiales en la Amazonía boliviana. *Revista Científica Agrociencias Amazonía* 1: 1–10.

Zimpel Neto CA (2009) *Na direção das periferias extremas da Amazônia: Arqueologia na bacia do Rio Jiparaná, Rondônia*. PhD Thesis, Universidade de São Paulo, Brazil.

Zimpel Neto CA and Pugliese FJ (2016) A fase Bacabal e suas implicações para a interpretação do registro arqueológico no Médio Rio Guaporé, Rondônia. In: Barreto C, Lima H and Betancourt CJ (eds) *Cerâmicas Arqueológicas da Amazônia*. Belém: MPEG, pp. 420–434.

Zuse S (2014) *Variabilidade cerâmica e diversidade cultural no Alto rio Madeira, Rondônia*. PhD Thesis, Universidade de São Paulo, Brazil.