**SUPPLEMENTAL MATERIAL**

**FISH SIZE AND AGE ESTIMATION**

This section provides information on the methodology and results of analyzes designed to estimate the size and age of the archaeological withemouth croaker, as well as the life cycle of the archaeological specimens recovered from Southeastern brazilian coast.

**Method of fish size estimation**

The body size of the zooarchaeological fish allows for the reconstruction of both the different ecosystems where the animals were probably caught, as well as the fishing techniques used. They also provide information on age, trophic level, and can also be used to identify possible anthropogenic or environmentally caused shifts in the population dynamics (Grouard et al. 2019). As sizes of all fish bones are highly correlated with live body size and weight (allometric size and growth are close to isometric distribution), there are many ways of estimating body size, live biomass (BM, grams) or Total Length (TL, mm), based upon various measurements of fresh fish skeletal parts (Grouard et al. 2019).

Otolith Length (OL) for all specimens from both sites were measured and the total body size (TL) of the fish were back-calculated using the following equation: TL = 24.34 + 22.57 OL (r = 0.988; n = 93) which is derived from a length regression analysis established for modern whitemouth croaker (Lopes et al. 2016). Archaeological specimens were then assigned to fish size groups according to Mulato et al. (2015).

**Method of age estimation of whitemouth croaker**

Age is also an important parameter to interpret fish lifecycles, as movements between habitats with distinct δ18Ow values may occur over their lifetimes.

Calcified fish structures like otoliths can be used to estimate age and growth parameters. This estimate relies on the structural pattern of growth: the succession of opaque and translucent zones, information regarding the periodicity of their deposition, and somatic growth pattern (Carbonara and Follesa 2019). The standardized ageing scheme (Carbonara and Follesa 2019) is based on estimated fish size, number of zones, theoretical birth date, the pattern of annulus deposition, age resolution (year or half-year) and the zone (opaque or translucent) appearance at the edge. A theoretical birth date is set for each species following the reproductive data available in the literature.

**Size and age estimation whitemouth croaker results**

Estimations of fish total length based on the equation for archaeological whitemouth croaker otoliths studied here ranged between 31.10‒48.92 for the Galeão shellmound and 20.08‒29.74cm for the Beirada shellmound (Table S1).

Table S1: Otolith general information (whitemouth croaker). (-) Otoliths not analyzed/ Data not disponible. OL: Otolith length; TL: total length.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Sample** | **Name of shellmound** | **Archaeological portion (otolith provenience)** | **Otolith weight****(gr.)** | **Number of annuli observed** | **Number of samples taken per otolith** | **OL (cm)** | **TL estimated (cm)** |
| BS‒809 | Beirada | Top | - | 5+ | 43 | 1.21 | 29.74 |
| BS‒810 | Beirada | Top | - | 3 | 32 | 0.75 | 20.08 |
| GS‒743 | Galeão | Base | 2,40 | - | - | 1.90 | 45.32 |
| GS‒744 | Galeão | Base | 1,63 | - | - | 1.91 | 45.54 |
| GS‒745 | Galeão | Base | 3,40 | 12+ | 54 | 2.06 | 48.92 |
| GS‒746 | Galeão | Base | 2,07 | - | - | 1.84 | 43.96 |
| GS‒762 | Galeão | Base | 1,28 | 10 | 40 | 1.83 | 43.74 |
| GS‒1073 | Galeão | Base | 1,80 | 11+ | 47 | 1.75 | 41.93 |
| GS‒1077 | Galeão | Base | 0,58 | - | - | 1.27 | 31.10 |
| GS‒1151 | Galeão | Base | 0,73 | 6 | 29 | 1.49 | 36.06 |

The seasonal information represented by the otolith edge reflects the last lifetime recording of the otolith and indicates (by reflected light) autumn/winter (translucent zone) and spring/summer (opaque zone) fisheries for the Galeão and Saquarema shellmounds samples. All of the Galeão shellmound specimens sampled belonged to adult fish as well as specimen BS‒809 from Beirada, but BS‒810 from the Beirada shellmound is in a sub‒adult phase (Table S1). The archaeological specimens from the Galeão shellmound present as being between 6 and 12 (+) years based on the counting of complete annual growth increments (one opaque + one translucent zones). Specimens from Beirada present as 3 (+) and 4 (+) years, or complete growth marks.

**THE LIFECYCLE OF THE ARCHAEOLOGICAL WHITEMOUTH CROAKER FROM SOUTHEASTERN BRAZILIAN COAST**

This section contains detailed results of the life cycle reconstruction of the archaeological specimens recovered from Galeão shellmound and Beirada shellmound.

**Reconstructing fish lifecycle**

The archaeological populations that have constructed the Galeão and Beirada shellmounds fished for Sciaenidae between 5,677 and 3,035 cal BP. However, a question remains: were the fish of the same size and experience the same lifecycle in pre‒Columbian and modern times?

Estimations of fish total length of this study based on the regression equation for archaeological whitemouth croaker otoliths ranged between 20 and 49cm long. These sizes are larger than the modern specimens of the Sepetiba Bay in Rio de Janeiro (Vincentini and Araujo 2003), since sizes in modern fisheries vary between 8 and 24 cm. In the modern Guanabara Bay, sizes of between 2.3 and 53.0 cm are found but 85% of individuals are classified as juveniles (Mulato et al. 2015).

According to the observation of complete growth increments, the fish from Galeão and Beirada were between 3 (+) and 12 (+) years old at time of capture. In the Sepetiba Bay, whitemouth croaker size and age distribution varied according to their location, with juveniles predominating in the inner zone and adults in the outer zone of the bay (Vincentini and Araujo 2003). The inner bay is a rearing ground during the first lifecycle period, and movement toward the sea occurs as fish increase in size and age.

Difference in whitemouth croaker lifecycle between Galeão and Beirada shellmounds specimens are revealed by both *pooled* data and pattern differences in intra‒otolith isotopic profiles (Figure 7, original manuscript).

Most of the peaks of positive δ18Ooto values for all samples could correspond to the autumn/winter season, mostly between the months of May and July (Santos et al. 2017). The opposite could correspond to spring and summer. However, there was no simple correspondence between zones of the annual growth marks and cyclicity in δ18Ooto values. Minimum and maximum δ18Ooto values can be associated with either opaque or translucent zones, interpreted as spring/summer and autumn/winter periods in reflected light, respectively.

Several explanations can elucidate the lack of correlation between isotopic and incremental cyclicity and the presence of non-regular cyclical variation in part of the profiles. The slowdown of somatic and otolith growth over fish lifetime. This causes the narrowing between the growth zones in the outer (older) part of the otolith compared to the inner (younger) part of the otolith.

**The lifecycle of the Galeão shellmound fish**

If there was a general match between the number of δ18Ooto cycles and the number of growth increments for the two individuals (GS‒745 and GS‒1073) with semi‒sinusoidal (second part) characteristics, this was not the case for the two specimens (GS‒762 and GS‒1151) that showed irregular patterns in δ18Ooto values. This is suggestive that environmental parameters such as regular seasonal temperature variations were the major factors that controlled regular cycles in δ18Ooto values while other environmental parameters controlled δ18Ooto peaks.

Closest oxygen isotope data of otoliths and shells was obtained from the Pine Island complex in Florida, USA, near estuarine/marine conditions (Walker and Surge 2006), but the data δ18O (‰ VPDB) from Galeão is still around 1‰ more positive. δ18Ooto values of up to +2‰ were associated with wide marine environments (Andrus et al. 2002).

Specimen GS‒1151 showed the greatest isotopic range and relatively the best correspondence between isotopic values and growth increment cyclicity, but this specimen shows small variations that were not associated to seasonality, with both minimum and maximum values presented in both translucent and opaque zone for δ18Ooto and δ13Coto. δ13Coto has the biggest peaks of positive value in autumn/winter and spring/summer. As expected, we observed more irregular patterns for δ13Coto when compared to the result for δ18Ooto.

The Guanabara Bay is actually a marine‒dominated estuary (Kjerfvee 1997), and the modern whitemouth croakers are generally associated with estuarine waters (Albuquerque et al. 2012) and/or brackish waters (Vazzoler 1991) in the early life stages. Isotopic profiles of two archaeological specimens (GS‒745, GS‒1073) suggest similar behaviour during the Middle Holocene. Because δ18Ooto is positively correlated to δ18Ow and negatively to temperature, the relatively low δ18Ooto values reflect higher temperature or lower δ18Ow values (or both) encountered during early life. Higher temperature can be found in shallow masses while lower δ18Ow values could be characteristic of water mass influenced by freshwater. Relatively low δ13Coto values during early life can result from a combination of residency in a water mass with lower DIC δ13C such as estuarine water and a higher metabolic rate as expected for young fish (Dufour et al. 2007).

At 6‒5,000 cal BP, the entrance of the Guanabara Bay was bigger than it is today (Amador et al. 1997), providing a higher influence of marine waters in the bay. Nowadays, the lowest δ13C sediments in the Guanabara Bay are restricted to the area very close to the mangrove forest (Cordeiro et al. 2017), where there is little export of mangrove material probably due to low tidal pumping related to the microtidal character of this ecosystem (Cotovicz et al. 2019). The four fish may have first resided in shallow waters during early life, with more pronounced estuarine or mangrove influences, and then moved to more open marine waters, within the bay or outside the bay. The existence of regular δ18Ooto cyclic variation in δ18Ooto values associated with growth marks until the capture of GS‒745 and GS‒1073, may suggests that 1) the major environmental factor of seasonal variation may be temperature and 2) these individuals have moved (annual cycles) from mangrove/estuarine to mostly marine waters influence and back until they were fished in a mostly marine environment during the summer. The other two (GS-762, GS‒1151) have more complex life stories: perhaps they have been staying more in the back of the bay, that is quite probable for the youngest one GS‒1151, and they could have been fished inside the bay.

Spite of the absence of adult whitemouth croakers catches by beach seines in Guanabara Bay (Andrade‒Tubino, 2009; Mulato et al. 2015; Franco et al. 2018), artisanal fisheries on the area frequently capture specimens around 40 cm through line and hook throughout the year in the bay, what could give us a trace about the capture technique applied in the past.

**The lifecycle of the Beirada shellmound whitemouth croaker**

The mean amplitude of δ18Ooto observed in the Beirada shellmound samples is higher than in the Galeão shellmound. However, the range between this site’s samples is smaller when compared to the Galeão shellmound specimens (Table 6, original manuscript). Isotopic data indicate that BS$-$809 experienced lower variation in δ18Ooto than BS‒810 and both resided in water masses usually characterized by lower δ13CDIC values than the fish found at the Galeão shellmound.

BS‒809 is a good example of seasonality registry, showing the biggest peaks of both elements in winter. BS‒810, the most marine influenced, register 4 peaks of δ18Ooto and δ13Coto in summer. These results indicate that both fish from the Beirada shellmound had lived in more estuarine/mangrove environments during their entire lifecycle. The two fish could have been caught in the end of spring or beginning of summer.

The δ13Coto values seem to trend with δ18Ooto, which is normally correlated to a larger influence of temperature oscillation. Our results of δ13C are within the Great and Little Bahama Banks (Patterson and Walter 1994).

The interruption of well delimited seasonal characteristics in the end of life of the Beirada otoliths could indicate that fish were trapped in a restricted site of the Saquarema Lagoon. Close to the mangrove/freshwater inner shelf. Brazilian indigenous fishing techniques used corral (large fishing traps) during high tides (Ramos et al. 1980; Diegues 1994). For both samples, the presence of the “tongue” (strip) of cold water (Carbonel 1998) could explain the enriched δ18Ow observed in the last growth season. It could be further explained by being in a coastal lagoon environment which was still in the process of its formation, probably connected to the sea in various locations (Turc 1999), and could have been favoured for fishery in the past. δ18Ooto values around +1.3 to +1.9 ‰ are found in environments marine influenced environments, such as Charlotte Harbor estuary (Walker and Surge 2006).

Barbosa-Guimarães (2011) indicates that shell mound builders of the Saquarema Lagoon complex between 6,726 and 3,699 cal BP used fish thorn fishing technology to catch whitemouth croaker, which is what the main catches of larger and medium sized fish consisted (Kneip 1988).

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