



Fishing during the early human occupations of the Atacama Desert coast: what if we standardize the data?

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Abstract

The Atacama Desert coast (18–30° S) presents one of the earliest chronologies in the South America region, whose first occupations date from ~13,000 cal BP. Since that time, coastal and marine resources have been a common component at sites along the littoral zone. Fish species have been particularly important, as have the fishing technologies developed and used by the coastal communities. However, even though several archaeological sites have been studied, there is no systematic macro-regional analysis of early fisheries along the Atacama Desert coast. Furthermore, differences in theoretical and methodological approaches, as well as research objectives, hinder comparisons between ichthyoarchaeological assemblages. Here, we present a comparative analysis of the Atacama Desert fish data obtained from publications and gray literature from ten archaeological sites dating from the Terminal Pleistocene to the Early Holocene. Through the standardization of contextual and ichthyoarchaeological information, we compared data using NISP, MNI, and weight to calculate fish density, richness, and ubiquity, in order to identify similarities and differences between assemblages. This exploratory approach aims to contribute to studies of fish consumption in the area, as well as proposing new methodological questions and solutions regarding data heterogeneity in archaeozoology.

Keywords Data standardization · Atacama Desert coast · Terminal Pleistocene · Early Holocene · Ichthyoarchaeology

Introduction

In order to understand the historical trajectories of a society or region, a meso-scale approach that allows comparison between locations, time intervals, and their variability must be considered. This necessitates the use of different sources and, in many cases, dealing with disparities in information as a result of several factors: when the data were produced or collected, the type of project for which the data were obtained, or even theoretical-methodological constraints.

These factors can be challenging when attempting accurately to integrate the information; therefore, it is essential to find ways to standardize the data.

In the modern digital age, large data sets have provided new opportunities for standardization, normalization, and the open access of archaeological evidence. Despite such achievements, methodological innovations can be incompatible with the heterogeneity of data sets (Kansa et al. 2011). This problem is also linked to the dual nature of archaeological evidence itself, as researchers usually distinguish both its cultural and natural aspects. In this respect, faunal remains are a paradigmatic example where zoological classification is employed as a tool for understanding cultural practices.

In the 1970s, the International Council of Archaeozoology (ICAZ) started to discuss appropriate measurements to standardize and publish data, producing a series of protocols that were uploaded in 2009 (Reitz 2009). Despite these efforts, some authors still maintain that archaeozoological raw data, analysis, and presentation are unstandardized (Driver 1992, 2011; Wolverson 2013; Steele 2015). Driver (2011) states that this is due to the lack of rules in archaeozoology and because the classificatory system

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is based on a fixed zoological taxonomy. Together with identification and analysis issues, some authors have suggested that more effective recovery methods are needed to achieve better management of the faunal data (Reitz and Wing 1999; Orton 2000; Butler and Campbell 2004; Lambrides and Weisler 2016).

During recent years, archaeozoology has been concerned with using data analysis to respond to large-scale questions. Several efforts have been undertaken in the study of ancient fisheries, using a variety of measures and estimations to compare the fish assemblages of a large area and/or a long historical sequence (e.g., Butler and Campbell 2004; Zangrando 2009; Orton et al. 2014; McKechnie and Moss 2016; Scartascini 2016).

The present study is a methodological exercise that explores the limitations and potentialities of standardization in order to perform accurate comparisons between contexts and faunal assemblages. To do so, we used fish data available from the earliest archaeological sites registered along the Atacama Desert coast (18–30° S), located between southern Peru and northern Chile, on the Pacific coast of South America. The archaeological contexts have been dated between ca. 13,000 and 8200 years cal BP, in what are known as the late Terminal Pleistocene and Early Holocene periods. In southern Peru, the presence of lithic artifacts and faunal remains associated with the exploitation of littoral resources shows an early coastal adaptation (Sandweiss et al. 1989, 1998; Lavallée et al. 1999, 2011; deFrance and Umire 2004; Reitz et al. 2016). Sandweiss and Rademaker (2011) have defined the phases of Jaguay (~ 13,000–11,400 years cal BP) and Machas (~ 10,600–8000 cal BP) in Quebrada Jaguay. Further south, the communities that inhabited northern Chile were part of the Chinchorro culture, known for their exploitation of coastal resources, as well as the development of distinctive mortuary practices (Standen and Santoro 2004; Arriaza et al. 2008; Santoro et al. 2012, 2020; Carter 2016). Finally, in the southernmost area of the Atacama Desert coast, several authors have identified the Huentelauquén cultural complex composed of human groups distributed along the arid and semi-arid regions of Chile, which developed a coastal adaptation evidenced by the presence of specific ecofacts and artifacts (Jackson et al. 2011; Salazar et al. 2015, 2018).

Despite these cultural differences, the exploitation of marine and coastal resources has been interpreted as a common feature of communities living in the area. In this regard, the capture and consumption of fish resources had socio-economic and ecological implications for human groups, as well as land/seascapes. Particularly, the Early Holocene has been understood as the beginning of a progressive specialization in the use of coastal and marine resources in some areas of the Atacama Desert coast, which was consolidated

during the Middle Holocene (Llagostera 1989, 1992; Olguín et al. 2014, 2015; Salazar et al. 2015; Béarez et al. 2016; Rebolledo et al. 2016; among others).

In order to evaluate this phenomenon, it is necessary to compare fish remains from different archaeological contexts during this time. Unfortunately, the heterogeneity of data hinders a regional analysis of fish distribution and exploitation in the area; therefore, it is mandatory to standardize the available data to improve our understanding of fisher-hunter-gatherer communities and their fishing practices. Here, we considered the contextual information and ichthyoarchaeological material published from ten archaeological sites from southern Peru and northern Chile. We created a single database that allowed us to standardize the data and select useful information for a comparative analysis, applying different ecological indices commonly used in archaeozoology. Additionally, we summarized both environmental and ethological traits in order to identify historical dynamics in a large-scale data set. In this way, we aim to provide new insights on standardization procedures and comparative analysis in archaeozoology discussing the quality of fish data produced, as well as contributing to the understanding of fish exploitation dynamics during the early human occupation in this macro-region.

Study area and environmental settings

The Atacama Desert (18–30° S) is situated along the southeastern coast of the Pacific Ocean, in what is now southern Peru and northern Chile (Fig. 1A). Its continental hyperaridity is mostly explained by orographic barriers, oceanographic characteristics, and climatic conditions. The coastline is characterized by a narrow littoral, with a small freshwater supply strongly influenced by the Pacific Ocean (Schulz et al. 2011). Belonging to the Peruvian Province (Camus 2001), this area is influenced by the homogenizing effect of the Humboldt Current System (HCS) and upwellings which generate high primary marine productivity.

In terms of fish distribution, Pequeño (2000: Fig. 7) defines this area as the *Distrito Atacameño*, i.e., the Atacama District. The author distinguished four categories of coastal fish: the first, which corresponds to coastal families (including intertidal and subtidal taxa), includes Blenniidae and Labrisomidae. On the continental shelf, Centrolophidae, Haemulidae, Sciaenidae, Myliobatidae, Merlucciidae, and Ophidiidae are found, among others. Pelagic-neritic fish are most represented by Engraulidae, Scombridae, Carangidae, and Clupeidae. Finally, epipelagic fish families are primarily represented by Triakidae, Carcharhinidae, and Gempylidae.

Although this area has been defined as a single ecoregion (Houston and Hartley 2003; Spalding et al. 2007; Dürr et al. 2011), the geomorphological configuration, fog zone

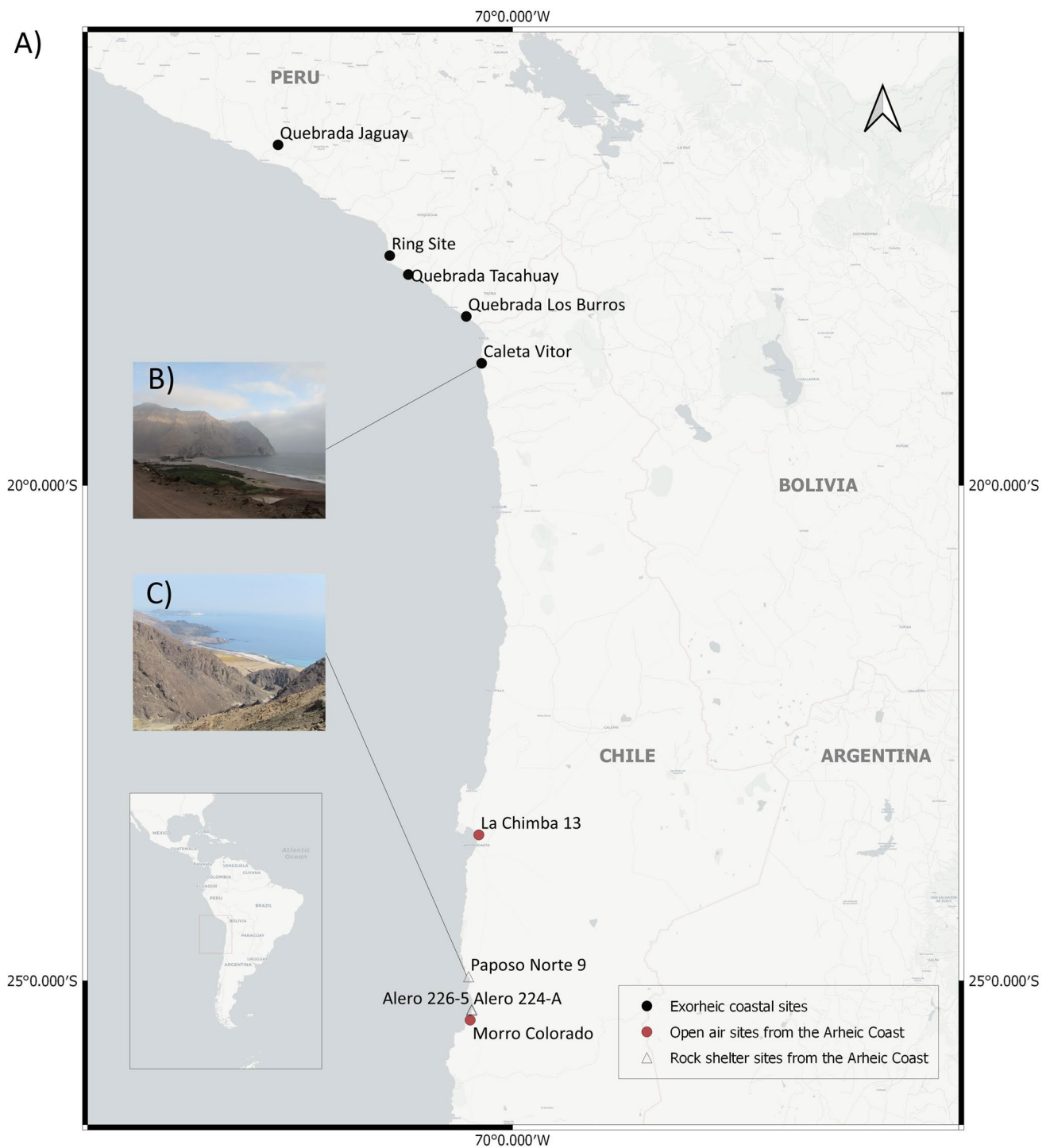


Fig. 1 A—Terminal Pleistocene–Early Holocene archaeological sites along the Atacama Desert coast; B—Exorheic coast (Caleta Vitor); C—Arheic coast (San Ramón)

distribution, and *loma* vegetation produce certain latitudinal heterogeneity (Thiel et al. 2007; Tapia et al. 2018; Bartz et al. 2020), which has implications for access to the sea and its resources. The northern portion (18–21° S), or Exorheic coast (EC), has an active cliff which is constantly decreasing

due to the surge effect. Also, the presence of surficial water flows allows the presence of oasis areas, characterized by diverse fauna and flora (Fig. 1B). The Arheic coast (AC) in the southern part (21–30° S) has an extremely narrow littoral, with a marine terrace between the coastline and

the Cordillera de la Costa (Fig. 1C). Despite the absence of a freshwater supply, an abundance of coastal resources is observed as a consequence of marine fogs, locally known as *camanchacas* (Paskoff 2010; Walk et al. 2020).

The Pleistocene–Holocene transition enormously affected the morphology and climate of the Atacama Desert. The increase of continental and oceanic temperatures produced marine transgressions with different results along the coast. Throughout the course of the Early Holocene (ca. 11,700–8200 year cal BP), the aridization process, an increase of SST (Sea Surface Temperature) and ENSO (El Niño/La Niña Southern Oscillation) cyclical events have produced interannual and interdecadal variability, influencing marine primary production (Latorre et al. 2003; Vargas et al. 2006). It is during the final phase of the Terminal Pleistocene that the first archaeological evidence has been recorded.

Archaeological context(s)

The archaeological sites studied here were selected according to the following criteria: data availability (in terms of contextual information, fish data, and radiocarbon dates), time span, and geographical location. Four of the ten sites are located in southern Peru (Quebrada Jaguay, Ring Site, Quebrada Tacahuay, and Quebrada Los Burros), while six are from northern Chile (Caleta Vitor 3, La Chimba 13, Paposo Norte 9, Alero 224-A, Alero 226–5, and Morro Colorado) (Table 1). Even though we recognize the Atacama Desert coast as a whole macro-region, we also recognize latitudinal differences associated with cultural differences (Llagostera 2005; Santoro et al. 2020). For this reason, we have classified the archaeological sites according to the two types of coast mentioned above: the Exorheic coast to the north and the Arheic coast in the south.

Exorheic coast archaeological sites

- Quebrada Jaguay (QJ-280): an open-air site with shell deposits located on an alluvial terrace 40 m above sea level (masl). It is located 2 km from the modern shoreline, which, in the vicinity, consists of sandy beaches with a rocky promontory (Sandweiss et al. 1998; Reitz et al. 2016). Excavations were classified into four sectors (I, II, III, IV) evidencing a human sequence that starts in the Terminal Pleistocene and ends in the Early Holocene period. Additionally, QJ-280 Early Holocene occupations were subdivided in two subperiods: EHI and EHII (Sandweiss et al. 1998).
- Ring Site (RS): open-air site consisting of an extensive shell midden deposit situated on a marine terrace 50 masl. It is located 0.75 km from the present shoreline,

which is characterized by a sandy beach (Sandweiss et al. 1989; Reitz et al. 2016). Excavations consisted of three columns (A, B, and D) and five pits (C, L, M, J, and TP-1), with a cultural stratigraphy from the Terminal Pleistocene until the Middle Holocene. The published faunal data are from Unit C, which is considered representative of Early Holocene occupation (Group 1).

- Quebrada Tacahuay (QT): open-air site located in an alluvial fan at 47–56 masl. The site is located 0.3 to 0.4 km from the present shoreline, consisting of a sandy beach with a rocky promontory (Keefer et al. 1998). Cultural deposits come from strata units 4, 4c3, 5B, 8, 8A, and 8B, which represents continuous human occupation from the Terminal Pleistocene until the Middle Holocene period (deFrance and Umire 2004).
- Quebrada Los Burros (QLB): located in the middle part of the eponymous ravine Quebrada Los Burros, at 170 masl, QLB is an open-air site 2 km from the actual shoreline, characterized by a rocky environment with some sandy beaches (Lavallée et al. 2011). Extensive open-area excavations (150 m²) revealed six occupational levels from the Early Holocene to the Middle Holocene epoch (Lavallée and Julien 2012). Early Holocene sequences were found in levels N4, N5, N6, and N7 (Fontugne 2012).
- Caleta Vitor 3 (CV3): an open-air site located at the mouth of Quebrada Vitor at ~25 masl, in front of a sandy beach. Its cultural sequence starts in the Early Holocene period with occupations continuing until recent times. The site has been divided into seven areas (CV1 to CV7), with the Early Holocene occupation starting in the deepest deposit of CV3 (Carter 2016), a shell midden 0.3–0.4 km from the present shoreline. Ichthyoarchaeological data came from the excavations of two 0.5 × 0.25 cm profiles (CV3-Perfil 1 and CV3-Perfil 2) (Rebolledo et al. 2021).

Arheic coast archaeological sites

- La Chimba 13 (LC13): located at the mouth of Quebrada Las Conchas, La Chimba 13 is an open-air site at ~260 masl. It is located 4 km from the current shoreline, which is characterized by a sandy beach. The site is composed of two depositional events with Early Holocene occupations (Llagostera et al. 1997). The ichthyoarchaeological data presented here comes from two 2 × 2 m units: N23/W07 and N54/W05 (Llagostera 1979; Llagostera et al. 1997).
- Paposo Norte 9 (PN-9): a rock shelter located in a marine terrace at ~25 masl and 0.2 km from the current shoreline, which is characterized by a sandy-rocky beach (Casteletti 2007). Human occupations at this site are from the Early and Late Holocene (Casteletti

Table 1 Archaeological sites from: *TP* Terminal Pleistocene, *EH* Early Holocene, *MH* Middle Holocene, *LH* Late Holocene

Area	Site	Location				Archaeological information							
		Geographical location	masl	Distance actual shore-line(km)	Type of beach	Type of site	Units/levels used here (Screen size)	Chronology					
								TP	EH	MH	LH		
EC	QJ-280	Alluvial terrace	40	2	Sandy/Rocky	Open air Shell-matrix	Sector I, II, III and IV (1.7 mm)						
	RS	Marine terrace	50	0.75	Sandy	Open air Shell-matrix	3 columns; 5 pits (6.35 mm)						
	QT	Alluvial fan	47-56	0.3-0.4	Sandy/Rocky	Open air Soil-matrix	Profile 3C: Unit 5 Bloque 3: Units 5B; 8 (3.175 mm)						
	QLB	Middle part of a ravine	170	2	Sandy/Rocky	Open air Shell-matrix	N4; N5; N6 (3.175 mm)						
	CV3	Mouth of a ravine	25	0.3-0.4	Sandy	Open air Shell-matrix	CV3-P1; CV3-P2 (2, 1, <1 mm)						
AC	LC13	Mouth of a ravine	260	4	Sandy	Open air Shell-matrix	N23/W07; N54/W05 (2 occupational levels) (n/i)						
	PN-9	Marine terrace	25	2	Sandy/Rocky	Rock shelter Soil-matrix	3 units; 2 pits (2-3 mm)						
	224-A	Marine terrace	20	0.6	Rocky	Rock shelter Soil-matrix	3 units; 2 pits (2-3 mm)						
	226-5	Slope next to mouth of a ravine	100	0.3	Rocky	Rock shelter Soil-matrix	Units (A; B; C; D) (2-3 mm)						
	MC	Marine terrace	20	0	Sandy	Open air Shell-matrix	Units (2; 3; 4A; 4B; 5) (2-3 mm)						

2007; Salazar et al. 2015, 2018). Fish remains came from three 1 × 1 m units (Unidad 1, 2, and 3) and two 0.5 × 0.5 m pits (Pozo 1 and 2).

- Alero 224-A: this site consists of a rock shelter located on a littoral terrace at ~20 masl and 0.6 km from the present coastline, characterized by a rocky beach (Salazar et al. 2018). Human occupations date from the Early and Late

Holocene. Ichthyoarchaeological data came from three units (Unidad 5, 6, and 7) and two pits (Pozo 1 and 2).

- Alero 226–5: this rock shelter is situated on a slope next to the mouth of Quebrada Cascabeles, at ~100 masl. This site is less than 0.3 km from the actual shoreline, characterized by a rocky beach (Salazar et al. 2018). Human occupations are from the Early and Late Holocene (Casteletti 2007). The fish remains studied here came from units A, B, C, and D (Casteletti 2007; Salazar et al. 2018).
- Morro Colorado (MC): an open-air site located on a 20 m rocky promontory, next to a sandy beach. This site presents a continuous cultural sequence from the end of the Early Holocene until the Late Holocene (Andrade and Salazar 2011; Salazar et al. 2018). The ichthyoarchaeological data came from five units (Unidad 2, 3, 4A, 4B, and 5) and a column (Rebolledo 2017).

Materials and methods

We generated a new database to include fish information from publications and gray literature available from 1977 to 2021 (Llagostera 1977, 1979; Llagostera et al. 1997; Sandweiss et al. 1989, 1998; deFrance and Umire 2004; Casteletti 2007; Béarez 2012; Reitz et al. 2016; Rebolledo 2017; Salazar et al. 2018; Rebolledo et al. 2021). All data were integrated into a single database based on three types of information: regional, archaeological, and ichthyoarchaeological. Contextual regional information includes the spatial position with regards to the two types of coast: Exorheic and Arheic. The archaeological information comprises the type of site and chronology, integrating radiocarbon dates available from published papers. Radiocarbon dates were calibrated using ShCal20 and Marine20 curves in OxCal (Heaton et al. 2020; Hogg et al. 2013). It is important to note that the radiocarbon dates were selected according to a margin of error ≤ 100 years (Table 2). Radiocarbon dates from La Chimba 13 were not considered since the margin of error exceeded 100 years; therefore, we have considered this archaeological site to be part of the Early Holocene.

Additionally, archaeological information included stratigraphical data from the sites. In this regard, layers and/or levels have been considered, as well as the excavated area and cubic meter of the sample matrix (m^3). The latter has been considered when evaluating the compatibility between fieldwork methods and representativity regarding site size.

Concerning the ichthyoarchaeological information, all scientific names have been standardized and updated following Fricke et al. (2020). In those cases where taxa could not be identified, we have labeled them as “indeterminate” and have not considered them during the analysis. Additionally, we have used the available quantitative data

associated with archaeozoological indices and the ethological information related to each species. We have also considered NISP (Number of Identified Specimens) and MNI (Minimum Number of Individuals) (Casteel 1974; Grayson 1984). Almost all sites presented both indices, with the exception of La Chimba 13, where fish information is restricted to otoliths and vertebrae. However, we have still decided to integrate this site and interpret it as a special case. As excavation areas differ between sites, we have combined the NISP and MNI per excavated volume in order to calculate the density of fish remains per m^3 (Jerardino 1995; Zangrando 2009), and we have also included the fish weight in those cases where information was available. Moreover, we have incorporated the richness and ubiquity index (U_i) in order to evaluate the presence of fish species from a regional perspective through time. The richness corresponds to the number of taxa counted at an archaeological site (Grayson 1984). As this index is directly affected by the size of excavation units (Grayson 1984; Cruz-Urbe 1988), it is mandatory to be cautious when analyzing the tendencies of fish assemblages between archaeological sites. For this reason, we also have compared richness with NISP and MNI.

The ubiquity index (Popper 1988), widely used in archaeobotanical studies, measures the presence or absence of a taxon in the total number of analyzed samples. This index is calculated as the percentage of samples in which a taxon is found, with values ranging from 0 (taxon not observed) to 1.00 (taxon observed in every sample or feature) (McKechnie and Moss 2016; Diehl 2017). Following Diehl (2017), the ubiquity index formula is:

$$U_{\text{taxon}} = N_{\text{taxon}} / N_{\text{total}}$$

In this case, U_{taxon} corresponds to the measured ubiquity of the fish taxon, N_{taxon} is the number of sites where the taxon appeared, and N_{total} corresponds to the total number of archaeological sites.

We have also included the habitat and ecology of the identified fish species. Four types of littoral allow the classification of fish taxa: (1) coastal-sandy; (2) coastal-rocky; (3) neritic-pelagic; and (4) pelagic-oceanic. These categories have been linked to the fishing techniques commonly used for each species.

Results have been divided into two sections: archaeological and fish standardization. The former is essential for the analytical procedures required for the second, since the “degree” of standardization of archaeological data permits comparative analysis between ichthyoarchaeological assemblages. Data integration has been summarized following spatial and chronological scales in order to identify differences and similarities between the types of coasts, as well as variations and continuities throughout the sequence.

Table 2 Radiocarbon dates (100 years) per archaeological site. Radiocarbon dates from La Chimba 13 were not considered for calibration

Site	Lab. no	Material	14C yr. BP	Reference
QJ-280	1959	Charcoal	7690 ± 100	Sandweiss et al. 1998
	1958	Charcoal	7620 ± 100	Sandweiss et al. 1998
RS	SI-6784	Shell	7675 ± 60	Sandweiss et al. 1989
	PITT-0142	Charcoal	7415 ± 65	Sandweiss et al. 1989
QT	108692AMS-97	Charcoal	10,750 ± 80	deFrance and Umire 2004
	172645AMS-01	Charcoal	10,690 ± 60	deFrance and Umire 2004
	160706AMS-01	Charcoal	10,660 ± 80	deFrance and Umire 2004
	122821AMS-98	Charcoal	10,510 ± 50	deFrance and Umire 2004
	160707AMS-01	Charcoal	10,050 ± 90	deFrance and Umire 2004
	172615AMS-01	Charcoal	9010 ± 40	deFrance and Umire 2004
	109354Conv-97	Charcoal	7990 ± 80	deFrance and Umire 2004
QLB	SacA 7591	Charcoal	7390 ± 35	Fontugne 2012
	GifA 100,342	Charcoal	7880 ± 90	Fontugne 2012
	GifA 100,345	Charcoal	7980 ± 90	Fontugne 2012
	SacA 7595	Charcoal	8235 ± 35	Fontugne 2012
	GifA 102,444	Charcoal	8260 ± 80	Fontugne 2012
	Gif-11738	Charcoal	7280 ± 60	Fontugne 2012
	GifA 102,445	Charcoal	8120 ± 90	Fontugne 2012
CV3	ANU31016	Charcoal	8420 ± 40	Santoro et al. 2017 (from Carter 2016)
	UGAMS 10,516	Wood	8260 ± 30	Santoro et al. 2017 (from Roberts et al. 2013)
	ANU31014	Charcoal	8075 ± 40	Santoro et al. 2017 (from Carter 2016)
LC13	P-2702	Charcoal	9400 ± 160*	Llagostera 1977
	P-2702	Charcoal	9680 ± 160*	Llagostera 1977
PN-9	D-AMS 008,355	Charcoal	9813 ± 37	Salazar et al. 2018 (from Salazar et al. 2015)
	D-AMS 011,300	Charcoal	9489 ± 37	Salazar et al. 2018
224-A	UGAMS 13,089	Shell	10,530 ± 30	Salazar et al. 2018 (from Salazar et al. 2013)
	D-AMS 018,343	Charcoal	10,441 ± 44	Salazar et al. 2018
	D-AMS 018,344	Charcoal	9955 ± 33	Salazar et al. 2018
226-5	Beta-190672	Shell	10,290 ± 60	Salazar et al. 2018 (from Castelleti 2007)
	Beta-190671	Shell	10,040 ± 60	Salazar et al. 2018 (from Castelleti 2007)
MC	UGAMS 13,094	Charcoal	7470 ± 30	Salazar et al. 2018 (from Salazar et al. 2015)

Results

Archaeological standardization: calibration of the radiocarbon dates and excavated volume

To standardize the information and identify similarities and differences with a diachronic perspective, Fig. 2 shows the radiocarbon dates according to ~ 1000 year time slots, starting at the Final Pleistocene–Early Holocene transition until the Early–Middle Holocene transition. According to the radiocarbon dates, two sites were occupied during 13,000 and 12,000 years cal BP (Quebrada Tacahuay and Alero 224-A). Following Reitz et al. (2016), we also include Quebrada Jaguay in this interval. Later, the period between 12,000 and 11,000 years cal BP is only represented by Arheic coast sites: Paposo Norte 9, Alero 224-A, and Alero 226–5. Even though the following interval

presents radiocarbon dates from Quebrada Tacahuay and Paposo Norte 9, there is no ichthyoarchaeological information for this time period. In fact, available fish data for the Exorheic coast come from the Quebrada Jaguay and La Chimba 13 sites, although their radiocarbon dates could not be calibrated (Llagostera 1977; Reitz et al. 2016). During the 10,000–9000 years cal BP interval, we found only three sites from the Exorheic coast: Quebrada Tacahuay, Quebrada Los Burros, and Caleta Vítor 3. Lastly, the interval 9000–8000 years cal BP is represented by the Quebrada Jaguay, Ring Site, Quebrada Tacahuay (without fish data), Quebrada Los Burros, Caleta Vítor 3, and Morro Colorado sites.

Regarding the distribution of radiocarbon dates, some tendencies were observed: a major concentration of remains from 9000 to 8000 years cal BP, while the period between 11,000 and 10,000 presented the fewest.

OxCal v4.4.3 Bronk Ramsey (2021); r:5 Atmospheric data from Hogg et al (2020)

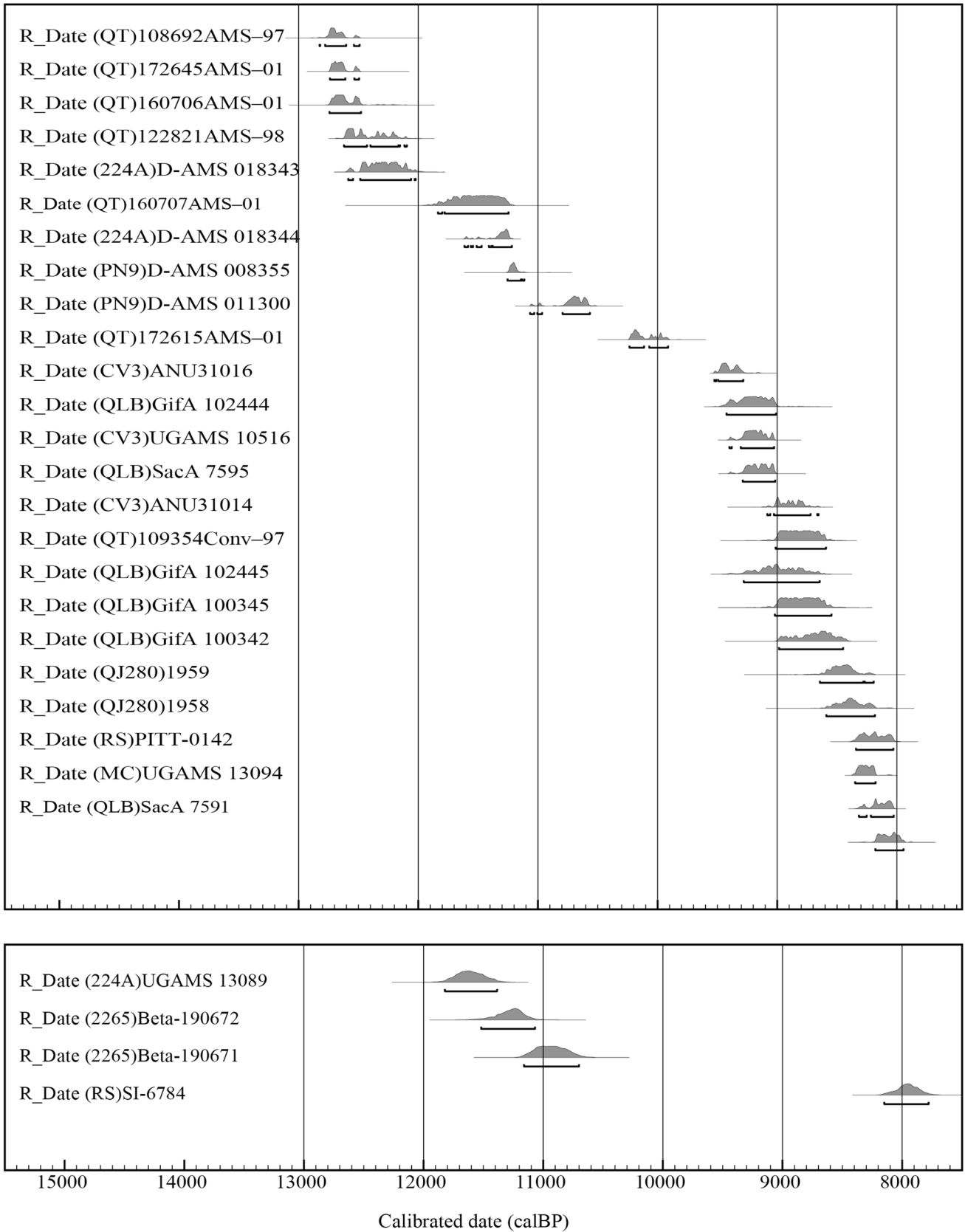


Fig. 2 Calibrated radiocarbon dates from Terminal Pleistocene and Early Holocene occupations: A—terrestrial samples; B—marine samples

The available data from the selected archaeological sites revealed important disparities. The Quebrada Jaguay, Ring Site, and Quebrada Tacahuay sites provided no information on excavated volumes, but the fieldwork data from the Quebrada Los Burros site enabled an estimation to be made. This was also the case for the Caleta Vítor 3, La Chimba 13, Paposo Norte 9, Alero 224-A, Alero 226–5, and Morro Colorado sites (Table 3). However, given the problems associated with the ichthyoarchaeological study of the La Chimba 13 site, i.e., that only otoliths were counted (see the “Materials and methods” section), we decided not to include this site in the fish density estimate.

Fish standardization: fish density, richness, and ubiquitous index

In total, NISP amounted to 14,669 and MNI resulted in 3752 individuals (Appendix 1). Most of the NISP came from the Exorheic Coast (53.22%) while MNI was greater along the Arheic coast (57.19%). Although the excavated volume is not available for all sites, we decided to perform an estimation of fish density based on the analysis. Figure 3A shows the Alero 226–5 site with the greatest excavated volume, followed by Alero 224-A, and Quebrada Los Burros, while Caleta Vítor 3 presents the lowest value. However, these tendencies change when considering fish density: Morro Colorado presents the highest value, followed by Quebrada Los Burros, and Alero 224-A (Fig. 3B). Additionally, the total fish weight at Morro Colorado and Quebrada Los Burros is considerably higher than the other sites (Fig. 3C).

The taxonomic compositions of all archaeological sites from the Early Holocene in the Atacama Desert coast are represented by 63 fish taxa. Depending on each archaeological site, taxa details are described according to family, genus, and/or species (Appendix 1). It is important to mention that even though a standardization of scientific names was made, there are still some specimens that could not be

included in the taxonomic classification, such as billfishes and Chondrichthyans.

The 63 fish taxa recognized are differentially distributed in each archaeological context, with a higher number of species at the Morro Colorado site ($N=34$), and fewer ($N=5$) at Quebrada Tacahuay and Alero 226–5. Except for Alero 226–5, the Arheic Coast presents the highest number of taxa at its sites. The richness of Arheic coast sites is similar to the Quebrada Los Burros site, the only one with more than 20 species in the northern area (Fig. 4). When comparing richness with NISP and MNI, there are some similarities between them (Fig. 5): the higher the NISP, the higher the richness. Quebrada Los Burros and Morro Colorado present the highest values in these three indices, with a richness of over 25 species. However, although Alero 224-A does not have a high NISP or MNI, it shows a high richness ($N=31$). The higher richness in 224-A is mainly due to the presence of a greater number of coastal-rocky taxa (Appendix 1), possibly reflecting a more intensive exploitation of this habitat and a reduced exploitation of the pelagic domain. On the other hand, those archaeological sites with a lower richness present lower NISP and MNI values, such as Quebrada Tacahuay and Alero 226–5, both with 5 species. The exception is Caleta Vítor 3 ($N=10$), with a richness close to that of Quebrada Jaguay ($N=12$).

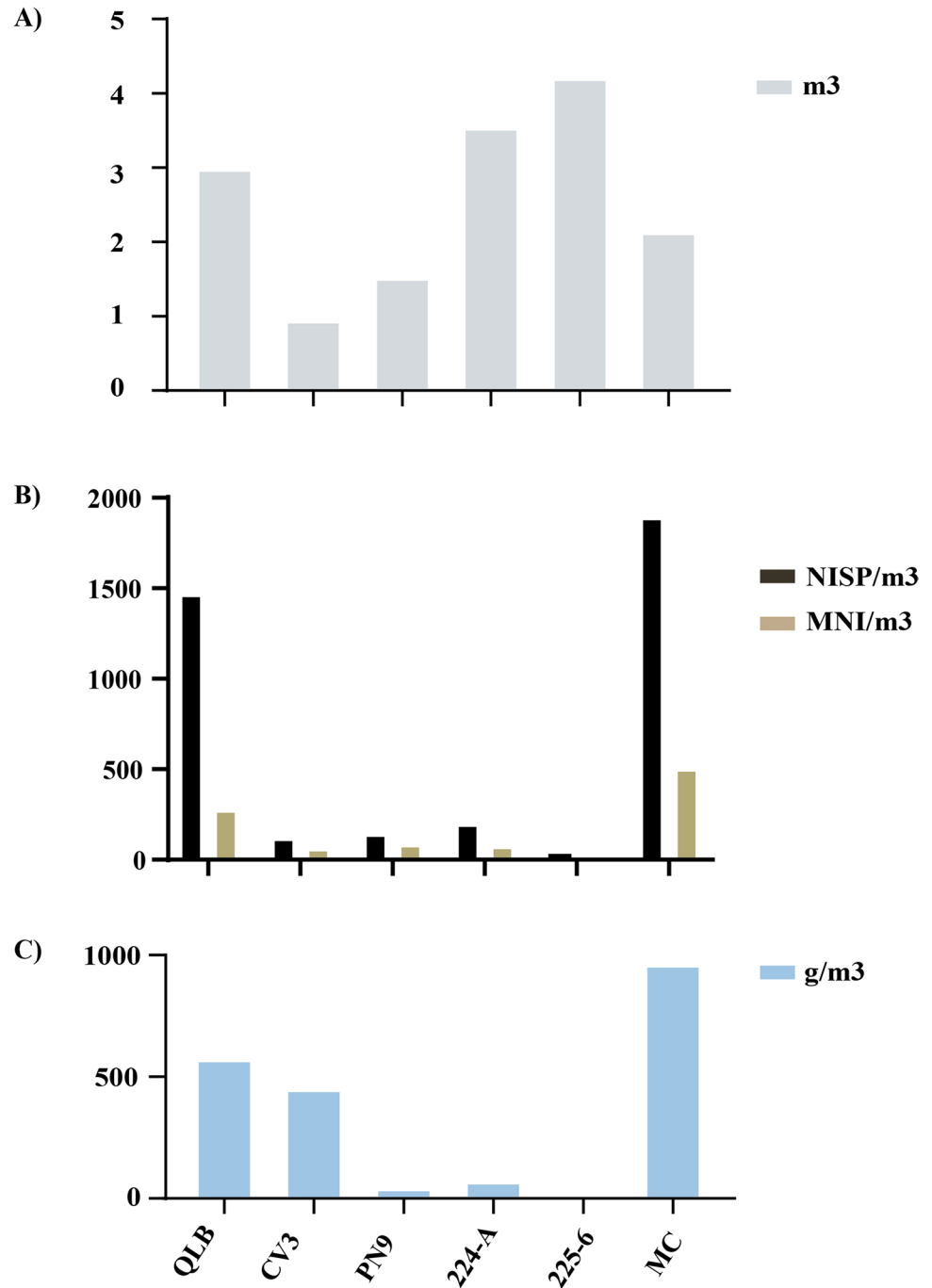
Since the fish density estimation could not be carried out for all archaeological sites, the ubiquity index (Ui) was used for comparison. The most ubiquitous taxa are sciaenids with *Callaus deliciosa* and *Cilus gilberti*, then the Carangidae family, which is almost exclusively represented by *Trachurus murphyi*. The Latridae (*Chirodactylus variegatus*), Haemulidae (*Anisotremus scapularis* and *Isacia conceptionis*), and Serranidae (*Paralabrax humeralis*) families are also well represented (Fig. 6). As shown in Table 4, there is an inverse relationship between the number of taxa and the ubiquity index.

Table 3 Quantitative information available on contextual and ichthyoarchaeological data

Area	Site	m ³	NISP	MNI	NISP/m ³	MNI/m ³
EC	QJ-280	-	1091	417	-	-
	RS	-	576	179	-	-
	QT	-	1538*	39	-	-
	QLB	3.08	4511	843	1465	274
	CV3	0.939	110	57	117	61
AC	LC13	5.154	-	545**	-	-
	PN-9	1.5135	212	126	140	83
	224-A	3.535	688	257	195	73
	226–5	4.2	149	53	35	13
	MC	2.1284	4023	1064	1890	500

*Includes total number of fragments(not necessary with taxonomic identification). **Considers only otoliths and vertebrae

Fig. 3 Excavated volume and fish density considering B—NISP/m³ and MNI/m³, and C—g/m³ per archaeological site



With only the exception of billfishes and *K. pelamis*, which thrive in pelagic-oceanic waters, the fish taxa identified in the total assemblage inhabit coastal and neritic-pelagic zones. Between regions, taxa richness does not show important differences: the Exorheic coast is mostly represented by neritic-pelagic and coastal-sandy taxa, while the Arheic coast is mostly represented by neritic-pelagic fish (Appendix 1). Major differences appear when considering habitat richness through the

chronological sequence: on the coast, rocky littoral areas present a decrease from 13,000 to 9000 years cal BP, and an increase around 8000 years cal BP. Regarding sandy areas, the highest values are found during 11,000–10,000, and 9000–80,000 years cal BP. It is interesting to note the progressive augmentation of a variety of species from the neritic-pelagic area, while the oceanic pelagic species are found during 12,000–11,000 and 9000–8000 years cal BP (Fig. 7).

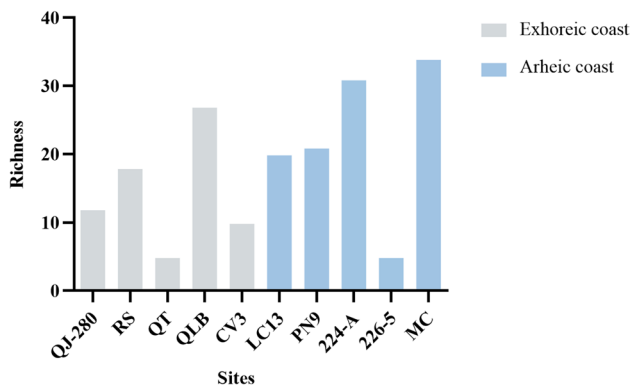


Fig. 4 Richness according to the region and archaeological site

The highest richness of coastal-rocky fish is observed at the Alero 224-A site between 13,000 and 12,000 years cal BP, with a NISP predominance of *Scartichthys* spp. At the Exorheic sites, Quebrada Jaguay presents a major richness of coastal-sandy species, while neritic-pelagic fish are mostly represented in Quebrada Tacahuay, with a major NISP abundance of Engraulidae. The most commonly used fishing techniques for this type of species are hook and line and fishing nets; to a lesser extent, the presence of some species that inhabit the intertidal zone suggests the possible use of scoop nets and spears.

Between 12,000 and 11,000 years cal BP, a similar representation of coastal-rocky fish is observed at the Paposo Norte 9, Alero 224-A, and Alero 226-5 sites. In the first two sites, the highest NISP values corresponds to *Scartichthys* spp., while *Semicossyphus darwini* is the most represented species in the latter. In addition, it is important to note that Paposo Norte 9 and Alero 226-5 also have a good representation of coastal-sandy taxa (sciaenids). During this period, species caught mainly by hook and line are still predominant, while those evidencing scoop net and spear fishing are in the minority.

Subsequently, from 11,000 to 10,000 years cal BP, Quebrada Jaguay only presents three species from the

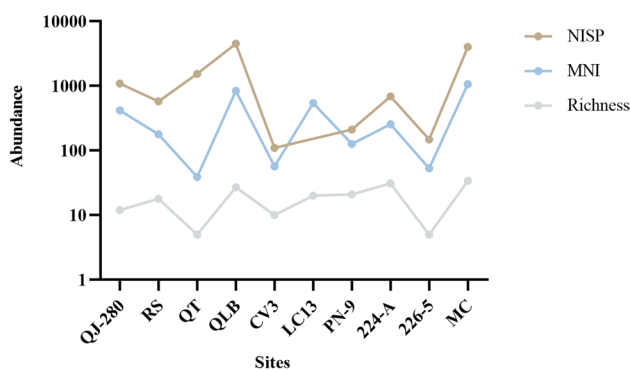


Fig. 5 Distribution of richness, NISP, and MNI according to archaeological sites

coastal-sandy zone, with the largest NISP corresponding to *C. deliciosa*. In the case of La Chimba 13, the most represented fishing areas are the rocky coast and the sandy coast, with a predominance of *A. scapularis* and *Cynoscion analis*, respectively. In terms of fishing techniques, fish taxa suggest the use of hooks and lines, nets and spears.

During the 10,000–9000 years cal BP occupations, even though there is a higher richness of neritic-pelagic taxa in Quebrada Tacahuay, Quebrada Los Burros, and Caleta Vitor 3, there is an NISP predominance of coastal-sandy species, especially with *C. deliciosa*. As in the previous period, possible fishing techniques used correspond to hooks and lines, nets, and spears.

Finally, during 9000–8000 years cal BP, Quebrada Jaguay presents a major proportion of coastal-sandy fish species, and Quebrada Los Burros has an equal amount of coastal-sandy and neritic-pelagic taxa, with an NISP predominance of the former due to the presence of *C. deliciosa*. The neritic-pelagic zone is also most represented at Caleta Vitor 3 (with *E. ringens*), and particularly in Morro Colorado, where an absolute NISP predominance of *T. murphyi* is observed. Finally, the coastal-rocky area is well represented at the Ring Site with *C. variegatus*. In terms of capture techniques, there was probably a preference for fishing nets, but hooks and lines were also employed. The presence of coastal-rocky species suggests the use of scoop nets, and the presence of large pelagic-oceanic taxa suggests the additional use of harpoons.

Discussion

Data standardization as an archaeological problem

Data standardization arises as one of the main problems when developing a large-scale study, whether it is a regional approach or a historical sequence. In the case of the Final Pleistocene–Early Holocene archaeological sites along the Atacama Desert coast, ichthyoarchaeological information needs to be evaluated using contextual data. This is especially important not only to compare assemblages, but also to evaluate the possibility of being able to make such comparisons.

The calibration of radiocarbon dates allows for the positioning of each archaeological site and its occupations in a defined range of time. In our case study, we positioned archaeological sites within 1000-year time slots, considering this division as a tool to order the data but not as fixed categories of human occupations. The time range begins around 13,000 cal BP, and continues to approximately 8200 cal BP. This wide time interval might hinder a detailed approach, but it does give us a general picture of the human communities' dynamics and their fishing practices. Additionally, it

Fig. 6 The three most ubiquitous species throughout the sequence

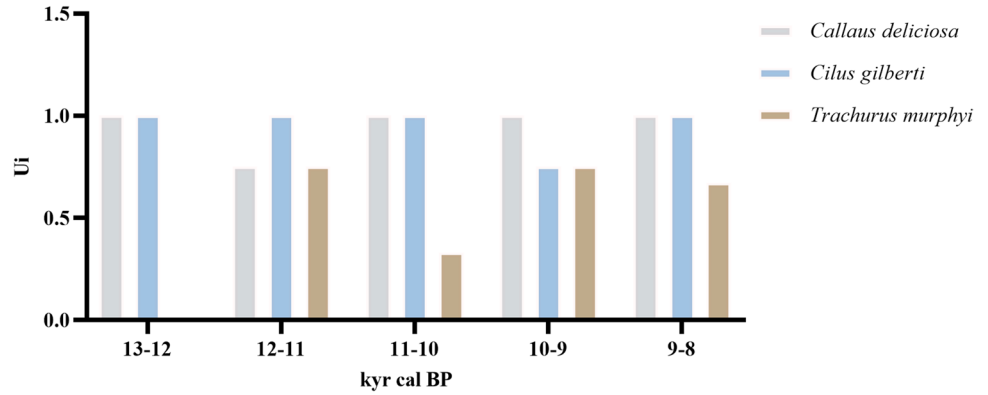


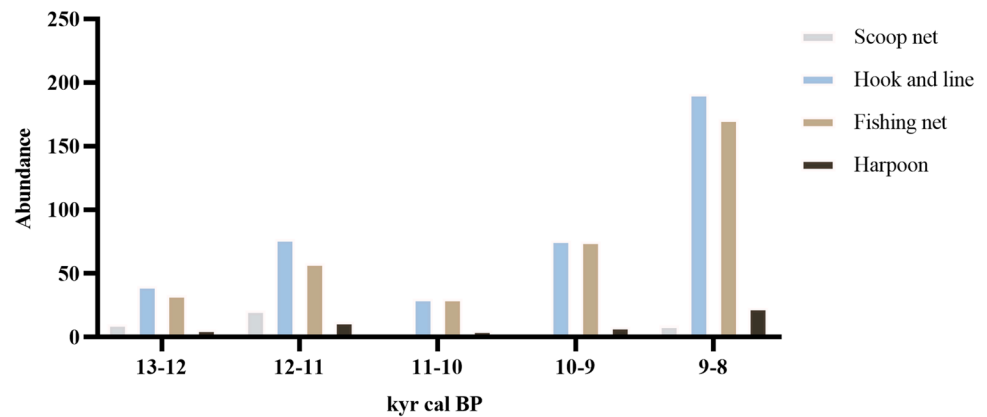
Table 4 Ubiquity index (Ui) and number of taxa (N)

UI	N	Taxa
0.9	2	<i>Callaus deliciosa</i> ; <i>Cilus gilberti</i>
0.8	1	<i>Trachurus murphyi</i>
0.7	3	<i>Anisotremus scapularis</i> ; <i>Chirodactylus variegatus</i> ; <i>Isacia conceptionis</i> ; Sciaenidae
0.6	2	<i>Paralabrax humeralis</i>
0.5	4	<i>Semicossyphus darwini</i> ; <i>Pinguipes chilensis</i> ; <i>Cheilotrema fasciatum</i> ; <i>Sarda chiliensis</i>
0.4	6	<i>Engraulis ringens</i> ; <i>Girella laevisfrons</i> ; Labrisomidae; <i>Labrisomus philippii</i> ; <i>Paralichthys adpersus</i> ; <i>Sebastes oculatus</i>
0.3	9	<i>Galeichthys peruvianus</i> ; <i>Scartichthys</i> spp.; Clupeidae; <i>Graus nigra</i> ; <i>Mugil</i> sp.; <i>Cyonoscion analis</i> ; <i>Acanthistius pictus</i> ; <i>Hemilutjanus macrophthalmos</i> ; Serranidae
0.2	16	<i>Aplodactylus punctatus</i> ; <i>Scartichthys gigas</i> ; <i>Scartichthys viridis</i> ; <i>Seriola lalandi</i> ; <i>Ethmidium maculatum</i> ; Engraulidae; <i>Thyrstites atun</i> ; <i>Sicyases sanguineus</i> ; Chondrichthyes; <i>Auchenionchus microcirrhis</i> ; <i>Auchenionchus</i> spp.; <i>Genypterus</i> spp.; <i>Paralichthys</i> sp.; <i>Chromis intercrusma</i> ; <i>Paralonchurus peruanus</i> ; <i>Katsuwonus pelamis</i>
0.1	21	<i>Odontesthes regia</i> ; <i>Bovichtus chilensis</i> ; Carangidae; <i>Seriola lalandi</i> ; <i>Carcharhinus</i> sp.; <i>Sardinops sagax</i> ; Clupeiformes; Haemulidae; Billfish; Kyphosidae; Labridae; <i>Auchenionchus variolosus</i> ; <i>Merluccius gayi</i> ; <i>Prolatilus jugularis</i> ; <i>Micropogonias altipinnis</i> ; <i>Robaloscion wieneri</i> ; <i>Scomber japonicus</i> ; Scombridae; <i>Scorpaena histrio</i> ; <i>Mustelus mento</i>

poses interesting questions concerning the prioritization of dating the “earliest” occupations over others, a phenomenon already observed in other areas (e.g., Campbell and Quiroz 2015). However, there is also a concentration of dates between 9000 and 8000 cal BP which could elucidate other factors affecting the presence of human occupation, as well as demographic variations, or differential use of space and archaeological site functions. In any case, these proposals—previously discussed by several authors—must be analyzed with more information.

In addition to the information on radiocarbon dating, the excavation data allows us to evaluate other aspects relating to the ichthyoarchaeological recovery methods. This standardization exercise can open new debates about the possibility of making comparisons in the Atacama Desert coast, and the need for collaborative work between different research teams. This will undoubtedly lead to a broader discussion about how to work with this kind of data, as well as its association with other resources such as invertebrates, seabirds, mammals, and artifacts (e.g., fishing gear).

Fig. 7 Fishing strategies according to taxa presence through time



The problem of data standardization is not new in archaeozoology. In this regard, O'Connor (1985: 29) indicates that “the quantification problem might be better approached by considering frequency rather than abundance.” Following this author, we chose to focus on the frequency of taxa, using fish density, richness, and the ubiquity index depending on the variables that we were comparing. Regarding fish density, this presents problems due to disparities of contextual information, which hinder the estimation of excavated volume. Even though this measure is normally recorded in fieldwork diaries, the information is often missing when results are published. This could be a useful tool, not only to standardize the archaeozoological information but also to deepen the discussion about defining shell middens, especially in the case of coastal contexts.

Richness gives us a first approach to characterize the total assemblage. It allows us to identify common elements among the assemblages, and the standardization of species names allows us to compare their presence or absence in a particular sample. This first stage was essential for applying the ubiquity index and to identify the most ubiquitous species in the total assemblage, but also to analyze data with spatial and temporal perspectives.

Despite the methodological difficulties we had to face during this analysis, it is always convenient to work with different types of indices (cf. Zohar et al. 2018). In addition to cultural, natural, and/or taphonomic issues, other variables such as fieldwork procedures, laboratory analysis and the way the results are published, also have an impact on archaeological interpretations at local and regional scales.

Fish standardization in the Atacama Desert coast

Previous analyses have determined the way we standardize ichthyoarchaeological materials during the early coastal occupations registered along the Atacama Desert coast. NISP and MNI have been considered, but the disparities of fish data hinder a comparison between samples using

their absolute frequencies. To overcome those difficulties, we have emphasized the distribution of taxa and fish habitat representation considering latitudinal and chronological differences.

Disparities in the contextual information available have hindered a regional comparison using fish density. For those sites from which data were compared, it must also be noted that the excavated volume was strongly influenced by the site's function and formation processes. In this regard, some authors have pointed out the importance of depositional processes, as well as the type of matrix for each context, which affect the preservation of fish remains through time (Jerardino 1995; Zangrando et al. 2021). In our case study, open air sites with a predominant shell matrix presented higher fish density values than rock shelter sites with a soil matrix. For this reason, interpretations concerning this type of index should be treated with caution.

Even though the fish density estimation could not be applied to all sites, tendencies associated with the excavated volume show interesting differences between them. Considering the total fish weight, Morro Colorado presents the highest value, followed by Quebrada Los Burros, both chronologically located between 10,000 and 8000 years cal BP. In the case of Caleta Vitor 3, according to Table 3, this site presents the smallest screen size of all the assemblages, which could affect the results associated with an abundance of fish remains and taxonomic representation, especially for small pelagic fish (Rebolledo et al. 2021). Beyond spatial differentiation between coasts, it seems that temporal variations will be more relevant to understand fish distribution in archaeological sites.

Along with fish density, other indices focused on the taxonomic distribution were developed. The 63 fish taxa evidence a greater richness within the total assemblage for a region with temperate waters, even though the species are differentially distributed. Here, it is important to note the bias of this index regarding the NISP and MNI values at each archaeological site, and to examine the trends relating

to each type of coast. In terms of richness, no major differences were found between the two coasts, although the values appeared to be somewhat higher and maximum biodiversity reached 34 species at one site (MC) on the Arheic coast. This shows the ecological homogeneity of the two coastal areas and supports the choice to study the Atacama Desert coast as a whole. Despite the consistency between the three indices, there are some interesting exceptions: Caleta Vitor 3 on the Exorheic coast and Alero 224-A on the Arheic coast. Caleta Vitor 3 presents a high richness value despite the low NISP and MNI, a phenomenon that could be partially explained by the recovery methods already mentioned, which allowed the identification of small fish species (Rebolledo et al. 2021). For Alero 224-A, a larger excavation volume could explain the identification of a wide variety of species, but this is not completely consistent with the NISP and MNI values. It may be that the sample size has allowed the necessary size to be reached and exceeded in order to obtain the maximum diversity represented at this site. With this in mind, a minimum of 700 NISP could be recommended for the analysis of fish remains in the area, to avoid the risk of being affected by the sample size bias.

The ubiquity index has made it possible to establish comparisons through the presence/absence of the species, and the recurrence of certain fish in the total archaeological record. The three most represented species ($U_i > 0.8$) reflect the relevance of Sciaenidae and Carangidae in the data and archaeological interpretation. It is worth asking whether this trend is related to the methods of recovery and analytical procedures of bones and otoliths, pre- and post-depositional taphonomic processes, fishing techniques, abundance, and variability of the species in the sea, human food preferences, or a combination of these factors. Although we are not considering the taphonomic processes of fish remains identified in this analysis, the question about the over and/or underrepresentation of certain species should be posed. For instance, the available data does not permit the comparison of this kind of information between archaeological sites, but it is possible to compare the U_i tendencies with the Survival and Recovery Index (SRI) proposed by Falabella et al. (1994). The species identified in our case study are part of SRI groups III (recovered only under special excavation procedures) to VI (best possibilities to recover). Furthermore, *S. violacea*, *T. atun*, *G. nigra*, and *Genypterus* spp. stand out as the species with lower U_i values, although they are well represented in terms of SRI. Regarding those species with the highest U_i values, it is interesting to note that the sciaenids dominate all the cultural sequences. This could be partially explained by the good bone and otolith preservation of *C. deliciosa* in deposits (Béarez 2012), its abundance throughout the year, and/or cultural preferences. This could also be related to the location of human settlements in areas

where the coastline is sandy and similarly exploited between 12,000 and 9000 years cal BP.

Concerning differences between the assemblages, there is little variation on the type of littoral represented along the Atacama Desert coast. Even though in both regions, the coastal species are well represented, there is a high number of rocky shore fish on the Arheic coast. This is consistent with the geographical features mentioned above, where the lithological composition suggests a northern coast with sandy substrate and a southern coast with a prevalence of rocky shores (Tapia et al. 2018). As a consequence, a variation of species dominance is observed: sciaenids are more present on the Exorheic coast, with the presence of *C. deliciosa* and *C. gilberti*. In the south, the Arheic coast is also dominated by sciaenids, but other families such as Haemulidae, Blenniidae, Paralichthyidae, and Carangidae are well represented. It is important to note that Carangidae is the most represented neritic-pelagic taxa, and its importance is primarily explained by Morro Colorado. The higher number of taxa, combined with the lowest diversity value in Morro Colorado, suggests that the main differences in the sample could be related to this site. In this regard, the predominance of Carangidae—and specifically *T. murphyi*—in Morro Colorado is one of the major variations in taxonomic distribution. The high percentage of this taxon at this site also affects the picture of the most exploited habitat during 9000–8000 years cal BP, when neritic-pelagic fish overtook nearshore fish from previous periods. In comparison with the Exorheic coast, Morro Colorado is contemporaneous with the latest occupations of Quebrada Los Burros and Caleta Vitor 3, two sites that present a considerable percentage of *T. murphyi*. This species is a particularly interesting case as it is already evidenced at Morro Colorado and plays a key role during the Middle Holocene, as well as at Quebrada Los Burros on the Exorheic coast and Zapatero on the Arheic coast (Béarez 2012; Rebolledo et al. 2016; Salazar et al. 2018).

Considering that the biogeographical background is similar in the Arheic coastal area, divergences between Morro Colorado and the other sites could be explained by its position in the occupational sequence. On a temporal scale, Morro Colorado dates fall in the transition from the Early to the Middle Holocene. At this time, an increase in SST has been registered by Flores and Broitman (2021) in Taltal (Arheic coast), which may have had a local impact on fish harvesting at this time. How this may have affected the northern area of the Atacama Desert coast is still an open question that needs to be answered in light of further palaeoecological and archaeozoological studies.

The comparative analysis has been adjusted to consider the characteristics of fish data and, as we have mentioned on several occasions, limitations in the data have not led us

to the detailed insights for which we were aiming. Even so, from the results obtained, it is possible to establish some guidelines regarding the fish capture strategies, as well as to propose future questions for regional ichthyoarchaeological studies. In this respect, the high variety of species can be understood as an “opportunistic catch” strategy, suggesting the use of coastal and maritime zones and their resources.

The wide variety of species and their ethological traits suggest the use of different fishing strategies. Among these, the possible use of hooks and lines and nets seems to be predominant over other techniques such as scoop nets, spears, or harpoons. Scoop nets and spears may have been used to catch fish in intertidal pools or along the beach, while harpoons would have been used from a boat to catch large pelagic fish as they struggle and need to be tired before they can be subdued. Concerning the most ubiquitous species, sciaenids and carangids are well represented throughout the sequence. Fish from both families live in schools, which facilitates their mass capture and the appearance of other species as by-catch. As other authors have inferred, this could reflect the use of nets, again evidencing the relevance of this fishing gear (Béarez, 2012; Disspain et al. 2016; Martens and Cameron 2019).

The spatial distribution does not seem to be as relevant as variations through the chronological sequence. At the beginning of the sequence, until 11,000 years cal BP, there was a major diversification of fishing strategies employed. In contrast, between 9000 and 8000 years cal BP, two strategies became predominant: fishing nets and hooks and lines, accompanied by a slight contribution from spearfishing. During this period, a major richness is also observed; thus, capture techniques could be related to the exploitation of fish on a larger scale. This behavior may be relevant for subsequent periods, especially during the Middle Holocene, where the presence of *T. murphyi* in the archaeological contexts eclipses the other species, associated with an intensification in fishing (Béarez 2012; Salazar et al. 2015, 2020; Rebolledo et al. 2016).

Conclusion

This study shows the fish composition of ten Terminal Pleistocene-Early Holocene archaeological sites on the Atacama Desert coast, between southern Peru and northern Chile. Methodological decisions to standardize data and develop a comparative study highlight the advantages and disadvantages of the archaeozoological method. This study also attempts to integrate environmental and archaeological information, to propose new lines of discussion about fishing harvesting through the Terminal Pleistocene and the end of the Early Holocene. It remains necessary to obtain further

information about palaeoclimatic features and archaeological contexts on both coasts, in order to understand fish harvesting during different time–space intervals. In addition, we need to increase our ichthyoarchaeological sample and improve available methodological tools to make better comparisons between assemblages. Further studies must include other lines of evidence, especially concerning marine (e.g., mollusks) and terrestrial resources. This could help explain how the trophic web has evolved from the earliest interactions with human communities throughout the chronological sequence, and also how different ecological conditions interact with cultural differences.

Finally, the standardization exercise presented here constitutes a synthesis generated from a compilation of ichthyoarchaeological data corresponding to the end of the Pleistocene and the beginning of the Holocene, using information from published papers and gray literature. This exercise is also, therefore, a reflection on the way we construct data and approach archaeological knowledge. Consequently, this information should be made available to a wider and more public audience, in order to build new bridges from which we can approach the past, where knowledge is constructed including all perspectives, allowing us to create new ones.

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Declarations

Competing interests The authors declare no competing interests.

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