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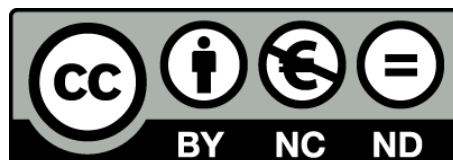
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Pre-Columbian Fishing on the Coast of the Atacama Desert, Northern Chile: An Investigation of Fish Size and Species Distribution using Otoliths from Camarones Punta Norte and Caleta Vitor

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Keywords

fishing, coastal Atacama Desert, zooarchaeology, otolith, Camarones Punta Norte, Caleta Vitor

Abstract

The bountiful marine resources of the northern Chilean coast offset the extreme aridity of the Atacama Desert in pre-Columbian times, underwriting permanent human occupation, and providing the basis for a long tradition of marine subsistence. We analysed fish otoliths (n=549) recovered from the sites of Camarones Punta Norte (occupied ca 7000–5000 years ago) and Caleta Vitor (occupied ca 9500–300 years ago) to investigate species distribution and changes over time. We also estimated the size of the fish based on relationships between otolith weight and fish total length (TL) obtained from modern samples of the predominant species, *Sciaena deliciosa*. The estimated size range of *S. deliciosa* from Caleta Vitor included fish that were significantly larger than those from Camarones Punta Norte, with the maximum TL (970 mm) almost double the modern maximum length documented. The fluctuating abundance of fish species and other marine taxa from Camarones Punta Norte indicates intense but sporadic use of the site over the span of occupation. In contrast, human occupation of the Caleta Vitor estuary is more continuous. Comparisons of the fish assemblages with a nearby contemporaneous site, Quebrada de los Burros in southern Peru, suggest that fishing technologies were similar along this section of the Pacific coast.

Introduction

The extreme aridity of the Atacama Desert in northern Chile led to a heavy reliance on marine resources as a source of food, as corroborated by palaeodietry studies (Aufderheide 1993, 1996; Pestle et al. 2015; Petruzzelli et al. 2012; Roberts et al. 2013). Even with the regional advent of agriculture ca 3500 years ago, the ocean continued to be essential to local subsistence (Núñez and Santoro 2011; Olguín 2014; Salazar et al. 2015). The Chilean sea, or the area of the Pacific Ocean west of the Chilean mainland, is a highly productive marine ecosystem due to the combined action of coastal upwelling and nutrients transported from the subantarctic region by the Humboldt Current (Bernal et al. 1983; Latorre et al. In press; Montecino and Lange 2009). In contrast to the scarce inland terrestrial and freshwater resources towards the Andes, the nearshore waters offer stable and predictable resources suitable for permanent human occupation. These resources provided pre-Columbian societies with a strong base on which to build a long-term tradition of coastal cultural systems sustained by marine subsistence (Grosjean et al. 2007; Llagostera 1979, 1992; Sandweiss et al. 1996, 1998; Valenzuela et al. 2015). In addition to these coastal resources, freshwater was available from springs that originated in the high Andes. The marine ecosystem had a low diversity of pelagic fish species with abundant but variable stocks, with variability associated with exploitation intensity and changes in environmental conditions (Andrade et al. 2014; Castro et al. In press; Olguín 2014; Olguín et al. 2014; Salazar et al. 2015; Yañez et al. 2001).

Today, the fishing industry remains important to Chile's economy; the western coast of South America produces more fish per unit area than any other region in the world (Montecino and Lange 2009). Stocks fluctuate dramatically, with the El Niño-Southern Oscillation (ENSO) mode of climatic variability having a strong influence on populations (Arellano and Swartzman 2010; Valdes et al. 2008). Investigations concerning past fish populations not only give insight into past occupants and environmental conditions of the area, but they are also essential in gaining an understanding of how fish stocks have changed over time and the impacts that human predation and changing climatic conditions have had on them. Documentary sources of fisheries data have limited time depth, whereas archaeological data can provide an indication of fish populations prior to industrialized fishing.

One way to examine the effects that habitat alteration and predation have had on fish stocks is through the analysis of fish otoliths from modern and archaeological samples, and an examination of changes through longer time scales. Archaeological otoliths have been used to determine species identification, season of fish death, and size, age and growth of individual fish, allowing inferences to be made regarding seasonality of site use, fishing methods, and cultural practices. When compared with modern samples, changes over time in fish population structure and species distribution can be investigated, thus, contributing significant information to the contemporary issues surrounding commercial harvesting of fish species. These data can also be used to better understand the past occupants of a site, their subsistence strategies, and movement within the landscape (for an overview of methods and applications, see Casteel 1976; Disspain et al. 2015). Here we examine species distribution and fish size based on fish otoliths from two sites along the coast of the Atacama, Camarones Punta Norte (CPN) and Caleta Vitor (CV), and investigate changes in fish size over time, as well as differences between the sites.

The Study Region and Sites

Camarones Punta Norte and Caleta Vitor are located within the hyperarid coastal strip of the Atacama Desert on the west coast of South America (Figure 1), which stretches approximately 1,150 km from southern Peru to the Copiapó River (~17–27°S). This strip is cut by the mouths of 10 narrow, steep-sided valleys running from the Andes in the east, cutting through the coastal cordillera to meet the sea (see Santoro et al. 2012 Figure 1). The coast is bounded by high cliffs (700–1000 m above sea-level) to the north and south of the coves.

The Atacama ranges to the east ascend from sea-level to more than 6000 m above sea-level in a distance of less than 200 km and are characterised by steep landscapes with diverse environmental conditions. The canyons conveying freshwater from the western slope of the high Andes to the coast across the Atacama Desert are today mostly devoid of surface water, with irrigation of the inner valleys consuming much of the sub-surface water that would otherwise reach the ocean. The present arid environment of the region seems unlikely to support intensive occupation, but palaeoenvironmental reconstructions indicate that there were plentiful water resources available to support human habitation along the coast during the Archaic period (Arriaza et al. 2001; Marquet et al. 2012; Rivadeneira et al. 2010). Particularly favourable environments were located around the estuaries of valleys, as opposed to the coastline that stretches south of the fertile coast, where minimal freshwater sources are available. Around the estuaries, rich and permanent marine resources are complemented with freshwater, land mammals, birds, freshwater shrimp, and fruits from trees. Vegetation today is mainly limited to valley floors, particularly adjacent to stream beds. These resources allowed for permanent habitation, with the occupants living and burying their dead on higher plateaus surrounding river deltas (Arriaza et al. 2001). The initial colonisation of the Atacama (11000–8000 years ago) coincided with a time of higher humidity and lower sea-levels, facilitating habitation in the area, while the fertile coast is argued to have been an ecological refuge around 5000 years ago during a time of increasing aridity (Arriaza et al. 2008; Gayó et al. 2015; Grosjean et al. 2007; Santoro et al. 2011). At this time, ENSO cycles brought warmer water flows that increased in frequency and magnitude later in the Holocene, which had a profound effect on the available marine biomass and coincided broadly with the appearance of agriculture in the region (Marquet et al. 2012; Rothhammer 2014; Sandweiss et al. 1996; Santoro et al. 2012; Williams et al. 2008).

Camarones Punta Norte is located 90 m above sea-level on the northern side of the mouth of one of the valleys conveying freshwater to the coast, the Valle de Camarones (Figure 1). The site is a small shell midden (area ca 4000m²) representing the accumulation of shell and other marine resources used by the prehistoric coastal population, the Chinchorro, or other social related groups. Seventeen radiocarbon dates across the period of occupation suggest continuous occupation of the site (see Gayó et al. 2015). People settled there ca 7000 years ago (Beta-251625, charcoal 6900±50 BP (Gayó et al. 2015 supp. info.)). The occupation of the site lasted until ca 5000 years ago (GaK-7130, charcoal 4950±210 BP (Gayó et al. 2015 supp. info.)), covering the Middle Archaic Period, which saw the inception of the Chinchorro culture. This occupation coincides with a productive time for the Pacific coast of northern Chile; there was an absence of mega El Niño, resulting in a prevalence of La Niña cold conditions, and an improved coastal marine biomass production. El Niño-like conditions, coinciding with a decrease in marine productivity, occurred from ca 5040–4150 cal. BP (Santoro et al. Under review-b). Camarones Punta Norte was initially excavated in the late 1970s (Dauelsberg et al. 1971 cited by Muñoz et al. 1993) and was reinvestigated by Santoro in 2006. Other sites at the mouth of the valley have also been subject to investigations (Arriaza et al. 2001; Muñoz et al. 1993; Rivera 1984; Rivera et al. 1974; Schiappacasse and Niemeyer 1984). Samples analysed in this study derive from the 2006 excavation season where a 0.7 m x 0.7 m square was excavated at the site to a

depth of 110 cm with 16 excavation units or layers. Excavated material was sieved through a 2 mm screen. Artefacts found at the site include shell and cactus spine fishhooks, knapped lithic material in the form of scrapers and knives, as well as faunal remains from fish, shellfish, sea birds, sea mammals – including a large number of fish otoliths. The Chinchorro, who occupied the site, were expert crafts people taking advantage of the rich biomass. They used tools such as fishhooks made of bone, shells and cactus needles, composite fishhooks, lines and nets made of reeds and cotton, elongated stone sinkers, bone prying tools, lithic knives, scrapers, awls and bifacial points (Arriaza et al. 2008; Santoro et al. 2005; Standen and Arriaza 2014).

Compared with Camarones Punta Norte, Caleta Vitor is a very large archaeological site. It is located at the mouth of a valley further north, Quebrada Vitor or Chaca (Figure 1), which consists of a broad sandy beach bounded at the north and south by cliffs reaching 800 m above sea level, and at the east by low sand dunes. The site is geographically and temporally extensive, consisting of different occupation sites, middens, mounds, and burials spanning from the Early Archaic Period to the Late Period (ca 9500–300 years ago) (see Table 1). The chronology of Caleta Vitor was determined from 65 radiocarbon dates obtained from marine (shell, feathers, and bones) and terrestrial (human bones, plant remains, and charcoal) organic material (Latorre et al. In press; Roberts et al. 2013; Santoro et al. Under review-b; Swift et al. 2015). Based on chronology, cultural, and physiographical features, this vast site was divided into seven archaeological areas labelled Caleta Vitor 1 to 7 (CV1 to CV7) (Figure 2). It was excavated as part of a larger research program by Chris Carter and Calogero Santoro, and was found to contain shell, bone, plant remains and otoliths, along with cultural material including (but not restricted to) lithics, ceramics, textiles, metal and wooden objects. Burials were not targeted but the remains of at least eight individuals were encountered during the excavations (Roberts et al. 2013; Swift et al. 2015). Excavation trenches were restricted to 0.5 m² and were spread across six of the site areas. Excavations were undertaken by hand following defined stratigraphic units. Trenches CV4/2, CV4/3, CV4/6 and CV6/2 did not display clear stratigraphy and were excavated in arbitrary 100 mm or 50 mm spits. Excavated material was sieved through a 1.7 mm screen. Areas of the site where otoliths were recovered from are CV1, a broad area shell midden with associated burials, CV2, which contains niche burials and a deep archaeological deposit, CV3, consisting of three artificial mounds with burials, CV4, an area of disturbed deposit with marked burials, and CV6, an extensive shell midden with burials. Table 1 presents minimum and maximum radiocarbon dates available for these individual areas within the site, with CV3 returning the oldest date, and CV6 returning the youngest. The site areas integrate stratigraphically overlapping chronologies rather than isolated and discontinuous periods of occupation.

Isotopic analysis of material from Caleta Vitor has been conducted (Roberts et al. 2013) with results indicating that the diets of occupants of the site were dominated by marine-based foods, predominantly from upper trophic levels (e.g., marine fish, sea lions, sea birds). Roberts et al. (2013) also provide a detailed background to the occupation of the site. Additionally, human remains from the site have been subjected to trace element analysis, revealing elevated levels of arsenic, which was most likely ingested through contaminated drinking water (Swift et al. 2015), and a radiocarbon dating program has been conducted, which investigates regional marine reservoir values (Latorre et al. In press). The analysis of otoliths presented here is part of this broader interdisciplinary project.

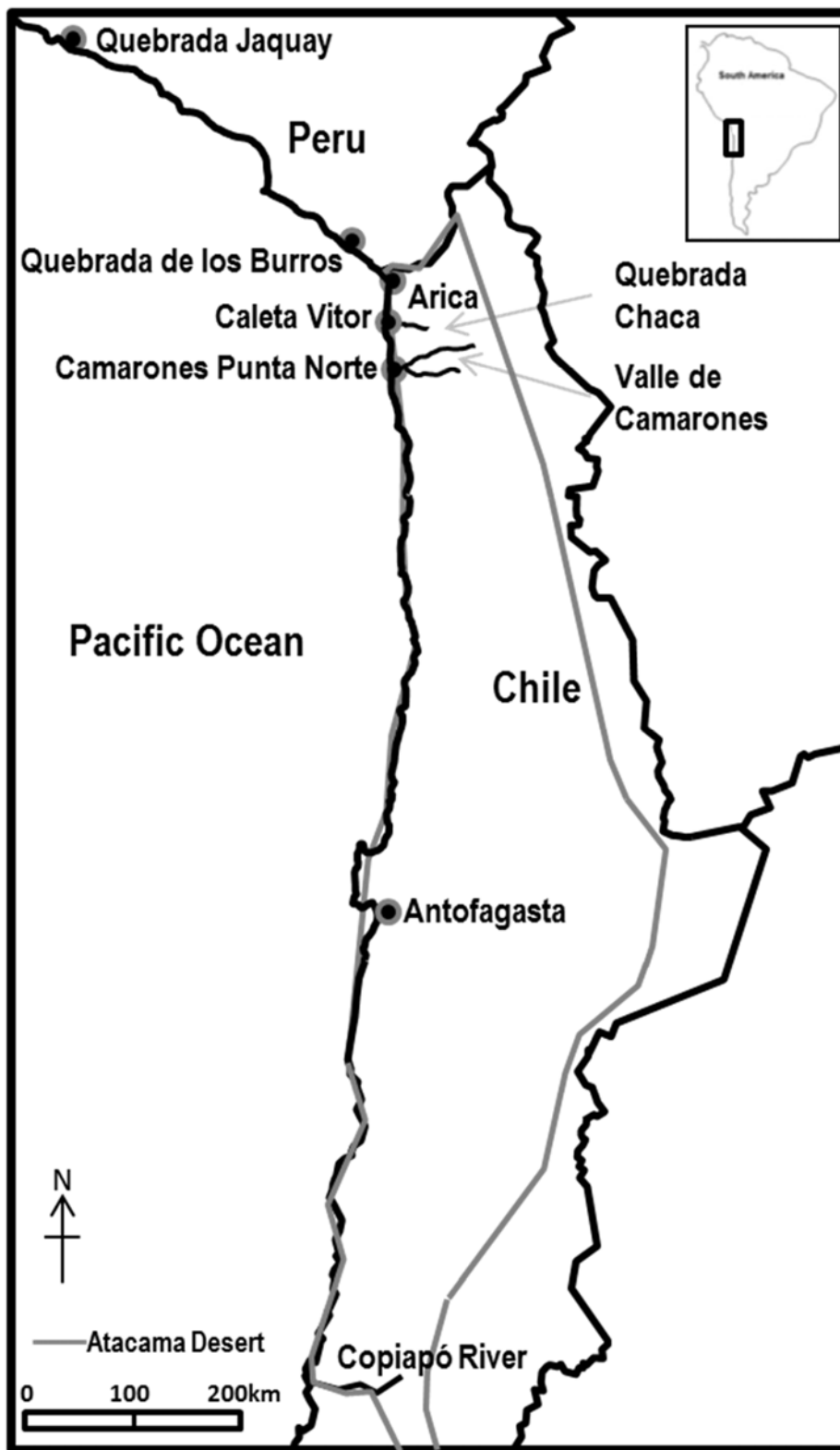


Figure 1. Map of the Atacama Desert showing site locations and places mentioned in the text.

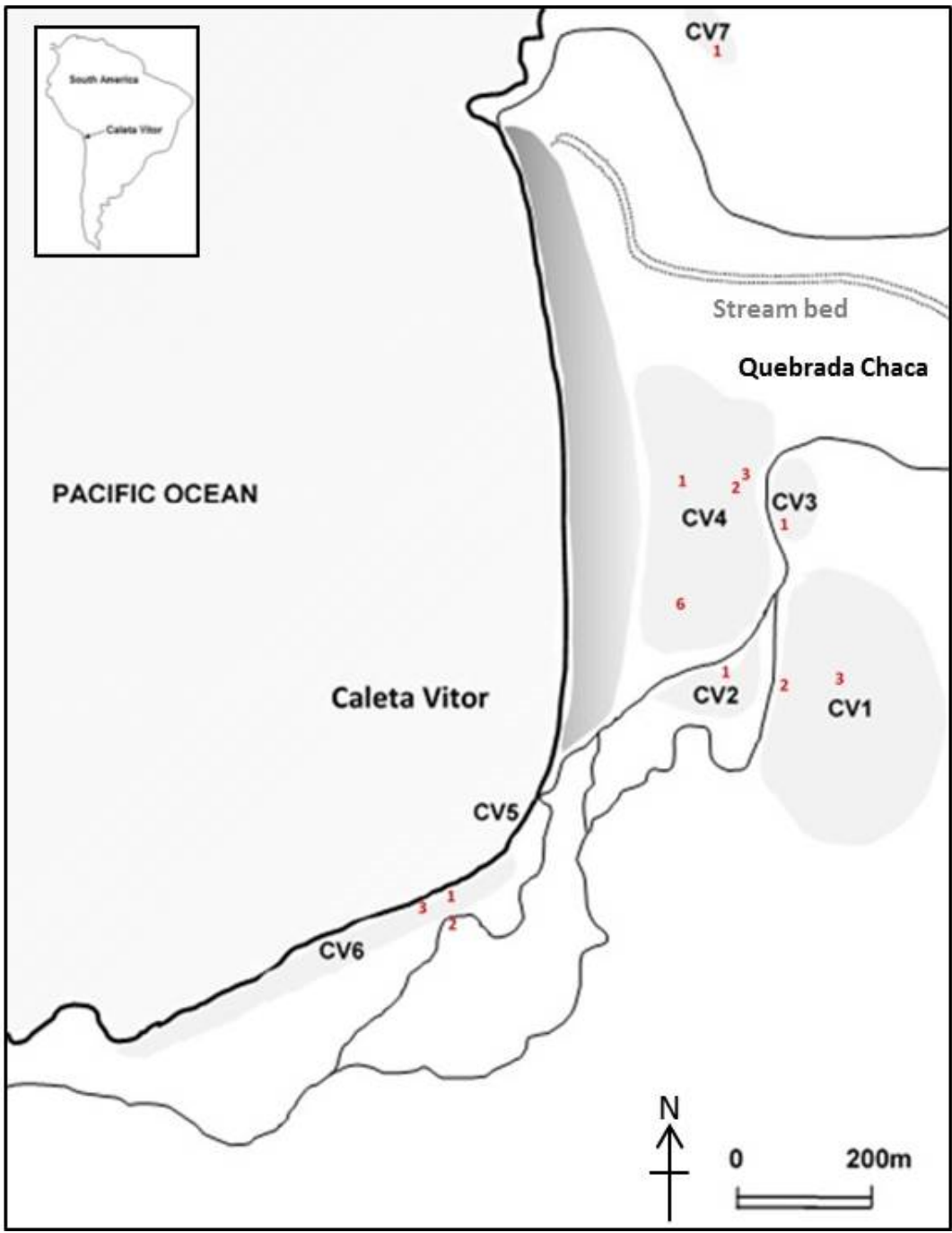


Figure 2. Caleta Vitor site map. Numbers in red relate to the location of excavation trenches.

Table 1. Minimum and maximum radiocarbon dates available for each excavation location with otoliths within Caleta Vitor, ordered from oldest to youngest site area. Radiocarbon ages were calibrated into calendar years using OxCal (v.4.2.4) (Bronk Ramsey 2009) and the SHCal13 calibration dataset (Hogg et al. 2013) for terrestrial samples and a mixed SHCal13/Marine13 (Reimer et al. 2013) dataset for human bone samples using a local DR value of 367 ± 198 (Latorre et al. In press). For bone samples the % marine was used as reported for each sample by Roberts et al. (2013) and Swift et al. (2015). Calibrated ages are reported at 2-sigma. ^a = Carter (unpublished data); ^b = Latorre et al. (In press); ^c = Roberts et al. (2013); ^d = Swift et al. (2015).

Site Area	Maximum Radiocarbon Date					Minimum Radiocarbon Date				
	Lab ID	Material	Radiocarbon Age (BP)	Calibrated Age (cal. BP)	Cultural Period	Lab ID	Material	Radiocarbon Age (BP)	Calibrated Age (cal. BP)	Cultural Period
CV3	ANU-31016 ^a	Charcoal	8420±40	9286-9491	Early Archaic	OZN-919 ^c	Human Bone (65% marine)	2420±35	1591-2280	Formative Period
CV1	UCIAMS-133691 ^b	Plant Macrofossil	5930±15	6656-6778	Middle Archaic	UGAMS-10507 ^c	Algarrobo pod	2470±25	2352-2699	Formative Period
CV2	UGAMS-10515 ^c	Charcoal	3820±30	3991-4286	Formative Period	OZP-580 ^d	Human Bone (74% marine)	1170±30	309-835	Late Period
CV4	OZN-920 ^c	Human Bone (42% marine)	2575±35	2013-2497	Formative Period	UGAMS-10519 ^a	Plant Material	420±20	330-500	Late Period
CV6	OZP-069 ^d	Human Bone (68% marine)	1940±30	1057-1672	Middle Horizon Period	UGAMS-10522 ^c	Corn	530±25	500-544	Late Period

Methods

Archaeological Samples

Otoliths (n=345 Camarones Punta Norte, n=204 Caleta Vitor) were extracted from the sieve residue during laboratory analysis. The proximal and distal surfaces of each otolith were photographed using a Canon EOS 50D digital camera equipped with a macro lens to create an archival record. Species identification was carried out based on reference collections.

All otoliths were weighed to a resolution of 0.001 g. While the majority of otoliths were well preserved with no obvious deterioration (see example Figure 3), some were broken and incomplete owing to post-depositional processes such as physical weathering and breakage; for the purpose of this study, to avoid inaccurate results, we used only complete samples to estimate fish length. Only one otolith, from Caleta Vitor, showed any signs of burning; this otolith was not included in the analysis because of the likelihood of shrinkage and weight loss (Shipman et al. 1984). Otolith weight was used to estimate fish length (total length, TL or fork length, FL) and fish weight. We acknowledge that otolith length can also be used to estimate fish size, and this method may be less sensitive to the effects of weathering or diagenesis on otolith weight; however, given otoliths are also prone to break, length can also underestimate fish size. We therefore chose to use otolith weight rather than length but acknowledge that fish lengths calculated using either method should be taken as minimum values. Relationships between otolith weight and fish length/weight for *Isacia conceptionis* and *Hemilutjanus macrophthalmos* were sourced from Medina and Araya (2001); values for *Trachurus murphyi* were derived from Araya et al. (2001) (Table 2). No equations for *Cilus gilberti* or *Sciaena deliciosa* were found. Given that *S. deliciosa* was the most abundant species in the archaeological assemblages from both sites, and dominate numerous archaeological assemblages from sites in the region (e.g., Béarez 2000; Sandweiss et al. 1998), modern samples were collected to determine otolith weight vs fish length and weight relationships.

In addition to the data collected from the fish otoliths, other faunal material in the assemblages (bone, crustaceans and molluscs), were extracted, counted and weighed. These remains were not identified to finer taxonomic resolution and are included to contextualise otolith data.

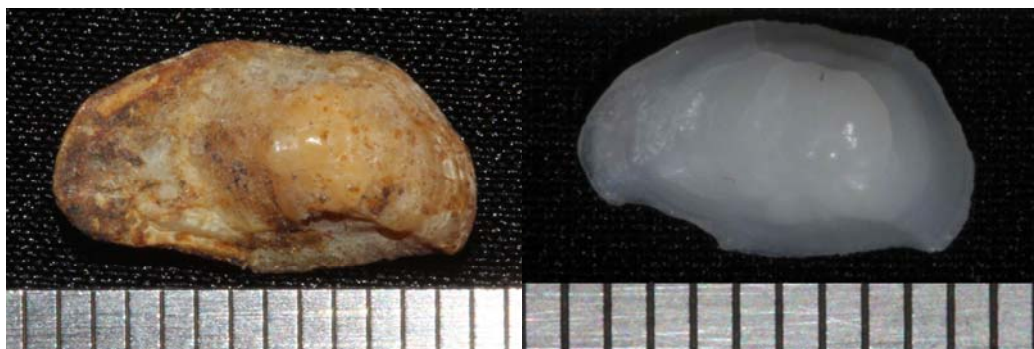


Figure 3. Examples of archaeological (left) and modern (right) *S. deliciosa* otoliths. Scale bar = mm. The archaeological sample originated from Caleta Vitor, CV1, Square 3, Level 4.

Table 2. Relationships between fish length/weight and otolith weight from the literature (Araya et al. 2001; Medina and Araya 2001).

Species	TL = aOW ^b				TW = aOW ^b			
	a	SE	b	SE	a	SE	b	SE
<i>Isacia conceptionis</i>	50.947	3.932	0.2861	0.025	2929.5	629.1	1.0977	0.077
<i>Hemilutjanus macrophthalmos</i>	91.532	3.311	0.4926	0.021	16127.8	1515.2	1.8238	0.056
<i>Trachurus symmetricus murphyi</i>	FL(cm)=((OW(mg)-7.508)/0/003) ^{1/2.53}							

Modern Samples

Seventy-two samples of *S. deliciosa* were collected from fish markets at Arica, Chile. The assemblage represents a range of the smallest to the largest sized fish available at the market over eight days in late April 2013 (n=39) and two days in early October 2014 (n=33). There was no significant difference in the size (TL) of fish sampled in the two periods. Catches originated from the waters off the coast of Arica, Chile. Each fish was weighed, measured, photographed, and the otoliths were removed. The otoliths were weighed (± 0.0001 g) and measured (± 0.01 mm). Measurements of both otoliths were averaged and used to estimate otolith size:fish size relationships. Fish length/weight of *S. deliciosa* archaeological samples was determined using the relationship between otolith weight and fish length/weight from these modern samples.

Results

Modern Samples

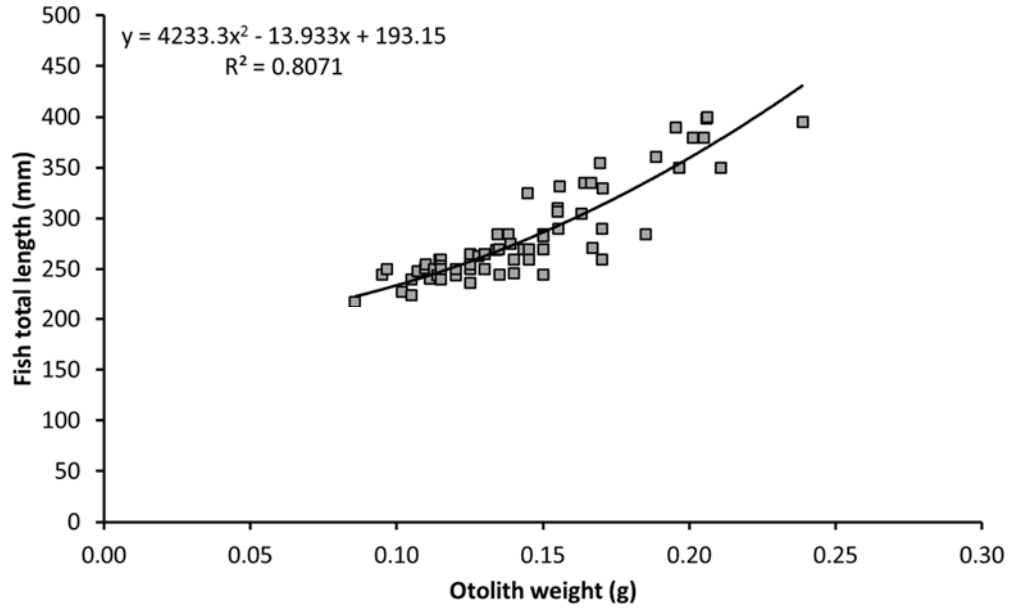
The modern *S. deliciosa* samples ranged in size from 218 mm (138 g) to 400 mm TL (887 g), with a mean of 283 mm (304 g). Otoliths ranged from 0.0848 g to 0.2406 g in weight, with a mean of 0.1435 g. The mean difference between left and right otolith weights was only 0.0008 g, indicating that both left and right otoliths can be used for size estimation. The relationships between fish TL and weight and otolith weight both showed a polynomial relationship (see Figure 4a and b).

Archaeological Samples

Species Distribution

Species identified within the Camarones Punta Norte and Caleta Vitor assemblages are all currently found along the coast of northern Chile. The sciaenid, *Sciaena deliciosa*, was the most common fish present at both sites, comprising approximately 87% of the number of identified species (NISP) of each assemblage (Table 3). The other sciaenid, *Cilus gilberti*, which possess much larger otoliths than *S. deliciosa*, was less abundant (3.8% NISP) at Camarones Punta Norte and 3.9% NISP at Caleta Vitor. *Trachurus murphyi* was more abundant at Caleta Vitor (5.4% NISP) than at Camarones Punta Norte (2.9% NISP). Two species of Haemulidae, *Isacia conceptionis* (4.3% NISP) and *Anisotremus scapularis* (2% NISP) were only present in the Camarones Punta Norte assemblage, while the Serranidae *Hemilutjanus macrophthalmos* was only present at Caleta Vitor (3.9% NISP).

a.



b.

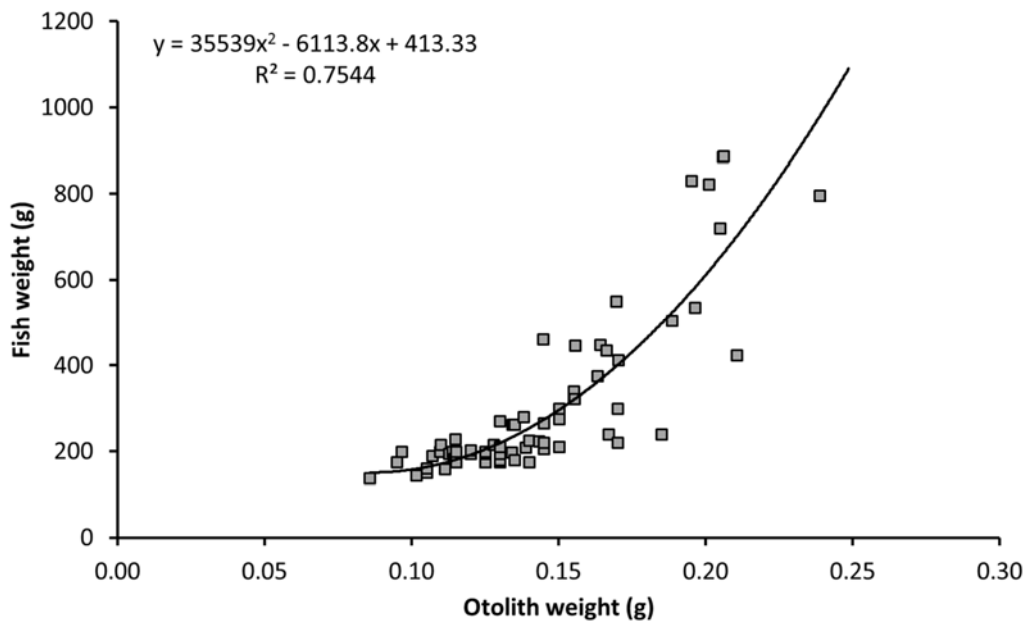
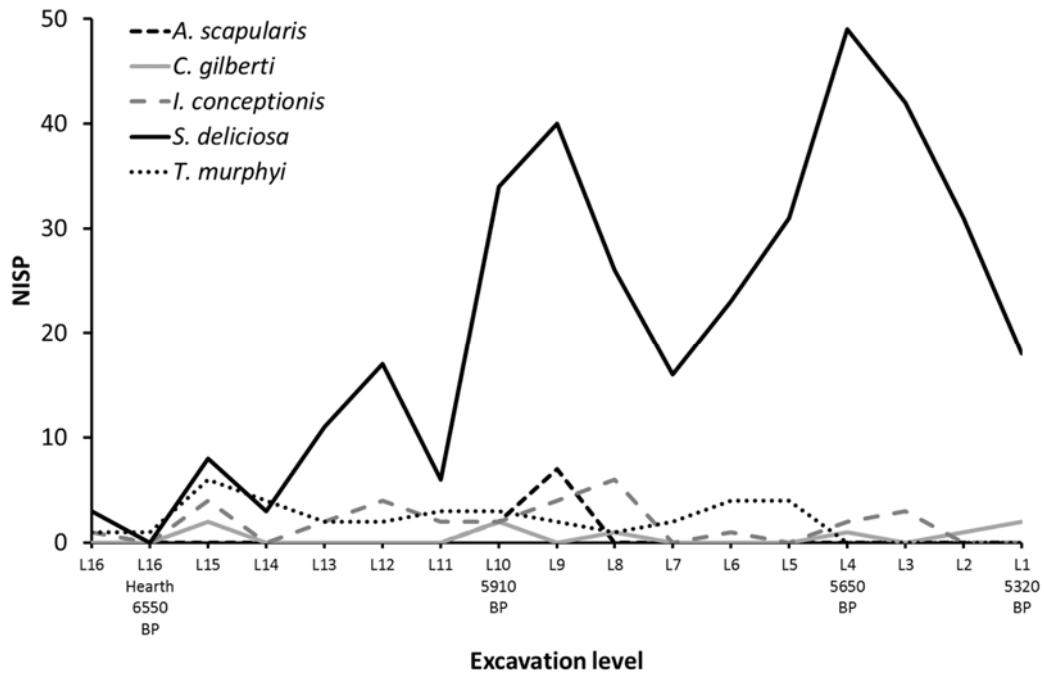


Figure 4. Relationship between modern *S. deliciosa* fish (a) TL (mm) and otolith weight (g) and (b) weight (g) and otolith weight (g).

a.



b.

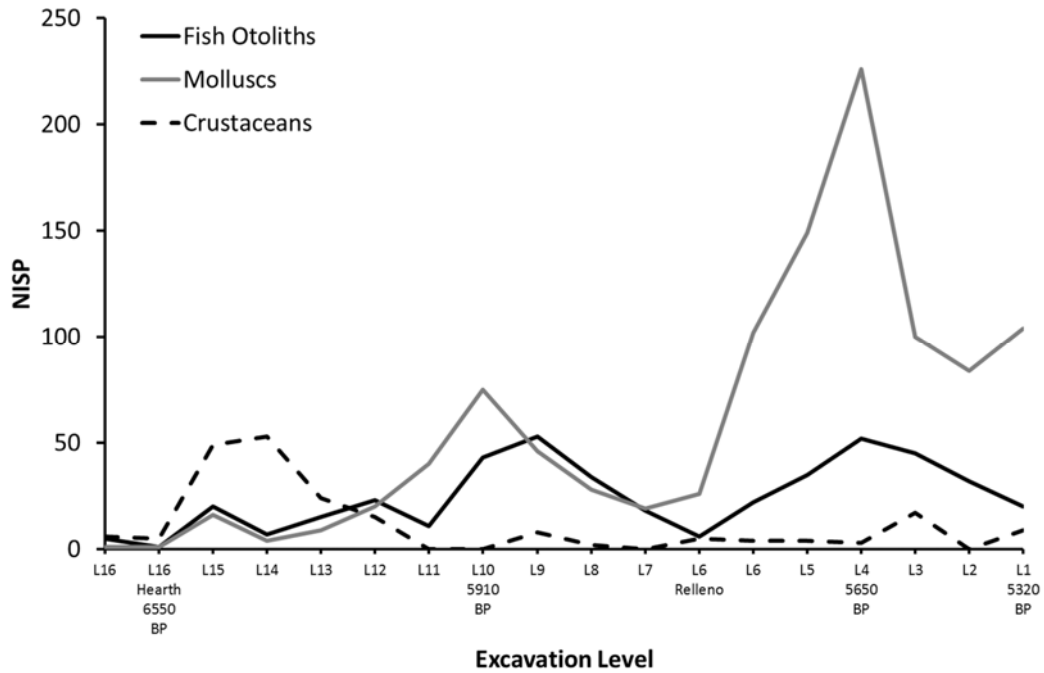


Figure 5a. Fish species distribution for the five most common species at Camarones Punta Norte based on fish otoliths; b: Taxonomic distribution based on fish otoliths (all species combined), molluscs and crustaceans at Camarones Punta Norte. NISP (number of identifiable specimens).

The frequency of *S. deliciosa* otoliths fluctuates throughout the excavation levels at Camarones Punta Norte, but exhibits peaks at approximately 6000 BP and 5600 BP (Figure 5a). The other fish species occurred at low abundances such that patterns by excavation level were difficult to ascertain. When the distribution of fish otoliths was compared with other taxa within the site (Figure 5b), molluscs—which include limpets, mussels, and snails—and crustaceans, such as rock crabs and barnacles, a similar pattern emerged.

At the Caleta Vitor site, the majority of the otoliths from all species were found in CV2 (n=93). *S. deliciosa* dominates the assemblages from all of the seven archaeological areas excavated within Caleta Vitor, ranging from 80.0% NISP at CV1 to 91.4% NISP at CV2 (Table 4). *T. murphyi* makes up 5.4% of the total assemblage from Caleta Vitor (Table 3), but is not present at CV2 or CV6. *C. gilberti* and *H. macrophthalmos* occur infrequently, each contributing 3.9% of the total NISP at Caleta Vitor. When compared with other remains at the site, it is evident that the NISP of fish otoliths recovered does not correlate with the percentage weight of fish bone from each trench (Figure 6). Fish bone from CV2/1 constituted 16.4% of the total weight of faunal material, while 85 otolith samples were found in this trench (Figure 6). From CV4/6, only six otoliths were recovered, while the fish bone made up 30.1% of the weight of the faunal remains from that trench.

Fish Size

The TL of *T. murphyi* from both sites were very similar, with maximum lengths of 529 mm (mean TL=463±29 mm) from Camarones Punta Norte and 555 mm (mean TL=462±35 mm) from Caleta Vitor (Table 3). The lengths of *S. deliciosa* from Camarones Punta Norte (max.=554.96 mm, mean=287±4 mm) were much smaller than those caught at Caleta Vitor (max.=970 mm, mean=358±9.52 mm) (Table 3). At Camarones Punta Norte the majority of *S. deliciosa* were estimated to measure <350 mm with weights of <1000 g (Figure 7a and b). In contrast, the majority of the *S. deliciosa* from Caleta Vitor ranged from 200-500 mm TL and up to 1500 g weight.

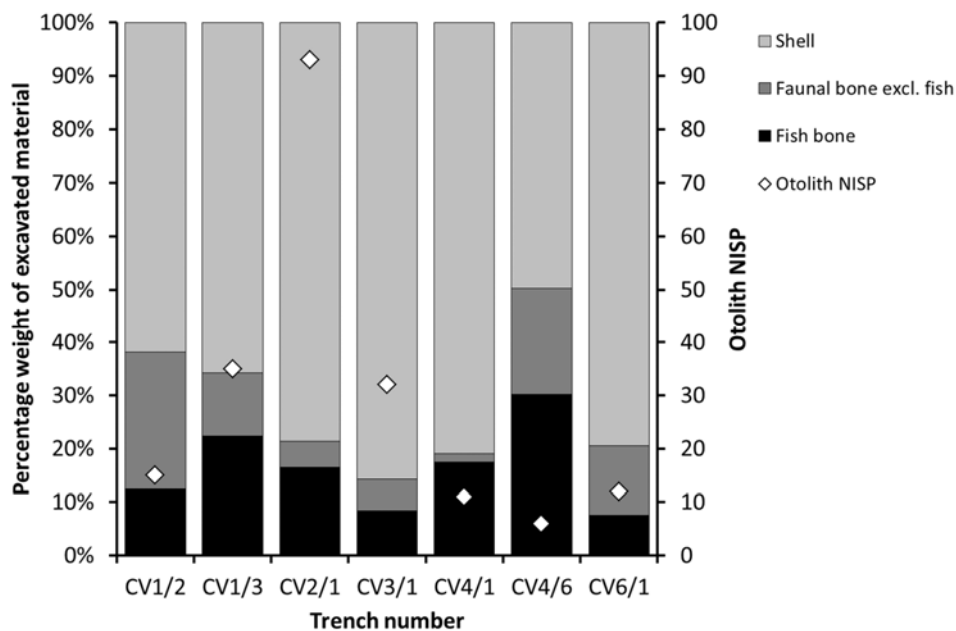
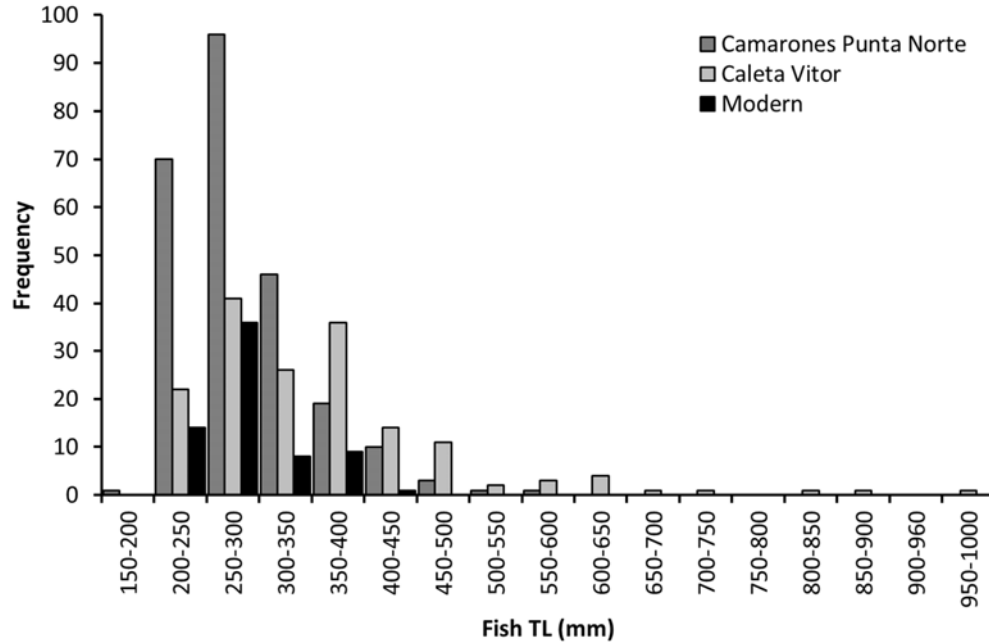


Figure 6. Taxonomic distribution of broad categories of faunal remains and otolith NISP (number of identifiable specimens) at Caleta Vitor.

a.



b.

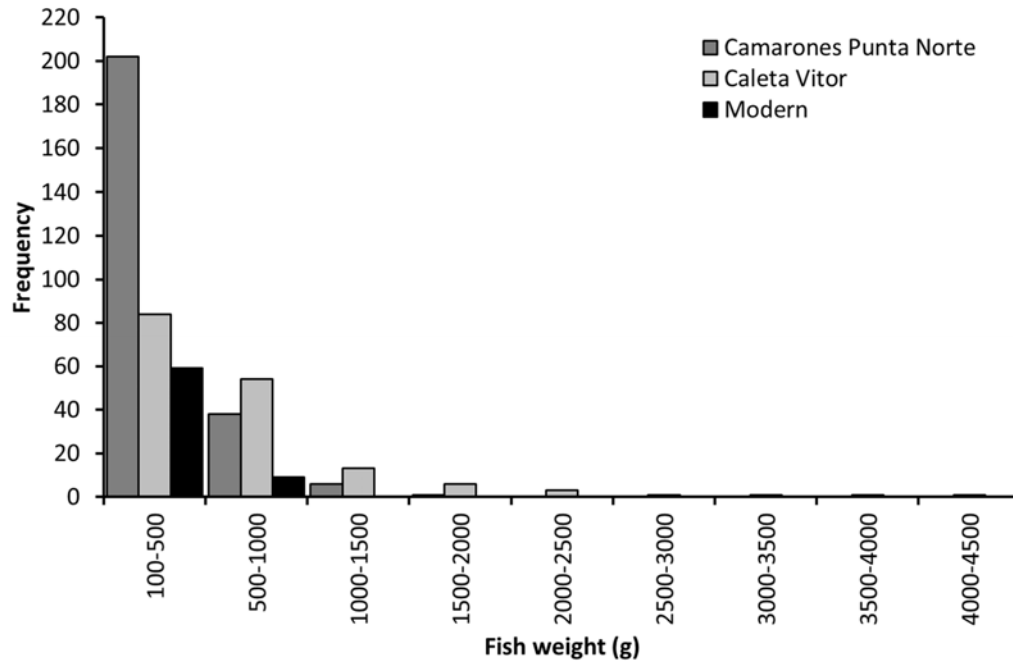


Figure 7. Estimated *S. deliciosa* (a) fish total length (TL) (mm) based on otolith weight:fish length relationships from modern specimens for Camarones Punta Norte, Caleta Vitor and the actual TL for the modern assemblage; and (b) fish weight (g) based on otolith weight:fish weight relationships for modern specimens for Camarones Punta Norte, Caleta Vitor and the actual fish weight for the modern assemblage.

Table 3. Fish species and estimated fish lengths based on otoliths from Camarones Punta Norte and Caleta Vitor. TL=total length; FL=fork length; SE=standard error

Site	Species	Family	Total NISP	% of assemblage	Number of complete otoliths	Fish length measurement	Mean fish length (mm)	SE (fish length) (mm)	Min fish length (mm)	Max fish length (mm)	Mean fish weight (g)	SE (fish weight) (g)	Min fish weight (g)	Max fish weight (g)
Camarones Punta Norte	<i>Anisotremus scapularis</i>	<i>Haemulidae</i> (grunts)	7	2.0	0	TL	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	<i>Isacia conceptionis</i>	<i>Haemulidae</i> (grunts)	15	4.3	12	TL	234	8	181	264	158	19	55	237
	<i>Trachurus murphyi</i>	<i>Carangidae</i> (jacks and pompanos)	10	2.9	5	FL	463	29	356	530	n/a	n/a	n/a	n/a
	<i>Cilus gilberti</i>	<i>Sciaenidae</i> (drums and croakers)	13	3.8	10	TL	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	<i>Sciaena deliciosa</i>	<i>Sciaenidae</i> (drums and croakers)	300	87.0	246	TL	287	4	194	555	341	16	338	1688
Total			345		273									
Caleta Vitor	<i>Hemilutjanus macrophthalmos</i>	<i>Serranidae</i> (sea basses, groupers and fairy basslets)	8	3.9	7	TL	239	24	125	316	144	41	10	313
	<i>Trachurus murphyi</i>	<i>Carangidae</i> (jacks and pompanos)	11	5.4	6	FL	462	36	308	555	n/a	n/a	n/a	n/a
	<i>Cilus gilberti</i>	<i>Sciaenidae</i> (drums and croakers)	8	3.9	5	TL	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	<i>Sciaena deliciosa</i>	<i>Sciaenidae</i> (drums and croakers)	177	86.8	164	TL	358	10	219	970	668	51	152	4356
Total			204		182									

Table 4. NISP (number of identifiable specimens) and % of fish species at Caleta Vitor based on otoliths.

Fish Species	CV1		CV2		CV3		CV4		CV6	
	NISP	%	NISP	%	NISP	%	NISP	%	NISP	%
<i>C. gilberti</i>	2	4.0	4	4.3	2	6.3	0	0.0	0	0.0
<i>H. macrophthalmos</i>	1	2.0	4	4.3	0	0.0	1	5.9	2	16.7
<i>S. deliciosa</i>	40	80.0	85	91.4	28	87.5	14	82.4	10	83.3
<i>T. murphyi</i>	7	14.0	0	0.0	2	6.3	2	11.8	0	0.0
Total	50		93		32		17		12	

Discussion

The fish species found at both Camarones Punta Norte and Caleta Vitor are a typical representation of the ichthyofauna of the coast of modern northern Chile. The majority of the assemblage comprised otoliths from *S. deliciosa*, a medium-sized (up to 500–550 mm TL (Béarez et al. 2015)) predatory fish, living on or near the sandy ocean floor, usually in depths of more than 20 m, but which can often be caught in shallower waters. It matures at a length of approximately 239 mm (Fishbase 2015), and feeds on crustaceans and small fish. It is likely these fish were caught with nets. Although other species were found, they were probably not the focus of the fishing efforts of the sites' occupants; their presence provides some information about past fish populations, as well as fishing strategies and technologies. They are all nearshore coastal species, some of which are highly prized seafood species and are commercially targeted today. *C. gilberti* is a large predatory schooling fish, reaching a TL of up to 1150–1200 mm (Béarez et al. 2015). This species is a prime table fish along the southern Pacific coast in South America, and feeds on small fish and crustaceans along the coast of Chile and southern Peru. *T. murphyi* is a heavily exploited (for fish meal), schooling pelagic fish adapted to both neritic and oceanic environments. They commonly grow to a TL of 450 mm long, but can reach lengths of 700 mm. At both Camarones Punta Norte and Caleta Vitor, maximum lengths were smaller than this modern maximum. Off Chile, the main horizontal migration pattern of the species is an offshore spawning migration in spring, and an inshore feeding migration in autumn and winter (Serra 1991). The presence of this species within the assemblages likely indicates that the sites were occupied during autumn and winter, when the fish were close to shore, and easier to catch. Alternatively, *T. murphyi*, along with the *S. deliciosa*, which also inhabits deeper waters, could have been captured further offshore with the use of watercraft. While watercraft are often found in post-Archaic periods in northern Chile (Llagostera 1990), there is some evidence of fishing for off-shore pelagic species from the Middle to Late Archaic periods, which indicates that watercraft may also have been used during these earlier times (e.g., Béarez et al. 2016; Castro et al. In press; Llagostera 1979; Olguín et al. 2015; Olguín et al. 2014). Further analysis of the otoliths, and an examination of the annuli, or growth rings, may reveal the season of death of the fish, and by inference the fishing strategies of the sites' inhabitants. *I. conceptionis* is a benthopelagic fish, inhabiting waters over rocky and sandy bottoms. It can reach lengths up to 600 mm TL and feeds on small crustaceans, polychaetes and algae. The otoliths within the assemblage at Camarones Punta Norte originated from fish much smaller than this length, with a maximum TL of 264 mm. *A. scapularis* (max. length 400 mm TL) forms schools in open water (usually 3–12 m in depth) above rocky, boulder strewn reefs, slopes and hard substrate. It feeds on benthic invertebrates and floating organic matter. *H. macrophthalmos* is found near drop-offs and among rock out-croppings over sand and rock, in depths greater than 10 m. It grows to a maximum length of 500 mm standard length (SL) and feeds on small fishes and crustaceans. Its presence within the assemblage, albeit with a maximum TL of 315 mm, indicates that the people of Caleta Vitor had the skills and tools required to fish in greater depths further from the coast.

The temporal fluctuations of fish species and faunal taxa at Camarones Punta Norte (Figure 5a and b) likely represent increases and decreases in the intensity of occupation at the site. The fish species fluctuate in synchronicity with the other faunal taxa, indicating that there was not a shift away from one species or taxa to another in response to environmental changes or altered resource availability. A significant increase in biomass occurred around 5500 cal. BP (Latorre et al. In press), which may explain the notable increase in faunal remains observed around this time at Camarones Punta Norte, followed by a decline in faunal consumption (Figure 5a and b). This fluctuating pattern may indicate that the site was used more or less intensively at intervals, with other areas in, or around, the estuary of Camarones favoured at different times; Camarones Punta Norte is just one small, isolated site, with surrounding sites within the estuary showing occupation since early in the Archaic period, similar to what is seen at Caleta Vitor (Corvalán 2011; Schiappacasse and Niemeyer 1984). It should be noted that preservation and site formation factors may also

have impacted the archaeology of the site and contributed to this pattern. Similarly, preservation or differential discard behaviours (butchering practices, activity area use or carcass transport strategies) may account for the irregular relationship between the frequencies of fish otoliths compared to fish bone at Caleta Vitor (Figure 6).

The high numbers of *S. deliciosa* otoliths recovered from both sites is similar to that seen elsewhere along the coast of the Atacama. At Quebrada Jaguay, most of the terminal Pleistocene and Early Holocene fish bones and otoliths came from sciaenid fish with a mode length of 172 mm (SL) (Sandweiss et al. 1998), while at Quebrada de los Burros, over 50% of the fish remains (NISP), dated to 7735±45 BP, were from *Sciaena spp.* (Béarez 2000). Sandweiss et al. (1998) suggested that the inhabitants of Quebrada Jaguay had a net fishing strategy focused on sciaenids, employing a specialized maritime subsistence strategy while resident at the site. At Quebrada de los Burros the size range of *S. deliciosa* suggested they were also caught with nets (Béarez 2000). At Camarones Punta Norte, the mean TL estimates were similar to that at Quebrada de los Burros (CPN=287 mm, QdIB=296 mm); however, the size range at Quebrada de los Burros, from 137–388 mm, consisted of smaller sized fish than Camarones Punta Norte (194–555 mm). In all of these sites, evidence for netting is scanty or indirect (i.e. stone sinkers), but today, fishermen along the coast of central Peru still use nets, among other techniques, to catch the same small size fish (Marcus 2008).

The sites of Quebrada de los Burros and Camarones Punta Norte are contemporaneous, although situated 130 km apart. The environmental conditions were likely broadly similar at each site at the time of occupation, allowing comparable suites of fish to be captured. Fishing technologies at the sites may have been shared, with the similar curves of both size frequency graphs (Figure 7a and Béarez 2000 Figure 7) reflecting the selectivity of fishing gear, possibly gill net size. The synchronicity of these sites may support the idea that the Chinchorro moved into the Atacama of northern Chile from similar settlements in southern Peru (e.g., Arriaza et al. 2008; Llagostera 1989, 1992; Rothhammer 2014; Standen et al. 2014; Standen and Santoro 2004; Umire 2013), bringing with them technologies suited to a marine and coastal environment. The use of nets indicates the importance of fish in the diet of the sites' inhabitants; nets require considerable time to make and maintain, suggesting social organisation that allows time to be allocated for net making and maintenance (Balme 1995; Colley 1987).

The *S. deliciosa* assemblage from Caleta Vitor was notably different to that from Camarones Punta Norte; the mean size of the fish was significantly larger, at 358 mm TL, with estimated sizes ranging from 219–970 mm TL. The majority of fish from Caleta Vitor were in the 200–500 mm size range. These differences may reflect the changing environment in the area. Caleta Vitor was occupied for an extended period of time, and thus would have experienced changes in the marine biomass in line with El Niño/La Niña fluctuations. Along the Atacama coast, there was a swing from the humid early Holocene to fully arid mid-Holocene conditions between ca 9500 and 8500 cal. BP, ending with the onset of modern climatic conditions around 4000 cal. BP (Betancourt et al. 2000; Grosjean et al. 2003; Grosjean et al. 2007; Latorre et al. 2003; Maldonado et al. 2005). Mollusc shell excavated from Caleta Vitor indicates that marine productivity increased at 5590 and 4380 cal. BP in relation to La Niña-like conditions; El Niño-like conditions may have occurred from 5040–4150 cal. BP, which have been linked to periods of lower productivity (Santoro et al. Under review-b).

The site at Camarones Punta Norte was no longer occupied after ca 5000 years ago. The changing environment may have forced occupants of the site to move completely out of the area or more likely, to relocate their settlement to other sectors of the Quebrada Camarones estuary, where other archaeological sites have been located and studied (Belmonte et al. 1995; Muñoz et al. 1991; Rivera 1984; Schiappacasse and Niemeyer 1984). At Caleta Vitor, more recent archaeological investigations show extensive and prolonged occupations in different locations of the bay throughout the time (Latorre et al. In press; Roberts et al. 2013; Santoro et al. Under review-a; Swift et al. 2015).

In relation to the sizes of the modern *S. deliciosa* samples, the assemblage from Camarones Punta Norte consisted of fish of a similar mean size and size range, with a maximum size (555 mm TL) in line with the maximum known length of the species (500–550 mm). The majority of the fish (79%) were larger than the modern size at maturity (239 mm), reflecting possible selectivity of harvesting. At Caleta Vitor, where the fish were generally estimated to be larger, 95% of the fish were larger than the size at maturity, likely indicating targeted fishing techniques or technology. The weights of 12 otoliths returned estimates of fish lengths more than the maximum modern length, with one individual, dated to approximately 3000–4500 cal. BP based on associated radiocarbon dates, estimated to be 970 mm long—almost double the modern maximum length. These large fish originate from a range of time periods, and were associated with radiocarbon dates ranging from modern through to approximately 6500 cal. BP (Roberts et al. 2013). Notably, none of the large fish originate from the time of earliest occupation at the site (9286–9491 cal. BP). These larger specimens, scattered throughout the temporal and spatial area of the site, represent the size that *S. deliciosa* could attain prior to commercial harvesting. These large fish could have been prized catches from deeper waters using hook and line technologies, or may have been caught in the nets with the smaller fish in shallower waters.

Over-exploitation of the marine environment is a major global issue (Erlandson and Rick 2008). Commercial harvesting of native fish species has significantly reduced fish stocks and has impacted on fish population structures. Prehistoric predation is also acknowledged to affect native fauna, therefore archaeological data may reflect impacted populations, and may not accurately represent pre-exploitation baselines (Butler 2001; Mannino and Thomas 2002; Rivadeneira et al. 2010). In addition, as archaeological ichthyofaunal assemblages result from cultural selection, they will reflect selective processes rather than be direct representations of former fish populations (Reitz 2004). Despite these factors, archaeological fish remains provide a snap-shot of past fish populations. Determining between environmentally and anthropogenically induced changes can be difficult, but fishing mortality can act as a selection pressure producing genetic change, and if larger individuals are more vulnerable to harvesting, then early maturing and slower growth might be favoured (Sutherland 1990). Numerous studies world-wide have identified the remains of fish estimated to be significantly or consistently larger than known modern specimens, as is evident at Caleta Vitor, attributing the decline in size to over-fishing and/or environmental degradation (e.g., Disspain et al. 2012; Leach and Davidson 2000; Plug 2008; Rivadeneira et al. 2010). The reverse has also been seen in assemblages, with mean fish size increasing over time (Leach and Davidson 2001), indicating complex processes at play, but it is widely accepted that industrialised fishing pressure and size-selective harvesting have drastically reduced stocks and impacted population structures (Fenberg and Roy 2008).

Conclusions

Analysis of the fish otoliths from Camarones Punta Norte and Caleta Vitor archaeological sites provides further and finer evidence documenting the reliance of the people of the Atacama Desert on marine resources. Without this bountiful and apparently inexhaustible resource provider, the deep history of humanity in this remote part of the planet would be different. The long-term chronological otolith analysis shows that there were important differential fluctuations in the species production along the coastal ecosystem throughout the Holocene (ca 9500–300 years ago), and that people likely managed these fluctuations by relocating their settlements either within the estuaries, or by moving out from them.

Based on fish seasonal behaviours, it appears that the coastal enclaves of Caleta Vitor and Camarones Punta Norte were occupied during autumn and winter, which correspond with the inland driest seasons. The large expanse and depth of shell middens along the Pacific coast, and particularly along the Atacama Desert, has been interpreted as a strong proxy to suggest that people maintained a sedentary or semi-sedentary life. This lifestyle was forced, in part, by the scarcity and geographic distribution of inland resources influenced by hyperarid conditions, and the contrasting, plentiful coastal marine resources (Chacama and Muñoz 2001; Marquet et al. 2012; Núñez 1986; Núñez et al. 1974; Zlatar 1983). The assemblages share similarities with contemporaneous sites in the region, containing large amounts of fish remains, providing evidence for the deployment of a range of fishing technologies, and reinforcing the importance of fish resources to the occupants of the coast of the northern Atacama Desert. The similarities between assemblages at Camarones Punta Norte and Quebrada de los Burros, further to the north, support the idea that people along the coast from southern Peru to northern Chile employed similar subsistence technologies, which may have been trespassed or exchanged between groups (Lavallée et al. 1999; Lavallée and Julien 2012; Lavallée et al. 2011; Santoro et al. 2012). Further morphological, isotopic and elemental analysis of the otoliths could provide insights into whether the site was inhabited/fish were targeted continuously or seasonally, while temperatures and upwelling patterns could be investigated through the use of isotopic or trace element analysis (see Latorre et al. In press).

Through estimates of fish size based on weights of otoliths, extremely large specimens of *S. deliciosa* were identified at Caleta Vitor, providing an indication of the size this species was capable of achieving prior to the industrialisation of fishing in the region. The over-exploitation of commercial fish species is a major global issue, which requires stocks to be managed and rehabilitated to ensure their survival. Archaeological data indicating significant alterations to a species' individual size can be used as evidence of the profound impact that modern uncontrolled industrialised harvesting could have on fishing biomass reproduction, and provide baseline data for their recovery.

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References

- Andrade, P., D. Salazar, J. Urrea and V. Castro 2014 Modos de vida de los cazadores-recolectores de la costa arica del Norte Grande de Chile: una aproximación bioarqueológica a las poblaciones prehistóricas de Taltal. *Chungara Revista de Antropología Chilena* 46(3):467–491.
- Araya, M., L.A. Cubillos, M. Guzmán, J. Peñailillo and A. Sepúlveda 2001 Evidence of a relationship between age and otolith weight in the Chilean jack mackerel, *Trachurus symmetricus murphyi* (Nichols). *Fisheries Research* 51(1):17–26.
- Arellano, C.E. and G. Swartzman 2010 The Peruvian artisanal fishery: Changes in patterns and distribution over time. *Fisheries Research* 101(3):133–145.
- Arriaza, B.T., V.G. Standen, E. Belmonte, E. Rosello and F. Nials 2001 The peopling of the Arica coast during the Preceramic: A preliminary review. *Chungara: Revista de Antropología Chilena* 33(1):31–36.
- Arriaza, B.T., V.G. Standen, V. Cassman and C.M. Santoro 2008 Chinchorro culture: Pioneers of the coast of the Atacama Desert. In H. Silverman and W.H. Isbell (eds), *The Handbook of South American Archaeology*, pp.45–58. Springer New York.
- Aufderheide, A.C. 1993 Reconstrucción química de la dieta del hombre de Acha. In I. Muñoz, B. Arriaza and A.C. Aufderheide (eds), *Acha-2 y los Orígenes del Poblamiento Humano en Arica*, pp.65–80. Arica: Ediciones Universidad de Tarapaca.
- Aufderheide, A.C. 1996 Secondary applications of bioanthropological studies on South American Andean mummies. In K. Spindler (ed.), *Human Mummies. A global survey of their status and the techniques of conservation*, pp.141–151. New York: Springer-Verlag.
- Balme, J. 1995 30,000 years of fishery in western New South Wales. *Archaeology in Oceania* 30(1):1–21.
- Béarez, P. 2000 Archaic fishing at Quebrada de los Burros, southern coast of Peru. Reconstruction of fish size by using otoliths. *Archaeofauna* 9:29–34.
- Béarez, P., F. Fuentes-Mucherl, S. Rebolledo, D. Salazar and L. Olguín 2016 Billfish foraging along the northern coast of Chile during the Middle Holocene (7400—5900 cal BP) *Journal of Anthropological Archaeology*(41).
- Béarez, P., D. Jackson and N. Mollaret 2015 Early Archaic fishing (12,600–9,200 cal yr BP) in the semiarid north coast of Chile. *The Journal of Island and Coastal Archaeology* 10(1):133–148.
- Belmonte, E., I. Muñoz and Y. Molina 1995 Contenido orgánico de un yacimiento habitacional de cazadores-recolectores en la desembocadura del río Camarones. In, *Actas del XIII Congreso Nacional de Arqueología Chilena*, pp.35–44. Antofagasta: Universidad de Antofagasta.
- Bernal, P., F. Robles and O. Rojas 1983 *Variabilidad física y biológica en la región meridional del sistema de corrientes Chile-Peru*.
- Betancourt, J.L., C. Latorre, J.A. Rech, J. Quade and K.A. Rylander 2000 A 22,000-Year Record of Monsoonal Precipitation from Northern Chile's Atacama Desert. *Science* 289(5484):1542–1546.
- Bronk Ramsey, C. 2009 Bayesian analysis of radiocarbon dates. *Radiocarbon* 51(1):337–360.
- Butler, V.L. 2001 Changing fish use on Mangaia, southern Cook Islands: resource depression and the prey choice model. *International Journal of Osteoarchaeology* 11(1-2):88–100.

Casteel, R.W. 1976 *Fish Remains in Archaeology and Palaeo-environmental Studies*. London: Academic Press Ltd.

Castro, V., C. Aldunate, V. Varela, P. Andrade, L. Olgún, F. García-Albarido, F. Rubio, P. Castro and J. Ruz In press Ocupaciones arcaicas y probables evidencias de navegación temprana en la costa arcaica de Antofagasta, Chile. *Chungara, Revista de Antropología Chilena* 48.

Chacama, J. and I. Muñoz 2001 Patrón funerario pre Chinchorro en un contexto de semi sedentarismo y complementariedad ecológica: el sitio Acha-2, extremo norte de Chile ca. 9.500 - 10.000 años a.p. *Chungara, Revista de Antropología Chilena* 33:51–54.

Colley, S.M. 1987 Fishing for facts. Can we reconstruct fishing methods from archaeological evidence? *Australian Archaeology* 24:16–26.

Corvalán, M. 2011 Estrategias de obtención de recursos durante el Arcaico Temprano en Camarones (norte de Chile): una aproximación a la organización tecnológica del sitio Cuya-3, desde el análisis del conjunto lítico. , Departamento de Antropología, Universidad de Tarapacá, Arica.

Dauelsberg, P., L. Alvarez and L. Chacon 1971 *Comunicacion sobre el sitio Punta Norte*. Santiago.

Disspain, M.C.F., S. Ulm and B.M. Gillanders 2015 Otoliths in archaeology: Methods, applications and future prospects. *Journal of Archaeological Science: Reports* In Press, Corrected Proof.

Disspain, M.C.F., C.J. Wilson and B.M. Gillanders 2012 Morphological and chemical analysis of archaeological fish otoliths from the Lower Murray River, South Australia. *Archaeology in Oceania* 47:141–150.

Erlandson, J.M. and T.C. Rick 2008 Archaeology, marine ecology, and human impacts on marine environments. In T.C. Rick and J.M. Erlandson (eds), *Human Impacts on Ancient Marine Ecosystems. A Global Perspective*, pp.1–19. Los Angeles: University of California Press.

Fenberg, P.B. and K. Roy 2008 Ecological and evolutionary consequences of size-selective harvesting: how much do we know? *Molecular Ecology* 17(1):209–220.

Fishbase 2015 *Sciaena deliciosa* (Tschudi, 1846) Lorna drum. Retrieved 16 October 2015 from <<http://www.fishbase.org/summary/Sciaena-deliciosa.html>>.

Gayó, E.M., C. Latorre and C.M. Santoro 2015 Timing of occupation and regional settlement patterns revealed by time-series analyses of an archaeological radiocarbon database for the South-Central Andes (16°–25°S). *Quaternary International* 356:4–14.

Grosjean, M., I. Cartajena, M.A. Geyh and L. Núñez 2003 From proxy data to palaeoclimatic interpretation: The mid-Holocene paradox of the Atacama Desert, northern Chile. *Palaeogeography, Palaeoclimatology, Palaeoecology* 194:247–258.

Grosjean, M., C.M. Santoro, L.G. Thompson, L. Núñez, V.G. Standen, G.A. David, A.M. Kirk and D.H. Sandweiss 2007 Chapter 3 - Mid-Holocene climate and culture change in the South Central Andes. In, *Climate Change and Cultural Dynamics*, pp.51–115. San Diego: Academic Press.

Hogg, A.G., Q. Hua, P.G. Blackwell, M. Niu, C.E. Buck, T.P. Guilderson, T.J. Heaton, J.G. Palmer, P.J. Reimer, R.W. Reimer, C.S.M. Turney and S.R.H. Zimmerman 2013 SHCal13 southern hemisphere calibration, 0–50,000 years cal BP. *Radiocarbon* 55:1889–1903.

- Latorre, C., J.L. Betancourt, K.A. Rylander, J. Quade and O. Matthei 2003 A vegetation history from the arid prepuna of northern Chile (22–23°S) over the last 13 500 years. *Palaeogeography, Palaeoclimatology, Palaeoecology* 194(1–3):223–246.
- Latorre, C., R. De Pol-Holz, C. Carter and C.M. Santoro In press Using archaeological shell middens dating as a proxy for past local coastal upwelling in northern Chile. *Quaternary International* In Press.
- Lavallée, D., P. Béarez, A. Chevalier, M. Julien, U. Usselman and M. Fontugne 1999 Paleoambiente y ocupación prehistórica del litoral extremo-sur del Perú. las ocupaciones del Arcaico en la Quebrada de los burros y alrededores (Tacna, Perú). *Boletín de Arqueología PUCP* 3:393–416.
- Lavallée, D. and M. Julien 2012 *Prehistoria de la Costa Extremo-sur del Perú. Los Pescadores Arcaicos de la Quebrada de Los Burros (10.000–7.000 a.P.)* Lima: Editorial Instituto Francés de Estudios Andinos.
- Lavallée, D., M. Julien, P. Béarez, A. Bolaños, M. Carré, A. Chevalier, T. Delabarde, M. Fontugne, C. Rodríguez-Loredo, L. Klaric, P. Usselman and M. Vanhaeren 2011 Quebrada de Los Burros. Los primeros pescadores del litoral Pacífico en el extremo sur peruano. *Chungara Revista de Antropología Chilena* 43(353–366).
- Leach, F. and J. Davidson 2000 Pre-European Catches of Snapper (*Pagrus auratus*) in Northern New Zealand. *Journal of Archaeological Science* 27(6):509–522.
- Leach, F. and J. Davidson 2001 The use of size–frequency diagrams to characterize prehistoric fish catches and to assess human impact on inshore fisheries. *International Journal of Osteoarchaeology* 11(1–2):150–162.
- Llagostera, A. 1979 9,700 years of maritime subsistence on the Pacific: An analysis by means of bioindicators in the north of Chile. *American Antiquity* 44(2):309–324.
- Llagostera, A. 1989 Caza y pesca marítima (9000-1000 a.C.). In J. Hidalgo, V. Schiappacasse, H. Niemeyer, C. Aldunate and Solimano (eds), *Prehistoria de Chile. Desde sus Orígenes hasta los Albores de la Conquista*, pp.57–79. Santiago: Editorial Andres Bello.
- Llagostera, A. 1990 La navegación prehispánica en el norte de Chile: bioindicadores e inferencias teóricas. *Chungara* 24:37–52.
- Llagostera, A. 1992 Early occupations and the emergence of fishermen on the Pacific coast of South America. *Andean Past* 3:87–109.
- Maldonado, A., J.L. Betancourt, C. Latorre and C. Villagrán 2005 Pollen analyses from a 50 000-yr rodent midden series in the southern Atacama Desert (25°30'S). *Journal of Quaternary Science* 20:493–507.
- Mannino, M.A. and K.D. Thomas 2002 Depletion of a resource? The impact of prehistoric human foraging on intertidal mollusc communities and its significance for human settlement, mobility and dispersal. *World Archaeology* 33(3):452-474.
- Marcus, J. 2008 *Excavations at Cerro Azul, Peru: The Architecture and Pottery*. Los Angeles: Cotsen Institute of Archaeology, University of California
- Marquet, P.A., C.M. Santoro, C. Latorre, V.G. Standen, S.R. Abades, M.M. Rivadeneira, B.T. Arriaza and M.E. Hochberg 2012 Emergence of social complexity among coastal hunter-gatherers in the Atacama Desert of northern Chile. *PNAS* 109:14754–14760.

- Medina, M. and M. Araya 2001 *Alimentación y relaciones tróficas en peces litorales de la zona de Iquique*, Universidad Arturo Prat Departamento de Ciencias del Mar, Iquique.
- Montecino, V. and C.B. Lange 2009 The Humboldt Current System: Ecosystem components and processes, fisheries and sediment studies *Progress in Oceanography* 83:65–79.
- Muñoz, I., B. Arriaza and A.C. Aufderheide 1993 El poblamiento Chinchorro: Nuevos indicadores bioantropológicos y discusión en torno a su organización social. In I. Muñoz, B. Arriaza and A.C. Aufderheide (eds), *Acha-2 y los Orígenes del Poblamiento Humano en Arica*, pp.107–132. Arica: Universidad de Tarapaca.
- Muñoz, I., S. Chacón and R. Rocha 1991 Camarones 15: asentamiento de pescadores correspondiente al período Arcaico y Formativo en el extremo norte de Chile. . In, *Actas del XI Congreso Nacional de Arqueología Chilena.*, pp.1–24. Santiago: Museo Nacional de Historia Natural, Sociedad Chilena de Arqueología, .
- Núñez, L. 1986 Evidencias arcaicas de maíces y cuyes en Tiliviche: hacia el sedentarismo en el litoral fértil y quebradas del Norte de Chile. *Chungara* 16-17:25–49.
- Núñez, L. and C.M. Santoro 2011 El tránsito Arcaico-Formativo en la circunpuna y valles occidentales del Centro Sur Andino: hacia los cambios “neolíticos”. *Chungara Revista de Antropología Chilena* 43(Número Especial 1):487–531.
- Núñez, L., V. Zlatar and P. Núñez 1974 Caleta Huelén 42: una aldea temprana en el norte de Chile. *Hombre y Cultura* 2:67–103.
- Olguín, L. 2014 El Rol económico de los recursos malacológicos durante el Holoceno medio en la costa arreica del norte de Chile: sitio Agua Dulce. *Revista Chilena de Antropología* 29:32–39.
- Olguín, L., V. Castro, P. Castro, I. Peña-Villalobos, J. Ruz and B. Santander 2015 Exploitation of faunal resources by marine hunter–gatherer groups during the Middle Holocene at the Copaca 1 site, Atacama Desert coast. *Quaternary International* 373:4–16.
- Olguín, L., D. Salazar and D. Jackson 2014 Tempranas evidencias de navegación y caza de especies oceánicas en la costa pacífica de Sudamérica (Taltal, ~ 7.000 años cal. a.p.). *Chungara Revista de Antropología Chilena* 46(2):177–192.
- Pestle, W.J., C. Torres-Rouff, M. Hubbe, F. Santana, G. Pimentel, F. Gallardo and K.J. Knudson 2015 Explorando la diversidad dietética en la prehistoria del Desierto de Atacama: un acercamiento a los patrones regionales. *Chungara Revista de Antropología Chilena* 47(2):201–209.
- Petruzzelli, B., A. Roberts, D. Pate, C.M. Santoro, T. Maddern, C. Carter and M.C. Westaway 2012 Stable carbon and nitrogen isotopic analysis of skeletal remains from Azapa 71 and Pica-8, Northern Chile: An assessment of human diet and landscape use in the late Holocene. *Journal of the Anthropological Society of South Australia* 35:52–80.
- Plug, I. 2008 Fish bone sizes as estimators of standard lengths of three southern African freshwater species with application to archaeological samples: a preliminary investigation. *South African Journal of Science* 104:71–75.
- Reimer, P.J., E. Bard, A. Bayliss, J.W. Beck, P.G. Blackwell, C. Bronk Ramsey, C.E. Buck, H. Cheng, R.L. Edwards, M. Friedrich, P.M. Grootes, T.P. Guilderson, H. Haflidason, I. Hajdas, C. Hatté, T.J. Heaton, A.G. Hogg, K.A. Hughen, K.F. Kaiser, B. Kromer, S.W. Manning, M. Niu, R.W. Reimer, D.A. Richards, E.M.

- Scott, J.R. Southon, C.S.M. Turney and J. van der Plicht 2013 IntCal13 and MARINE13 radiocarbon age calibration curves 0–50,000 years cal. BP. *Radiocarbon* 55(4).
- Reitz, E.J. 2004 "Fishing down the Food Web": A Case Study from St. Augustine, Florida, USA. *American Antiquity* 69(1):63–83.
- Rivadeneira, M.M., C.M. Santoro and P.A. Marquet 2010 Reconstructing the history of human impacts on coastal biodiversity in Chile: constraints and opportunities. *Aquatic Conservation: Marine and Freshwater Ecosystems* 20:74–82.
- Rivera, M.A. 1984 Cuatro fechados radiocarbonicos para sitios arqueologicos del litoral norte de Chile. *Nuestro Norte* 2:5–11.
- Rivera, M.A., P. Soto, L. Ulloa and D. Kushner 1974 Aspectos sobre el desarrollo tecnologico en al proceso de agriculturizacion en al norte Pre-Hispano, especialmente Arica (Chile). *Chungara: Revista de Antropología Chilena*(3):79–106.
- Roberts, A., F. Donald Pate, B. Petruzzelli, C. Carter, M.C. Westaway, C.M. Santoro, J. Swift, T. Maddern, G.E. Jacobsen, F. Bertuch and F. Rothhammer 2013 Retention of hunter–gatherer economies among maritime foragers from Caleta Vitor, northern Chile, during the late Holocene: Evidence from stable carbon and nitrogen isotopic analysis of skeletal remains. *Journal of Archaeological Science* 40(5):2360–2372.
- Rothhammer, F. 2014 En torno a la emergencia de complejidad funeraria temprana en la costa norte de Chile. *Chungara Revista de Antropología Chilena* 46:145–151.
- Salazar, D., V. Figueroa, P. Andrade, H. Salinas, L. Olgún, X. Power, S. Rebolledo, S. Parra, H. Orellana and J. Urrea 2015 Cronología y organización económica de las poblaciones arcaicas de la costa de Taltal. *Estudios Atacameños Arqueología y Antropología Surandinas* 50:7–46.
- Sandweiss, D.H., H. McInnis, R.L. Burger, C. Asuncion, B. Ojeda, R. Paredes, M.d.C. Sandweiss and M.D. Glascock 1998 Quebrada Jaguay: Early South American maritime adaptations. *Science* 281(5384):1830–1832.
- Sandweiss, D.H., J. Richardson III, B. , E.J. Reitz, H.B. Rollins and K.A. Maasch 1996 Geoarchaeological evidence from Peru for a 5000 years B.P. onset of El Niño. *Science* 273(5281):1531–1533.
- Santoro, C.M., B.T. Arriaza, V.G. Standen and P.A. Marquet 2005 People of the coastal Atacama Desert: Living between sand dunes and waves of the Pacific Ocean
In P. Veth, M. Smith and P. Hiscock (eds), *Desert Peoples: Archaeological Perspectives*, pp.243–260. Melbourne: Blackwell Publishing.
- Santoro, C.M., V. Castro, C. Carter and D. Valenzuela Under review-a Marine communities in the Atacama Desert. Masters of the sub-tropical Pacific coast of South America. In G. Prieto and D.H. Sandweiss (eds), *New Perspectives on the Social Dynamics and Economic Interactions of Andean Maritime Communities*. University Press of Florida.
- Santoro, C.M., E.M. Gayo, C. Carter, V. Castro, D. Valenzuela, V.G. Standen, R. DePol Holz and C. Latorre Under review-b Cultural resilience and the role of molluscs in the gourmet cuisine of prehistoric coastal Atacama Desert people. *Journal of Island and Coastal Archaeology*.
- Santoro, C.M., M.M. Rivadeneira, C. Latorre, F. Rothhammer and V.G. Standen 2012 Rise and decline of Chinchorro sacred landscapes along the hyperarid coast of the Atacama Desert. *Chungará (Arica)* 44:637–653.

- Santoro, C.M., P.C. Ugalde, C. Latorre, C. Salas, D. Osorio, D. Jackson and E.M. Gayo 2011 Ocupación humana Pleistocénica en el desierto de Atacama: Primeros resultados de la aplicación de un modelo predictivo de investigación interdisciplinaria. *Chungara, Revista de Antropología Chilena* 43(Número Especial 1):353–366.
- Schiappacasse, V. and H. Niemeyer 1984 *Descripción y análisis interpretativo de un sitio arcaico temprano en la Quebrada de Camarones*, Santiago: Museo Nacional de Historia Natural y Universidad de Tarapaca.
- Serra, R. 1991 Important life history aspects of the Chilean jack mackerel, *Trachurus symmetricus murphyi*. *Investigacion Pesquera* 36:67–83.
- Shipman, P., G. Foster and M. Schoeninger 1984 Burnt bones and teeth: an experimental study of color, morphology, crystal structure and shrinkage. *Journal of Archaeological Science* 11(4):307–325.
- Standen, V.G., B. Arriaza, C.M. Santoro and M. Santos 2014 La práctica funeraria en el sitio maestranza Chinchorro y el poblamiento costero durante el Arcaico Medio en el extremo norte de Chile. *Latin American Antiquity* 25(3):300–321.
- Standen, V.G. and B. Arriaza, T. 2014 The Chinchorro culture: hunter, gatherers and fishers of the Atacama coast. In N. Sanz, B.T. Arriaza and V.G. Standen (eds), *The Chinchorro Culture: A comparative perspective. The archaeology of the earliest human mummification*. Paris: United Nations Educational, Scientific and Cultural Organisation.
- Standen, V.G. and C.M. Santoro 2004 Patrón funerario arcaico temprano del sitio Acha-3 y su relación con Chinchorro (costa norte de Chile). *Latin American Antiquity* 15:89–109.
- Sutherland, W.J. 1990 Evolution and fisheries. *Nature* 344(6269):814–815.
- Swift, J., M.L. Cupper, A. Greig, M.C. Westaway, C. Carter, C.M. Santoro, R. Wood, G.E. Jacobsen and F. Bertuch 2015 Skeletal arsenic of the pre-Columbian population of Caleta Vitor, northern Chile. *Journal of Archaeological Science* 58:31–45.
- Umire, A.O. 2013 Rasgos funerarios Chinchorro en la costa del extremo sur peruano. *Chungara Revista de Antropología Chilena* 45:209–235.
- Valdes, J., L. Ortlieb, D. Gutierrez, L. Marinovic, G. Vargas and A. Sifeddine 2008 250 years of sardine and anchovy scale deposition record in Mejillones Bay, northern Chile. *Progress in Oceanography* 79:198–207.
- Valenzuela, D., C.M. Santoro, J.M. Capriles, Q.M. J., R. Peredo, E.M. Gayo, I. Montt and M. Sepúlveda 2015 Consumption of animals beyond diet in the Atacama Desert, northern Chile (13,000–410 BP): Comparing rock art motifs and archaeofaunal records. *Journal of Anthropological Archaeology* 40:250–265.
- Williams, A., C.M. Santoro, M.A. Smith and C. Latorre 2008 The impact of ENSO in the Atacama Desert and Australian arid zone: Exploratory time-series analysis of archaeological records. *Chungara* 40:245–259.
- Yañez, E., M.A. Barbieri, C. Silva, K. Nieto and F. Espindola 2001 Climate variability and pelagic fisheries in northern Chile. *Progress in Oceanography* 49:581–596.
- Zlatar, V. 1983 Replanteamiento sobre el problema Caleta Huelén 42. *Chungara* 10:21–28.