

Ancient Fisheries and Marine Ecology of Coastal Peru

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RECENT RESEARCH, EXEMPLIFIED by chapters in this volume, documents the profound impact of people on marine fisheries and ecology in many areas (e.g., Lauwerier and Plug 2004; Pauly 1995; Pauly and Christensen 1995; Pauly et al. 1998, 2000). Although we do not disagree with evidence for the human role in precipitating some environmental changes, the Peruvian case suggests that in some instances evidence for the impact of ancient fisheries on marine ecology is subtle and should be evaluated in the context of other environmental forces. Climate models, zooarchaeology, and stable isotopes highlight the antiquity of marine resource use in coastal Peru, the importance of the sea as the primary source of animal protein in the human diet throughout the Early and Middle Holocene, and the role of oceanic and atmospheric dynamics in the resilience of this ecosystem in the face of human fishing pressure.

Peru has one of the longest archaeological fishery records in the Americas. Exploitation of marine invertebrates and vertebrates began during the Terminal Pleistocene (e.g., Sandweiss et al. 1998) and continues today. Such a record is also found in Chile and Ecuador (e.g., Jerardino

et al. 1992; Llagostera 1979, 1992; though see Núñez et al. 1994; Reitz and Masucci 2004; True 1975). In contrast with regions in which human fishing strategies impacted marine ecosystems, multiple lines of evidence suggest that the biotic effects of natural variability in oceanic and atmospheric forces moderated anthropogenic effects in Peru. The region is characterized by changes in the frequency of El Niño–Southern Oscillation (ENSO) which influence marine and terrestrial productivity in complex but significant ways. ENSO itself operates in the presence of tremendous productivity supported by the Peru Current upwelling system. This productivity does not appear to have been severely impacted by fishing pressure until the twentieth century. Even now, some argue that natural, ENSO-created variability damages the fishery as much as does industrial fishing methods, perhaps more so (e.g., Barber and Chavez 1977, 1983, 1986; Chavez et al. 2003). Thus, the impact of ancient fisheries on the marine ecosystems of Peru must be considered in the context of oceanic and atmospheric forcing, as well as human behavior. In this chapter, the environmental background of Peru's

marine ecosystem, the antiquity and economic significance of the fishing tradition, human impact on marine ecosystems, and the biotic effects of variability in ENSO and the Peru Current are reviewed, with emphasis on archaeological evidence from the Early Preceramic (13,000 and 11,000 cal BP) through the Initial (4200–2800 cal BP) periods.

THE PERU CURRENT AND THE ENSO

The Peru Current and ENSO dominate both terrestrial and marine ecosystems of the Peruvian Coast today. To assess the impact of anthropogenic and nonanthropogenic forces on the marine ecosystems of Peru, the impact of ancient fisheries as well as of ENSO and the oceanic conditions within which ENSO operates must be considered. Though both the Peru Current and ENSO vary through time, evidence suggests that their combined influence has deep roots. These forces act on multiple time scales (Chavez et al. 2003).

The coastal upwelling ecosystem supported by the strong flow of the Peru Current is one of the most productive in the world (Bakun 1996; Briggs 1974:137, 1995:253; Idyll 1973; Santander 1980; Schweigger 1964). During most years, the cool Antarctic Peru Current flows north along the coast of Chile and Peru, turning westward from the coast near the Peru-Ecuador border. Typically Peruvian waters are temperate, with cool, nutrient-rich waters upwelling near shore in response to the Peru Current and steady trade winds. One of the world's richest fisheries is supported by nutrients brought to the surface by cold benthic waters rising from the ocean floor in response to prevailing winds and currents.

In contrast to the biological abundance of the sea, terrestrial resources are limited. The combination of the Andean rain shadow and the Peru Current contributes to one of the world's driest coastal deserts, with a relatively narrow seasonal cycle of sea and terrestrial temperatures. The only significant, quasi-permanent freshwater sources are braided

streams draining high-altitude glaciers in the Andes.

Thus, the primary characteristic of the Peruvian coast is the exceptionally rich marine ecosystem in which the upwelled nutrients support an abundant quantity of zooplankton and phytoplankton. A characteristic complex of invertebrates and vertebrates feed on these microorganisms (Chirichigno 1982; Hildebrand 1945; Reitz 1988a, 1988b; Reitz and Sandweiss 2001; Schweigger 1964). Typical Peru Current invertebrates include echinoderms (Echinodermata), chitons (Polyplacophora), scallops and mussels (e.g., *Argopecten purpuratus*, *Aulacomya* spp., *Choromytilus chorus*, *Perumytilus purpuratus*, *Semimytilus algosus*), clams (e.g., *Mesodesma donacium*, *Protothaca thaca*, *Donax obesulus*), gastropods (e.g., *Fisurella* spp., *Acmaea* spp., *Thais* spp.), and crustaceans (e.g., *Balanus* spp.). Typical Peru Current vertebrates include whales and dolphins (Cetaceans), sea lions and seals (Pinnipedia), pelicans (*Pelecanus* spp.), cormorants (*Phalacrocorax* spp.), boobies (*Sula* spp.), herrings (Clupeidae), and anchovies (Engraulidae). In addition, some members of other fish families are common along the Peruvian coast, particularly jacks (Carangidae), grunts (Haemulidae), drums (Sciaenidae), and mackerels (Scombridae). Members of these groups are found in both inshore and offshore waters; most are typical of nearshore waters associated with rocky headlands, sandy beaches, open littoral, and the lower reaches of the few intermittent or perennial streams that occur along the coast. The precise complex of organisms accessible from each archaeological site depends on the latitude of the site, local topography and geomorphology, coastline orientation, the width of the continental shelf, and the tectonic history of the specific locality (e.g., Navarrete et al. 2005). The resources available at each site also vary through time in response to long-term variations in ENSO cycles (Reitz and Sandweiss 2001; Sandweiss 2003; Sandweiss et al. 2004).

The dry, temperate climate is punctuated at irregular intervals by complex oceanic and

atmospheric events referred to jointly under the term “ENSO.” Often, “El Niño” refers to the oceanic component and “Southern Oscillation” to the atmospheric one, with “ENSO” encompassing the complementary El Niño (warm events) and La Niña (cool events) states in this natural mode of oscillation (Fedorov and Philander 2000). At irregular intervals, El Niño events depress the thermocline in the eastern equatorial Pacific, resulting in coastal warming in Peru and northern Chile and a notable decrease in nearshore biological productivity. The trade winds slacken or reverse during the warming phase of the ENSO cycle, and rain falls along the desert coast and western slopes of the Andes. Today, warming events recur at 2- to 15-year intervals and persist from several months to over a year. During this time, tropical surface water displaces cool, upwelled water upon which local ecosystems rely. At such times, sea surface temperatures (SST) can reach 28 to 29°C, exceeding “normal” temperatures by 5°C or more at some locations (Chavez et al. 1999). Mobile temperate organisms die or migrate to cooler waters, immobile organisms die or decline dramatically, and floods inundate coastal deserts. El Niño conditions contrast with those of La Niña, in which local coastal waters are cooler than average; these may drop as much as 8°C (Chavez et al. 1999). The phases of ENSO cycles are associated with striking changes in biological productivity (Chavez et al. 1999; Chavez et al. 2003). At the same time, other large-scale changes occur on different time scales.

Though chronologies vary, many proxies indicate changes in frequency and intensity of the ENSO cycle from the Terminal Pleistocene to the present and its impact on marine ecosystems throughout the Pacific Basin (e.g., Trenberth and Otto-Bliesner 2003). These include, among others, lake records from the Ecuadorian highlands (Moy et al. 2002; Rodbell et al. 1999), central Chile (Jenny et al. 2002; Maldonado and Villagrán 2002), the Galapagos (Riedinger et al. 2002), Australia (McGlone et al. 1993), and New Zealand (Shulmeister and Lees 1995); Andean

ice cores (Thompson et al. 1985, 1995); corals from Australia (Gagan et al. 1998) and New Guinea (Tudhope et al. 2001); eastern equatorial Pacific deep-sea cores (Loubere et al. 2003); and Peruvian coastal flood records (Fontugne et al. 1999; Keefer et al. 2003). The frequency and impact of ENSO also can be tracked for the most recent 13,000 years through analysis of marine organisms in archaeological sites (e.g., Andrus et al. 2002a; Rollins et al. 1986a, 1986b; Sandweiss 2003; Sandweiss et al. 1996, 1999, 2001a, 2004). These proxy data may be summarized as follows: (1) prior to 9000 cal BP, ENSO operated, but information on the frequency of that variation is not available; (2) from 9000 to 5800 cal BP, ENSO cycled at very long intervals, and coastal waters in northern Peru were generally warm compared to today; (3) from 5800 to 3000 cal BP, ENSO cycled less frequently than it does today, while the sea off northern Peru was cool; and (4) since 3000 cal BP, ENSO has varied within the range of historically known frequencies, and coastal waters generally are cool.

For evidence of environmental change unrelated to human behavior one need look no further than the devastating effects of ENSO in 1982–1983 and 1997–1998 on primary productivity and on invertebrate and vertebrate populations. These well-studied nonanthropogenic impacts are orders of magnitude greater than any known human impact. In fact, it took the 1972 ENSO combined with a decade or more of intensive industrial fishing to depress the anchoveta (*Engraulis ringens*) fishery, which rebounded reasonably well between the 1982–1983 and 1997–1998 events.

ENSO is a powerful and overwhelming factor in the Peru-Chilean Province and in Peruvian history. Although it undoubtedly is true that predator-prey relationships such as those between sea otters and sea urchins in the California kelp forest exist in the zoogeographic Peru-Chilean Province defined by the Peru Current, the nutrient upwelling associated with the current is the major ecological driver at the base of the food chain (Schweigger

1964). This source of nutrients supports all higher organisms, including brown (Phaeophyceae) and red (Rhodophyceae) algae (Schweigger 1964:195–198) and seabirds such as cormorants (*Phalacrocorax gaimardi*; Zavalaga et al. 2002). Species requiring reliable cool waters are vulnerable to direct and indirect impact, and their populations are likely limited by warm El Niño water temperatures. For example, the intertidal kelp (*Lessonia nigrescens*) experienced massive mortality as a result of the ENSO event of 1982–1983 in northern Chile, and recovery of this population was very slow (Martínez et al. 2003). Species that prefer continental shelf habitats are further limited by the size and availability of such habitats in Peru (Richardson 1981). With the possible exception of recent human behavior, people could not disrupt the ENSO cycle or directly access the nutrients borne by the upwelling. However, when the upwelling is disrupted by the ENSO cycle, disaster strikes every organism that relies upon it. Thus the driver in this province is more clearly physical and chemical than biological. If one were unaware of the impact of long-term variability in ENSO, it would be simple to conclude that the changes in the faunal record seen in these data were due to biological dynamics within the ecosystem, human impact on the Peruvian ecosystem, or to changes in cultural patterns unrelated to environmental factors. Yet, as will be shown below, the most important changes in the Peruvian fishery can be linked to climatic change. This complicates interpretations of the impact of people on marine fisheries and ecology in this area.

THE ANTIQUITY OF THE FISHING TRADITION

As on other maritime coasts, the archaeological record of western South America is biased against coastal sites prior to sea level stabilization around 6,000 calendar years ago (Richardson 1981). Surviving evidence of maritime-oriented sites is most likely to be associated with

a narrow, steep continental shelf where the rising sea caused relatively little horizontal displacement of the shoreline. In Peru, the shelf is narrowest near Talara and from the Paracas Peninsula south into northern Chile. Field work in these two regions has located many maritime-adapted sites predating sea level stabilization. Four of these sites were occupied between 13,000 and 11,000 cal BP and yield clear evidence for the antiquity and extent of the Peruvian fishing tradition (Table 6.1).

Peru's early cultural history is divided into Preceramic and Ceramic stages. The Preceramic stage is subdivided into Early (13,000–9000 cal BP), Middle (9000–5800 cal BP), and Late (5800–4200 cal BP) periods based upon a variety of criteria (see Benfer 1984; Keefer et al. 1998; Pozorski and Pozorski 1987; Quilter 1991; Sandweiss 1996b; Sandweiss et al. 1989, 1998). Early and Middle Preceramic coastal sites have neither cotton nor ceramics. Although by definition Late Preceramic sites lack pottery, many have evidence of intensive agriculture that focused on industrial crops such as gourds and cotton, associated with monumental architecture (e.g., Béarez and Miranda 2000; Bonavia 1982; Haas et al. 2004; Pozorski 1983; Pozorski and Pozorski 1979a; Quilter 1991; Quilter et al. 1991; Sandweiss et al. 2001b; Shady Solís et al. 2001). The Late Preceramic Period is also known as the Cotton Preceramic (Engel 1957:138–142; Moseley 1975:21–22). The subsequent Initial Period (4200–2800 cal BP; e.g., Pozorski and Pozorski 1979b, 1987, 1992) is characterized by ceramics, agriculture, monumental structures, and many other aspects of a complex cultural life.

Reliable quantitative estimates of demographic trends during this time are not available for the Peruvian coast (for one attempt, see Rick 1987). The general trend is for population to grow over the millennia from what must have been small groups of semisedentary fishers to much larger communities by the fifteenth-century Spanish conquest, when individual coastal valleys had populations often numbering in the tens of thousands (Cook 1981).

TABLE 6.1

<i>Percentage of Vertebrate Minimum Number of Individuals (MNI) from Marine and Terrestrial Habitats</i>				
SITE (LATITUDE)	% MARINE	% TERRESTRIAL	MNI	CAL BP
Southern Peru-Chilean Province (17°–12° S)				
Quebrada Tacahuay	91.7	8.3	72	12,750–11,950
Ring Site	99.1	0.9	436	11,400–5850
Quebrada Jaguay	83.9	16.1	248	13,050–8250
Paloma Probability Samples	97.7	2.3	132	8500–5450
Northern Peru-Chilean Province (9°–8° S)				
Cardal 1/4-inch Samples	85.3	14.7	34	3250–2800
Almejas 1/4-inch Samples	93.0	7.0	114	7500
Pampa de las Llamas 1/4-inch Samples	87.0	13.0	77	4500–3500
Ostra Base Camp	100.0	–	144	7100–6200
Alto Salaverry	100.0	–	64	4950–4050
Paiján Complex	16.2	83.8	761	12,250–9150
Panamanian Province (4°–2° S)				
Sitio Siches				
Honda Phase	99.6	0.4	512	5850–5150
Siches Phase	99.8	0.2	2195	7900–6750
Amotape Phase	92.0	8.0	50	10,650–10,050
Real Alto	94.9	5.1	236	Middle Valdivia
Las Vegas	42.8	57.2	145	11,400–7,450

NOTE: Dates from Benfer (1984), Chauchat (1988, 1992), Sandweiss et al. (1983, 1989, 1996), and Stothert (1988), calibrated via Calib 5.0 (Hughen et al. 2004; McCormac et al. 2004; Reimer et al. 2004; Stuiver and Reimer 1993). Age ranges from means of oldest and most recent ¹⁴C dates where available, discounting outliers rejected by the excavators. No ¹⁴C dates are available for Alto Salaverry, dated by association with similar sites and artifacts. Faunal data, excluding human and invertebrate MNI, from Byrd (1976, 1996), Chase (1988), deFrance et al. (2001), Pozorski and Pozorski (1979a), Reitz (1987, 1988a, 1988b, 1995, 1999, 2003, 2005), Reitz and Cannaroni (2004), Reitz and Sandweiss (2001), Sandweiss et al. (1989), and Wing (1986). Data for Las Vegas omits earlier, Pre-Vegas deposits.

Likewise, patterns of residential mobility and sedentism remain unresolved. Perhaps during the Terminal Pleistocene small groups of coastal fishing communities were seasonally migratory, at least within the coastal sector. Although there are indications that early coastal populations migrated between the coastal setting and the highlands (Sandweiss et al. 1998), for most of Peruvian history coastal populations were sedentary. Even under highland influence or domination by the Wari and Inca (ca. AD 600–1000 and AD 1470–1532 (or 1350–950 and 480–418 BP), most coast-dwellers were the traditional peoples of the shore with their specialized knowledge of coastal resource extraction

and traditional claims to fishing grounds (see, for instance, Rostworowski 1981; Sandweiss 1992). The complexity of making a living safely and reliably from the sea calls upon tools, skills, and knowledge that are incompatible with part-time fishing. Evidence of extensive trade networks linking various parts of the Andean region appears very early in the Peruvian sequence, suggesting that exchange rather than residential mobility was the preferred way to obtain resources not locally available (e.g., deFrance 2005; Pozorski 1983; Pozorski and Pozorski 1979b, 1987; Reitz 1988a; Sandweiss 1996a; Shady Solís et al. 2001; Wing 1972:332, 1986, 1992), and isotopic data reviewed below

likewise suggest year-round occupation at Siches and Ostra.

A fishing tradition combined with the use of a few, mainly small, terrestrial animals is the oldest verifiable protein-acquisition strategy in coastal Peru (Table 6.1). Although some continue to argue on theoretical grounds that these were hunting economies focused on large terrestrial animals, or at least fishing economies that grew out of earlier coastal (or interior) hunting traditions, the antiquity and intensity of fishing traditions is evident at all of the oldest coastal sites for which vertebrate data are available. These sites include Quebrada Tacahuay (deFrance et al. 2001; Keefer et al. 1998), the Ring Site (Sandweiss et al. 1989), Quebrada Jaguay (Reitz 2005; Sandweiss et al. 1998), and the complex of sites known as Paiján (Chauchat 1988, 1992; Wing 1986). The early levels of these sites date at least between 13,000 and 11,400 cal BP, if not earlier, and they extend from the southernmost boundary of Peru to the northernmost (Figure 6.1). Theories relying upon migratory highland-coastal terrestrial hunting tradition lack zooarchaeological support. Although other indicators point to coastal-highland connections at some sites, we do not know if these are evidence of migrations or of exchange networks.

Except for the Paiján example, echinoderms, molluscs, crustaceans, fishes, seabirds, and some marine mammals were used to the exclusion of almost all terrestrial animals. The few terrestrial animals in collections from these sites are primarily lizards, small birds, and mice. Although terrestrial plant remains are limited at these sites, they are present at least at Quebrada Tacahuay and Quebrada Jaguay (deFrance et al. 2001; Sandweiss et al. 1998). It is presumed also that marine plants, including algae, were used throughout the archaeological sequence as they were during Inca times as well as today (Sandweiss 1992:125–126; Schweigger 1964:195–197; Zavalaga et al. 2002). Direct archaeological evidence for this use will necessarily be limited.

The Paiján sites are an interesting exception in that they document the extent to which people

used marine resources even when the coast was relatively distant. Although most early sites lie within 3 km of the modern shore, the Paiján sites are 14 to 36 km from the present-day coastline. Because the continental shelf is relatively wide in the Paiján region, these sites were even further from the shore when they were occupied. Despite the distance, marine animals comprise 16 percent of the MNI (minimum number of individuals); testifying to the presence of the maritime tradition at locations not directly on the coast. Among the few terrestrial animals identified in the Paiján collections, lizards comprise 70 percent of the individuals, while deer make up less than 1 percent (Wing 1986).

Data from other sites demonstrate that this tradition extended throughout the Holocene (e.g., Reitz 2004). Faunal data from Middle Pre-ceramic sites such as Quebrada de los Burros (Béarez 2000; P. Béarez, personal communication 2005), Paloma (Reitz 1988a, 1988b, 2003), Ostra Base Camp (Reitz 2001; Reitz and Sandweiss 2001), and Sitio Siches (Reitz and Cannarozzi 2004) document intense use of marine resources. The Quebrada de los Burros study focused on fishes, but most of the other vertebrates are marine birds rather than terrestrial animals (P. Béarez, personal communication 2005). The Paloma, Ostra, and Siches studies include all vertebrate classes to the extent that they were present in the samples studied. Essentially 100 percent of the vertebrate individuals are from the sea (Table 6.1). Quebrada de los Burros, Paloma, and Siches all contain evidence of domesticated plants, but the emphasis on marine animals continued unabated (Lavallée et al. 1999; D. Piperno, personal communication 2004; Piperno and Pearsall 1998:271; see Piperno and Stothert [2003] for examples from Ecuador).

Over 80 percent of the vertebrate individuals are marine even at Late Pre-ceramic and Initial Period sites with more abundant evidence for domesticated plants, such as Alto Salaverry (Pozorski and Pozorski 1979a), Los Gavilanes (Bonavia 1982; Wing and Reitz 1982), Cardal (Burger and Salazar-Burger 1991; Reitz 1987; Umlauf 1993), El Paraíso (Quilter and Stocker

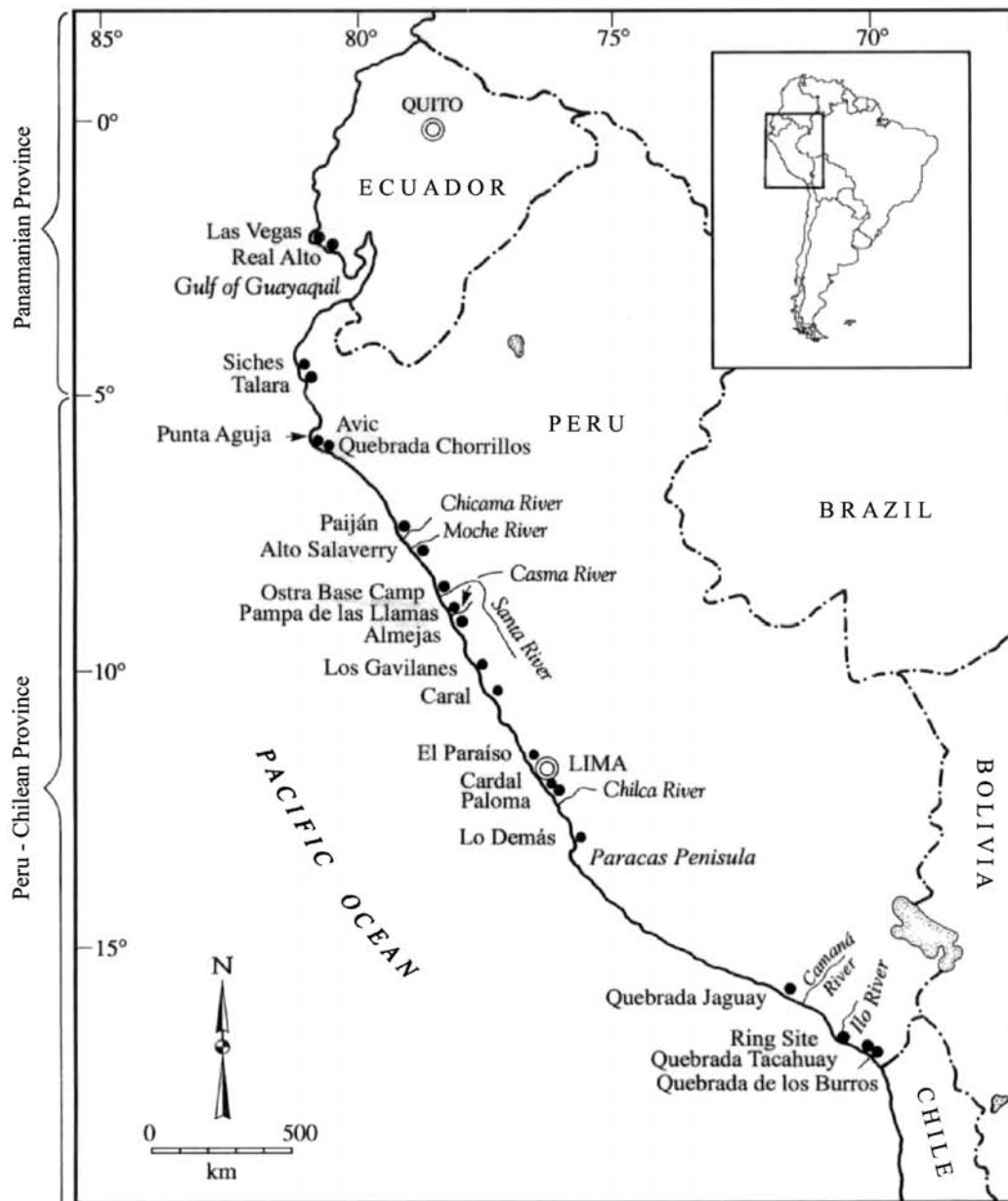


FIGURE 6.1. Map of the study area.

1983; Quilter et al. 1991), and Pampa de las Llamas (Pozorski and Pozorski 1987; Reitz 1999). Although data for classes other than fishes are not presently available from Caral, a similar pattern is likely at that site (P. Béarez, personal communication 2005; Béarez and Miranda 2000; Shady Solís et al. 2001; also known as Chupacigarro Grande [East]). This is the case at

sites located within a few kilometers of the coast as well as at sites 23 to 50 km from the sea. In many cases, the crops consist primarily of bottle gourd (*Lagenaria siceraria*) and cotton (*Gossypium barbadense*), industrial plants that enhanced the fishing effort but were not themselves new sources of nutrients (e.g., Grobman 1982:149; Piperno and Pearsall 1998:267–280).

[AU1]

The fishing tradition continued as an important source of protein beyond the Initial Period (e.g., Chavez et al. 2003; Marcus et al. 1999; Roselló et al. 2001; Rostworowski 1977; Sandweiss 1992; Sandweiss et al. 2004). Although marine resource use continued past the Initial Period, our focus is on the early part of the Peruvian cultural sequence for several reasons. Firstly, the issue of the primacy of fishing in early economies remains unresolved, and the overwhelming evidence in favor of a long tradition is underappreciated by many researchers. Exploring the impact of people on marine fisheries requires establishing the antiquity of the fishing tradition in Peru, as well as identifying the anthropogenic and nonanthropogenic forces that could have produced changes in the Peruvian fishery as seen through the filter of the zooarchaeological record. Our focus on the early part of the sequence is mandated for another reason as well. Ironically, zooarchaeological evidence for fishing after the Initial Period is extremely limited, particularly considering that geographical location is an important variable. Data from the few collections that have been published suggest that during at least a portion of this later period the archaeological record reflects the ENSO's impact on sardine and anchoveta populations (Sandweiss et al. 2004), a phenomenon that needs to be studied further with improved data from throughout the coastal strand.

Thus, until the end of the Initial Period most animal-based nutrients were obtained from a fishing tradition that was fully developed as early as 13,000 cal BP, and most plant nutrients were obtained from nondomestic sources until around 3500 cal BP. In view of the regional dominance of this tradition, it seems likely that any disruption in marine productivity would profoundly influence human life there.

ECONOMIC SIGNIFICANCE OF ANCIENT FISHERIES

Archaeologists long have debated the economic importance of marine resources relative to

terrestrial animals and/or plants (see Erlandson [2001] and Yesner [1980], among others). In 1975, Michael Moseley proposed what is known as the Maritime Foundation of Andean Civilization (MFAC) hypothesis to explain the appearance of large sites with complex architecture before large-scale food production from irrigation agriculture on the central Andean Coast (Moseley 1975, 1992). Although the MFAC hypothesis is important in discussions of Andean technology, settlement patterns, and social organization, we will not enter into it here in the interest of focusing on the ancient fisheries themselves.

We emphasize, however, that the dichotomy of terrestrial versus marine resources as a basis for the development of Andean architectural and social traditions is a false one. Typically this argument degenerates into a terrestrial plant versus marine animal argument, that terrestrial plants played a more important role in cultural florescence than did marine animals or vice versa. Humans are biologically broad-spectrum omnivores; they require fats, proteins, some minerals, and fat-soluble vitamins from animal sources, and they require carbohydrates, other minerals, and water-soluble vitamins from plant sources. There are few energetically efficient ways around this nutritional imperative. Fundamentally, people on the coast of Peru always used nutrients from both the plant and the animal kingdoms. Due to the low diversity of terrestrial plants and animals in the Peruvian coastal desert, some plant (e.g., Piperno and Pearsall 1998) and most animal (Reitz 2001) nutrients, but by no means all, likely were obtained from the sea until such time as production of domestic food plants became part of the subsistence system. None of the data presently available suggest that large terrestrial animals played a dominant role in the diet of early coastal Peruvians.

Thus, from a nutritional perspective, it is unlikely that people ever concentrated all of their economic efforts exclusively upon either marine animals or terrestrial plants. The earliest sites tend to lack well-preserved macrobotanical

remains except under unusual circumstances, thus the range of wild plants included in these maritime economies is poorly documented, which does not mean they were not used. From the limited evidence available from early sites, it is clear that fishing did not preclude using terrestrial plants (e.g., Benfer 1990, 1999; A. Cano, personal communication 2001; deFrance et al. 2001; Piperno and Pearsall 1998; Quilter 1991; Quilter et al. 1991; Sandweiss et al. 1989; Weir and Dering 1986; Weir et al. 1988). Equally clearly, using plants did not interrupt the use of marine resources; the earliest domestic plants (gourds and cotton) actually facilitated the fishing tradition. There is no reason that either activity would preclude the other; in this region there are many reasons why they should not.

Even after domestic sources of plant-based nutrients were available, the need for energy, high-quality protein, other nutrients, and raw materials from animal sources remained. Ancient fisheries supplied those needs, a tradition that continued even after domestic animals were available to meet the animal-based nutritional needs. This does not mean that terrestrial resources were excluded from the human diet before domestic plants became available. Biologically that seems extremely unlikely.

The debate on the development of Peruvian culture history should be recast using an energetically and nutritionally realistic model in which the contribution of both plants and animals to the development of Andean cultures is acknowledged. Human and nonhuman biological evidence indicates that ancient fisheries were combined with nondomestic plant foods to support early cultural florescence. Nutrients from domestic plant sources grew in importance over the centuries, with domestic animal nutrients eventually added to the mix. Cultural florescence would not have occurred without critical proteins, fats, vitamins, and minerals from the sea.

It seems likely that one of the problems that had to be resolved as people moved inland to grow crops was how to retain access to their traditional protein base. Improvements in tech-

nology offered by cotton netting and reliable exchange networks between coastal and coastal plain communities were the solution that developed in the Peruvian case. One might even wonder if settlements initially moved to better-watered locations away from the sea in order to grow more cotton so more fish could be caught. Eventually these inland peoples found themselves committed to life away from the sea, but still dependent on it for protein. Much of subsequent Peruvian history may reflect solutions to the problem of maintaining, or controlling, access to the sea while living some distance away from it.

EVIDENCE FOR HUMAN IMPACT ON MARINE ECOSYSTEMS

Given the length and the intensity of the Peruvian fishing tradition, evidence of human impact on the marine ecology, including resource depletion, would be expected. Indeed, archaeological evidence suggests that fishing specialization grew at the community level and that the types of marine organisms used did change (e.g., Reitz 2001, 2003, 2004; Reitz and Cannarozzi 2004; Reitz and Sandweiss 2001; Sandweiss et al. 2004; see also Table 6.1). Such changes could be evidence of a response to anthropogenic damage to the system, or they could have been culturally generated and subsequently led to such damage. Changes in many other cultural practices accompany these technological and biological shifts (e.g., Moore 1991; Sandweiss 1996a, 1996b; Sandweiss et al. 2001a). The parsimonious explanation is that these changes in fishing outcomes, as well as in the cultural patterns associated with them, are related to ENSO and Peru Current fluctuations rather than to overfishing (e.g., Sandweiss et al. 2001a, 2004). Nonetheless, the possibility that this is evidence for human responses to a marine ecosystem altered by overfishing, other aspects of resource depletion, or changes in cultural behavior unrelated to fishing must be considered. We focus here on two aspects of human behavior that could have affected the

marine ecosystem: technology and seasonal fishing schedules.

Technology is an important ingredient in fishing traditions. Changes in technology could be a response to changes in the resource base, cause a change in the resource base, or, at the very least, result in an altered zooarchaeological assemblage. In any case, the archaeological record would contain a different suite of marine organisms. One need only look at the changes in marine ecosystems during the twentieth century to appreciate the impact that a new technology can have. Unfortunately, most of the evidence currently available only supports the conclusion that more sophisticated research is needed. In particular, distinctions between nearshore and offshore fishing need to be examined more closely. Reasons and outcomes for deep diving and for using tools such as nets, leisters, traps, boats, and hooks should also be considered. A third aspect that should be studied more closely are differences along a continuum between small-scale fishing by family groups to serve local needs, and large-scale, specialized fishing producing a surplus for trade under state control.

Cotton netting is one of the most important technological innovations that correlates with changes in the Peruvian archaeological record. If overfishing or other forms of resource depletion were important in Peruvian history, widespread deployment of cotton nets could be related to increased yields of small, low trophic level fishes such as anchovetas and small herrings. The strength of this as a causal relationship is weakened by the presence of cotton at sites that have few small fishes (Pozorski and Pozorski 1979a) and the presence of small fishes at sites without cotton (Chauchat 1988, 1992; Pozorski and Pozorski 1984; Reitz 1995, 2003; Reitz and Canarozzi 2004; Reitz and Sandweiss 2001; Wing 1992). Prior to the introduction of cotton netting, small fishes may have been captured with devices made of noncotton fibers such as the twined and knotted cordage found at Quebrada Jaguay (Sandweiss et al. 1998). The important points are that cotton is not essential to the fish-

ing tradition or to the capture of low trophic level fishes, and that cotton netting is not directly linked to fishing outcomes.

Another important animal-related technological change is the appearance of domestic animals on the coast during the Initial Period (e.g., Bonavia 1996:130–135, 141–145, 152–157). Domestic animals consisted of guinea pig (*Cavia porcellus*) and two members of the family Camelidae, the llama (*Lama glama*) and alpaca (*Vicugna pacos*). The incorporation of domesticated animals into coastal economies was part of a broader diversification strategy. None of these animals were domesticated on the coast, instead they were production alternatives received from elsewhere, as were most of the crops. In spite of this domestic meat source, fishing remained an important source of animal protein (e.g., Moore 1991), in part, perhaps because natural pasture is scarce on the coast and most human-derived pasturage must be irrigated, diverting water away from crops of more direct economic and nutritional value to people.

Another cultural change that might lead to overfishing and other forms of resource depletion is year-round use of marine resources. A common problem in distinguishing between anthropogenic and nonanthropogenic factors is that much of the evidence for changes in seasonal fishing schedules could instead be evidence for climate change. The same markers that indicate seasonal periodicity in resource use also may indicate a change over time in temperature and other climate variables. We can discriminate between evidence for climate change and seasonal periodicity by combining biogeography, geochemistry, and growth habits of environmentally sensitive animals to obtain multiyear records of water temperatures. Such data can then be compared to climate models to determine if the animal died during a cooler or warmer part of the year, and whether the seasonal temperature variations are similar or dissimilar to modern conditions. For instance, the sea catfish (*Galeichthys peruvianus*) from Sitio Siches in Figure 6.2 died when water temperatures were cool.

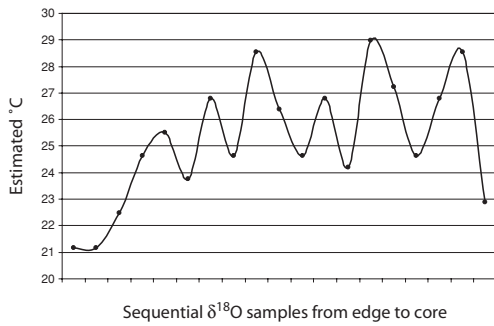


FIGURE 6.2. Season of capture estimated using $\delta^{18}\text{O}$ -based seasonal temperature oscillations in a sea catfish (*Galeichthys peruvianus*) otolith from Sitio Siches. Temperatures are estimated from Grossman and Ku (1986) equation B, assuming a constant .5‰ $\delta^{18}\text{O}$ water value. Temperatures on y axis are listed for relative comparative value and should not necessarily be interpreted as accurate absolute values. The x axis represents sequential samples micromilled through ontogeny. $\delta^{18}\text{O}$ precision is better than .1‰ (1□).

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Oxygen isotope measurements in fish otoliths and mollusc valves also can define season of capture of individual organisms, and, by extension, seasonal fishing schedules. Using incremental growth rings to estimate season of capture for Peruvian examples is problematic in that ENSO fluctuations result in a variable seasonal cycle. One way to circumvent this variability is to analyze isotopes sequentially throughout the life of individuals (Figure 6.2). As temperature oscillated seasonally during the life of this individual, so too did the oxygen isotopes precipitated in the otolith aragonite as they grew. Season of capture is denoted by the $\delta^{18}\text{O}$ values in the last isotopic measurement compared to earlier seasonal oscillations survived by the organism, with the $\delta^{18}\text{O}$ values having a negative relationship with ambient temperature. This assessment offers a minimum season of occupation. The $\delta^{18}\text{O}$ values in the terminal growth band in sea catfish otoliths and cockle (*Trachycardium procerum*) valves from Ostra and Sitio Siches indicate that fishing occurred during both warm and cool parts of the year, but particularly during the cool season (Table 6.2).

Isotope data were generated via laser and conventional micromill extraction as described by Andrus et al. (2002b). Data generated via

TABLE 6.2

Combined Sea Catfish Otolith (*Galeichthys peruvianus*) and Cockle Valve (*Trachycardium procerum*) Season of Capture Estimates from Ostra Base Camp and Sitio Siches Based on $\delta^{18}\text{O}$

SITE/SEASON	WARM SEASON	COOL SEASON
Ostra Base Camp	2	5
Sitio Siches	2	2

conventional extraction are more precise and of a finer spatial resolution than those generated via laser. As a result of these and other differences in the methods, conventional micromill data should be considered more robust. Both methods indicated that Ostra specimens were captured in both warm and cool seasons, thus lending strength to the assessment of seasonality at that site. The two micromilled samples from Siches indicated a cool season occupation, while the two laser samples suggest a warm season occupation.

When isotopic and biogeographic data are combined, we are led to the conclusion that Paloma, Ostra, and Sitio Siches are multiseasonal occupations, if not permanent ones (Reitz 2003; Reitz and Cannarozzi 2004; Reitz and Sandweiss 2001). Such data strengthen the argument that the predominance of warm-water fishes and molluscs at these sites and not at more recent ones reflects climatic conditions rather than changes in targeted species or fishing schedules. If fishing was mainly a cool-season activity then the assemblage should be dominated by cool-water animals. Instead, warm-water animals currently more typical of northern locales are found in these assemblages (Reitz 2001).

If it is true that these sites were occupied during multiple seasons (if not throughout the year) then marine organisms at these sites experienced sustained, intense, multiseasonal fishing for centuries. Though such data do not distinguish among periodic seasonal use of these sites, frequent but not continuous occupation, and essentially permanent occupation,

it seems likely that many of the early sites were used during several seasons, if not permanently. Fishermen, of course, guard their fishing grounds jealously, and it is unlikely that people left any productive traditional fishing claim, or gear too heavy to transport inland, unattended for long (e.g., Acheson 1981; Yesner 1980). Additionally, these seasonality data demonstrate that the apparent full-time dependence on marine resources in this region occurred very early, with no measurable negative impact on the fishery. Much more work needs to be done to (1) associate changes in fishes represented in archaeological deposits with fishing technology and other cultural patterns, and (2) assess the possibility that some of these changes were driven by overfishing rather than by nonanthropogenic changes. For the time being, the evidence for fisheries change due to technological innovations or to overfishing is inconclusive at best.

EVIDENCE FOR BIOTIC EFFECTS OF VARIABILITY IN ENSO AND THE PERU CURRENT

Whereas the evidence for anthropogenic drivers for changes in fishing is limited or problematic, evidence for a nonanthropogenic source of variability is compelling. Stable oxygen isotopes and faunal biogeography suggest that the combination of change-resistant species adapted to the natural variability of ENSO and Peru Current productivity buffered the ecosystem from adverse impacts of human predation until very recently. The changes found in the archaeological record appear to reflect that natural variability.

The oxygen isotope profiles of archaeological and modern sea catfish otoliths from Ostra and Siches suggest that at one time seasonal SST variability was greater than it is today (Andrus et al. 2002a, 2003; see Carré et al. [2005] for Early Holocene data from southern Peru for the wedge clam [*Mesodesma donacium*]). The oxygen isotope profile in Ostra sea catfish otoliths indicates that the annual temperature at that site

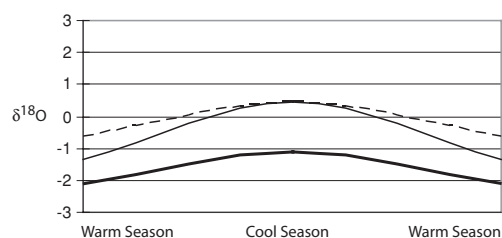


FIGURE 6.3. Sea surface temperatures based on $\delta^{18}\text{O}$ in modern and archaeological sea catfish (*Galeichthys peruvianus*) otoliths. Modern otoliths are from north-central Peru, and archaeological otoliths are from Ostra Base Camp and Sitio Siches (modified from Andrus et al. 2002a, 2002b).

was similar to that experienced today, but that the seasonal range was greater (Figure 6.3; Andrus et al. 2002a, 2002b, 2003). We cannot associate months of the year with these warm and cold seasons because our hypothesized climate change might alter the months in these seasons in some unknown way. Elsewhere it is reported that associating seasonal patterns with specific months is problematic (e.g., Claassen 1998:150–152). The temperature range at Ostra was nearly 7 to 8°C compared to an approximately 5°C range in modern otoliths. Most of the above-modern temperatures evidenced in the Ostra otoliths occurred in the summer months; temperatures averaged almost 3°C warmer during the Ostra occupation compared to temperatures today. In contrast, at Sitio Siches between 7900 and 5150 cal BP, the amplitude of the seasonal cycle was similar to modern, but offset by about +3°C.

The Ostra otolith data are consistent with those derived from cockle (*T. procerum*) valves. The mean $\delta^{18}\text{O}$ range of valves that grew during the powerful 1982–1983 El Niño was 1.3‰ (Andrus et al. 2003; Rollins et al. 1987). In contrast, the mean $\delta^{18}\text{O}$ range in shells from Ostra is approximately 1.5‰ (Andrus et al. 2003; Perrier et al. 1994). Thus shells from Ostra, none of which contain evidence of El Niño in their growth structure, suggest a wider seasonal SST range than experienced by modern cockles during the 1982–1983 El Niño event. Unfortunately, absolute temperatures cannot be calculated

because the former bay at Ostra was an evaporative environment with different oxygen isotope chemistry (U. Brand, personal communication and unpublished data 2002; Perrier et al. 1994).

These data support the hypothesis that ENSO events were less frequent or absent for some millennia prior to about 5800 cal BP and the seasonal range in water temperatures was greater in north-central, coastal Peru than it is today. The isotope profiles themselves are too short to infer the frequency and duration of ENSO cycling, but the seasonal temperature range they suggest explains the warm-water fauna found at Ostra and other sites north of 10° S between ca. 9000 and 5800 cal BP (Reitz 2001, 2004; Reitz and Sandweiss 2001; Sandweiss et al. 1996). Temperature changes of only a few degrees can fundamentally alter a marine ecosystem, impacting the productivity of coastal waters, the reproductive and growth habits of traditional prey species, and the distribution of these animals (Attrill and Power 2002; Perry et al. 2005; Richardson and Schoeman 2004; Sielfeld et al. 2002; Ware and Thomson 2005).

Thus, some changes in the archaeological record may result from natural variability influencing marine biogeography, resource availability, and, hence, fishing strategies (Navarrete et al. 2005; Sandweiss et al. 2001a, 2004). For example, a shift in the frequency of ENSO may be responsible for the disappearance of two bivalves (*Choromytilus chorus* and *Mesodesma donacium*) from north coast archaeological sites around 3000 cal BP (Sandweiss et al. 2001a). The modern ranges of these two molluscs suggest that they would be present in northern Peru only under cool-water conditions with very infrequent ENSO warming events.

In another example, twentieth-century records show that the cycles of fisheries dominated by either sardines (Clupeidae) or anchoveta (Engraulidae) correlate with multi-decadal climate variability (Chavez et al. 2003). The “sardine regime” is associated with warmer conditions and higher-frequency ENSO events, and the “anchovy regime” is characterized by

cooler conditions and lower-frequency ENSO cycles. Fish remains at Lo Demás, occupied between approximately AD 1480 and 1540, document a similar shift from a fishery dominated by anchoveta to one dominated by sardines by about AD 1500 (Sandweiss 1992; Sandweiss et al. 2004). This shift correlates with records for increasing ENSO frequency at the same time. Earlier sites from the Middle and Late Holocene sites also have fish assemblages that suggest similar regime changes.

ANCIENT FISHERIES AND MARINE ECOLOGY OF COASTAL PERU

Environmental variation is a key factor in the antiquity and role of the fishing tradition in Peru. That variation is associated with changes in the types of marine resources used and also with cultural changes (e.g., Quilter 1991, 1992; Quilter and Stocker 1983; Quilter et al. 1991; Sandweiss 1996b; Sandweiss et al. 2001a). In spite of millennia in which people focused on a suite of marine animals for much, if not all, of their animal-derived nutrients, in at least some cases throughout the year, we see no strong evidence for human-induced changes in the marine ecosystem; at least none that cannot be ascribed to nonanthropogenic factors.

As of this writing, no one has examined the later archaeological record for human impacts on shellfish, seabird, sea mammals, or fish populations along the Peruvian coast. Our examination of the types of fishes in the archaeological record finds that changes in these materials are more likely related to ENSO variability on fish populations than to human predation, and that changes in the types of fishes taken throughout the early sequence are a result of ENSO variability more than of human fishing pressure (see also Sandweiss et al. 2004). It remains possible that some changes, such as an increase in offshore or benthic species, might be technologically driven later in the sequence (e.g., Marcus et al. 1999).

The most parsimonious interpretation of this evidence is that changes in fishing

outcomes, as well as in the cultural patterns associated with them, are related to ENSO and Peru Current fluctuations rather than to anthropogenic impact. At the moment, neither fishing technologies nor fishing schedules are strong candidates as the cause or the response to anthropogenic impact on the Peruvian fishery. We expect that applications of isotopic and related approaches will soon provide new data to further distinguish between anthropogenic and nonanthropogenic signatures in the Peruvian zooarchaeological record. Such analysis will improve our understanding of resource depletion and other consequences of ancient fisheries for the marine ecology of coastal Peru unrelated to ENSO.

Levels of predation pressure high enough to trigger rapid change seem not to have been reached during prehispanic times. Clearly, the recent human impact on the marine ecosystems of Peru may be attributed to the advent of several new conditions that altered the entire ecosystem. These include a commercial fishing technology that extracts huge numbers of fishes and other marine organisms, serious exploitation of a resource area not previously exploited, and intentional or unintentional extraction of organisms from the entire food chain. This is quite different from the characteristics of earlier fishing traditions (Jackson et al. 2001). If we add to this the trend for increasingly warmer waters during the twentieth century, then even a rich fishery, one that sustained human life for millennia through many variations in ENSO frequency, duration, and strength as well as variations in the Peru Current, at last could do so no longer. This most recent assault clearly has an anthropogenic component.

Modern fisheries managers need to consider this story carefully. Ancient fishing was not a simple, inflexible strategy (Andrus et al. 2002a; Reitz 2001, 2004; Sandweiss et al. 2004). Some of the changes in fishing strategy were probably responses to nonanthropogenic changes in the resource base associated with changes in ENSO and other with geological, atmospheric, and oceanic phenomena. The pri-

mary role we ascribe to nonanthropogenic factors for changes in the ancient Peruvian fishery may or may not be supported by additional research. The important point is that the fishing strategy, and probably the structure of the fishery itself, changed markedly in the twentieth century and that the consequences of those changes have severely impacted an ecosystem that otherwise appears extremely resilient.

If resource managers and conservation biologists use archaeological data to manage modern fisheries, they must recognize that the answers will not be simple dichotomies of human versus nonhuman causality and anthropogenic resource depletion. The historical record presented by archaeological data should be viewed as a complex web in which environmental and cultural variables are woven together into a fabric rich with variety and surprises. The Holocene environment itself was not a uniform, stable stage upon which people could depend. Flexibility is evident in both the cultural and the noncultural record. It remains to be seen if the need to be flexible was entirely due to nonanthropogenic environmental changes, or if people share some responsibility for changes in the Peruvian resource base. Not only are many recent historical baselines derived from depleted or collapsed fisheries (Jackson et al. 2001), their use in management plans presumes static ecological conditions that the Peruvian archaeological record suggests was not characteristic of this region.

CONCLUSIONS

After approximately 13,000 years of a major focus on the sea for protein and what must at times have been intense fishing pressure, only in the last 100 or so years has the human impact on the resource base exceeded the influence of natural variability. This is counterintuitive but can be attributed to two factors unique to this region. The most obvious is the productivity of the coastal upwelling system. With so much nearshore productivity, it may be hard to disrupt the system. Related to this is ENSO, which passed through

many phases in the Pleistocene and Holocene, alternating among stages where it is "on" or "off," slowed or accelerated. It may be that organisms in these systems are supported by the Peru Current and adapted to the massive disruptions caused by ENSO to such an extent that the resource base was able to sustain intense mortality caused by fishing until very recently. In other words, what may be interesting in the Peruvian case is that it took the combined pressure of a series of intense El Niños in the later half of the twentieth century coupled with international, industrial-scale fishing to affect this region in any significant way. More robust assessment of this hypothesis requires stronger evidence. Regrettably, many of the limitations identified by Yesner (1980) continue to characterize studies of maritime peoples. We look forward to continued research into the relationship between humans and marine ecosystems in Peru with more sophisticated techniques.

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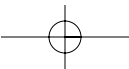
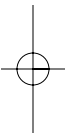
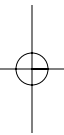
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