Re-evaluating the resource potential of lomas fog oasis environments for Preceramic hunter–gatherers under past ENSO modes on the south coast of Peru

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ABSTRACT

Lomas — ephemeral seasonal oases sustained by ocean fogs — were critical to ancient human ecology on the desert Pacific coast of Peru: one of humanity's few independent hearths of agriculture and "pristine" civilisation. The role of climate change since the Late Pleistocene in determining productivity and extent of past lomas ecosystems has been much debated.

Here we reassess the resource potential of the poorly studied lomas of the south coast of Peru during the long Middle Pre-ceramic period (c. 8000–4500 BP): a period critical in the transition to agriculture, the onset of modern El Niño Southern Oscillation ('ENSO') conditions, and eustatic sea-level rise and stabilisation and beach progradation.

Our method combines vegetation survey and herbarium collection with archaeological survey and excavation to make inferences about both Preceramic hunter–gatherer ecology and the changed palaeoenvironments in which it took place. Our analysis of newly discovered archaeological sites — and their resource context — show how lomas formations defined human ecology until the end of the Middle Preceramic Period, thereby corroborating recent reconstructions of ENSO history based on other data.

Together, these suggest that a five millennia period of significantly colder seas on the south coast induced conditions of abundance and seasonal predictability in lomas and maritime ecosystems, that enabled Middle Preceramic hunter–gatherers to reduce mobility by settling in strategic locations at the confluence of multiple eco-zones at the river estuaries. Here the foundations of agriculture lay in a Broad Spectrum Revolution that unfolded, *not* through population pressure in deteriorating environments, but rather as an outcome of resource *abundance*.

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1. Introduction

"Climatically … the Peruvian coast is in a state of delicate balance, and even a slight change of oceanic circulation pattern affecting the

humidity of the air would be sufficient to cause the retreat of the lomas." [Edward Lanning, 1963: 369.]

The coast of Peru is one of the world's driest deserts and yet for much of the year its air is pregnant with water vapour, a paradox due to the rigid stratification of its tropical air masses above the cold Humboldt Current offshore. Along the seaward Andean footslopes this creates the unique ecological phenomenon of *lomas* — 'oases born of mists' (Dollfus, 1968, cited by Rostworowski, 1981: 34, *our translation*) — in which vegetation flourishes during the austral winter, before fading back to barren desert in the summer. The role that these lomas fog oases played in the long history of human ecology that was to lay the foundations here for one of humanity's few independent hearths of agriculture and cradles of "pristine" civilisation, has been much debated.

Over the long trajectory of the Middle Preceramic Period (c. 8000—4500 BP) hunter—gatherers here exploited a variety of ecological niches, juxtaposed along this otherwise extremely arid littoral, including: the riparian oases along the floodplains of rivers arising in the Andean hinterlands; estuarine wetlands; and not least, one of the world's richest marine ecosystems sustained by deep upwelling offshore. Explaining how, and *why*, human exploitation shifted between these different ecologies through time is key to understanding increasing sedentism and the emergence of agriculture here. And there is a dichotomy in interpretation of precisely how important lomas fog oases were to these changes: illuminated by only a few detailed, well-reported investigations along almost 2500 km of Pacific coastline, most notably in Chilca (e.g. Engel, 1987; Quilter, 1991), and Quebrada de los Burros in the far south (e.g. Lavallée and Julien, 2012). This remains a fundamental issue, not least because lomas environments — highly sensitive both to climate shifts and to human impact — were seemingly abandoned at the end of the Middle Preceramic Period: a critical time period during which intensified exploitation of marine resources, alongside the cultivation of cotton and food plants on river floodplains (Moseley, 1975), laid the foundations for larger scale populations and the first emergence of Andean social complexity.

Early investigators, particularly struck by the density of lithic artefacts encountered in the lomas, asserted that these environments were the prime resource for Early Holocene hunter-—gatherers on the Peruvian coast, and moreover, that they had formerly been far more extensive. Lanning (1963, 1967) and Engel (1973) believed that the lomas had provided rich resources for transhumant hunter—gatherers living there during winter months: what Engel (1981: 24) called the 'fog oasis situation'. They further interpreted the occurrence of large expanses of desiccated vegetation and snail shells outside the limits of today's lomas formations as evidence of their former extent. Indeed, Lanning (1967: 51) believed that ever since their first occupation in the Terminal Pleistocene the lomas had been in constant retreat, as the fog belt lifted due to changes in the Humboldt Current, contracting to a tenth of their original extent by the time of their abandonment around 4450 BP.

Soon, however, this model of lomas ecology in the early prehistory of Peru came to be challenged as a 'transparent adventure in environmental determinism' (Craig and Psuty, 1968: 126). Its critics (*inter alia* Parsons, 1970; Craig, 1985, 1992) argued, as Lynch (1971: 140) summarises, that 'lomas vegetation and animal life could never have been important to man, that the greater previous extent of lomas vegetation has not been established and that … there is no reason to believe that the climate of coastal Peru has been substantially different from the present during postglacial times'. Relict extensions of desiccated vegetation and snails were,

it was suggested, the product of occasional El Niño Southern Oscillation ('ENSO') climatic perturbations, rather than of permanently more extensive lomas. Indeed, some of these extraordinarily preserved formations of desiccated *Tillandsia* date far back into the Pleistocene (Hesse, 2014). Many see little evidence for any significant long-term climatic change throughout the Holocene on the Peruvian coast (e.g. Craig and Psuty, 1968; Parsons, 1970; Craig, 1985, 1992; Wells and Noller, 1999).

Instead, other factors were now invoked to explain the changes in archaeological patterning observed to occur at the end of the Middle Preceramic, including over-exploitation of fragile lomas ecologies driven by population growth (e.g. Patterson and Moseley, 1968: 124; Cohen, 1978b; Weir and Derring, 1986), and indeed technological change. For Moseley (1975), argued that rather than diminution of lomas resources driving people to exploit marine resources, it was an enhanced ability to do so, thanks to the introduction of cotton agriculture. Moreover, Lanning's model had failed to take into account the effects of rising sea levels on the archaeological pattering observed on the central Peruvian coast (Richardson, 1998), and new findings suggested far greater time depths for maritime adaptations (Sandweiss, 2009). Such refinements, however, still leave the ultimate cause of the abandonment of the central Peruvian lomas to be fully explained.

Meanwhile, there have been significant advances in palaeoclimatic research. Broad scale climatic changes are thought to have occurred in Peru throughout the retreat of the glaciers that mark the Pleistocene—Holocene transition and the stabilisation of sea levels that followed. These may have significantly affected monsoonal circulation and tropical rainfall of Amazonian origin over the Andes (e.g. Betancourt et al., 2000; Mächtle and Eitel, 2012). Most palaeoclimatic reconstruction, however, using proxy record from both on and off shore locations across the Andes, has focused on the history of ENSO variation, and its effect on the Humboldt current, along the Pacific coast of Peru during the Holocene (e.g. Rollins et al., 1986; Sandweiss et al., 1996, 2004; Rodbell et al., 1999; Moy et al., 2002; Sandweiss and Kelley, 2012; Etayo-Cadavid et al., 2013; Loubere et al., 2013; Carré et al., 2012, 2013, 2014). On the Peruvian coast itself where 'standard palaeoclimatic records are absent or underdeveloped' (Sandweiss, 2003: 23), these often entail proxy data recovered from archaeological deposits.

In this paper we revisit the 'lomas dichotomy' in the light of new investigations of the lomas formations of the Peruvian south coast: defined herein as the 250 km of Pacific coastline encompassed by the Pisco, Ica, Río Grande de Nazca and Acarí river valleys. These valleys have a distinctive geomorphology, climate and hydrology from those of Peru's north and central coasts (Beresford-Jones, 2011), and from those further south to the Chilean border (the 'far south'). Consequently, for much of Peru's prehistory, they also have a shared and distinctive cultural trajectory, commonly labelled 'south coast' by archaeologists (e.g. Willey, 1971: 78).

Our findings arise out of collaborations between Cambridge University's One River Project and the Royal Botanical Gardens Kew, as follows:

1. New investigations of the botany and ecology of the highly endemic and lomas formations of this region. To date these are largely unstudied, and indeed the few references to them (Parsons, 1970; Oka and Ogawa, 1984: 115; Craig, 1985) betray inaccuracies that underplay their resource potential.
2. New archaeological investigations of these south coast lomas and their associated littoral to reveal an entire Preceramic landscape. Although the south coast archaeological record comprises some of Peru's most famous cultural manifestations, not least Paracas and Nasca, their Preceramic predecessors have

not been much investigated since the pioneering work of Engel in the 1950's.

The paucity of previous scientific investigation here is, in part, because the lomas of the south coast are relatively remote from modern settlement as the course of the Pan-American highway is diverted much further inland than elsewhere along Peru's littoral. Yet this has also better preserved their fragile biodiversity and their Preceramic archaeological record, and, as we will see, conveys certain clarities to the interpretations of its ancient human ecology.

We will use these findings to reassess the importance of lomas resources to Preceramic human ecology on this previously under-studied part of the Peruvian coast, revisiting the question of why changes took place through time in the context of the latest, detailed Holocene palaeoclimatic reconstructions specific to the south coast.

2. The ecology of lomas fog oases

There are two sources of water along the arid Peruvian coast, each arising in distinct seasons. The first arises from the small portion of intense precipitation over the Amazon Basin during the austral summer that overcomes the formidable rain shadow of the Andean cordillera, to drain their western flanks in seasonal streams and rivers (Prohaska, 1973). The second is more ephemeral — at least in non-ENSO years — arising in the austral winter, between around August and November, as a deepening inversion layer saturated with moisture over cold seas is blown inland by trade winds. Where this marine stratus inversion layer encounters the coastal Andean flanks between 300 and 1000 m asl, orographic cooling causes fogs to coalesce, resulting in fine, horizontally moving drizzles (*garúas* or *camanchacas*). This moisture is sustained by reduced evaporation due to stratus cloud cover producing 'occult precipitation' and fostering formations of fog-drip vegetation known as lomas. Since vegetation creates the interception surface area on which fog condenses and is trapped, this growth acts greatly to increase the amount of water that would be deposited on barren slopes (Engel, 1973; Walter, 1973; Oka, 1986; Muenchow et al., 2013). As this occurs, lomas formations blossom across the desert with intense green meadows and pasture.

The term 'lomas' is used colloquially in Peru to describe the Andean foot slope and coastal cordillera all along the Pacific, so that ecologists, geographers and archaeologists have come to use the term idiosyncratically, as Craig (1985: 28) notes, for various distinct ecological niches, including desert scrub found at higher altitudes and vegetation along erratic quebrada watercourses. Here, we use the term *sensu stricto* to mean those plant communities which rely exclusively on fog: depauperate for much of the year, dominated by *Tillandsia*, but flourishing with lush, ephemeral herbaceous growth during the winter months (Dillon et al., 2003).

Such fog oases are to be found along parts of the western coast of South America between ~6°S and 30°S (Manrique et al., 2010). In Peru there are at least 70 discrete localities supporting lomas, occupying a total of some 8000 km² (Péfaur, 1982; Dillon et al., 2003; Dillon, 2011). Their vegetation communities are clearly delimited ecosystems, unique within the context of South American ecology and floristic composition (Stafford, 1939; Dillon, 2011). They consist of varying mixtures of annuals, short-lived perennial and woody vegetation, represented by a total of some 850 species in 385 genera and 83 families (Dillon, 2011). They are home also to a variety of animal life (Péfaur, 1981; Zeballos et al., 2000).

Around 40% of the plant species in the lomas communities of the south coast can be classed as perennials and maintain themselves through the dry season by a variety of vegetative, starch-rich, underground storage organs ('geophytes', Fig. 6B and C) such as roots,

corms, tubers and bulbs (in the case of the 15% that are monocots). Indeed, we find that many plants previously classed here as annuals turn out, on excavation, to be perennials, arising from deep corms on contractile roots, or simply re-sprouting from apparently dead leafless stems, supplied by enlarged roots or stems.

When sustained winter fogs arrive, and depending upon the intensity and duration of the fog season, these perennials re-sprout, thereby increasing moisture capture and acting as 'nurse plants' for annuals to germinate anew from the previous year's seed production. Once winter gives way to spring and increasing amounts of sunshine, all the lomas comes into flower simultaneously to maximise rapid pollination and set seed, many of which are adapted to resist high summer temperatures and lie strewn across the desert surface, awaiting the return of winter fogs.

Lomas vegetation is highly sensitive to ENSO climatic perturbations and indeed, certain lomas plants depend on the periodic recurrence of El Niño to propagate themselves (Caviedes, 1984; Manrique et al., 2010; Dillon, 2011). Importantly, however, our research shows that the relationship between lomas ecosystem productivity and ENSO is rather complex: while some parts of the lomas ecosystem wax under particular ENSO variations, others wane. We return to consider the implications of this later.

Within lomas formations vegetation occurs in distinct belts whose composition is determined by variations in moisture availability, which are predominantly a function of altitude, but also of slope, aspect and type of ground surface in relation to the intensity, direction and velocity of coastal fog (Ono, 1986; Rundel et al., 1991; Muenchow et al., 2013). The most diverse herbaceous fog meadow flourishes with winter fogs in a belt immediately beneath the altitude at which the inversion layer intercepts the land (Péfaur, 1982; Muenchow et al., 2013). Along its margins, particularly further inland where conditions are more arid, the lomas of the south coast are characterised by transitional belts occur composed of low-density areas of cacti, and high-density formations of *Tillandsia* species, which can extend over vast tracts of desert (Péfaur, 1982; Rundel and Dillon, 1998; Whaley et al., 2010; Hesse, 2012).

Unlike most lomas which occur along the foothills of the Andes themselves, those of the south coast are separated from the main Andean cordillera by an expanse of uplifted desert sedimentary tableland around 60 km wide (Beresford-Jones, 2011). Here, lomas formations — from north to south: Morro Quemado, Asma, Amara-Ullujaya and San Fernando — occur along the seaward flanks of the Coastal Cordillera (Fig. 1). These fragments of granite batholith run along the Pacific coast for almost 150 km, and rise abruptly out of the ocean to attain heights of around 800 m, 1000 m and 1791 m asl, in the Lomas of Morro Quemado, Amara-Ullujaya, and San Fernando, respectively. These south coast lomas formations thus lie almost on the littoral, and quite far from the parallel inland courses of the north-south flowing Río Ica, and the most westerly of the Río Grande de Nazca's several tributaries.

3. New investigations in the lomas of the south coast

From 2012 to 2014 Cambridge University's One River Project and the Royal Botanical Gardens Kew, collaborated on new investigations of the lomas of the south coast through joint and several fieldwork entailing:

1. RBG Kew undertook a spatial analysis of vegetation and floristic composition in the lomas of San Fernando and Amara by systematic collection of herbarium vouchers in plots across transects to identify species and develop understanding of the ecology, biodiversity across the south coast lomas. An important purpose of this work is to produce baseline species and
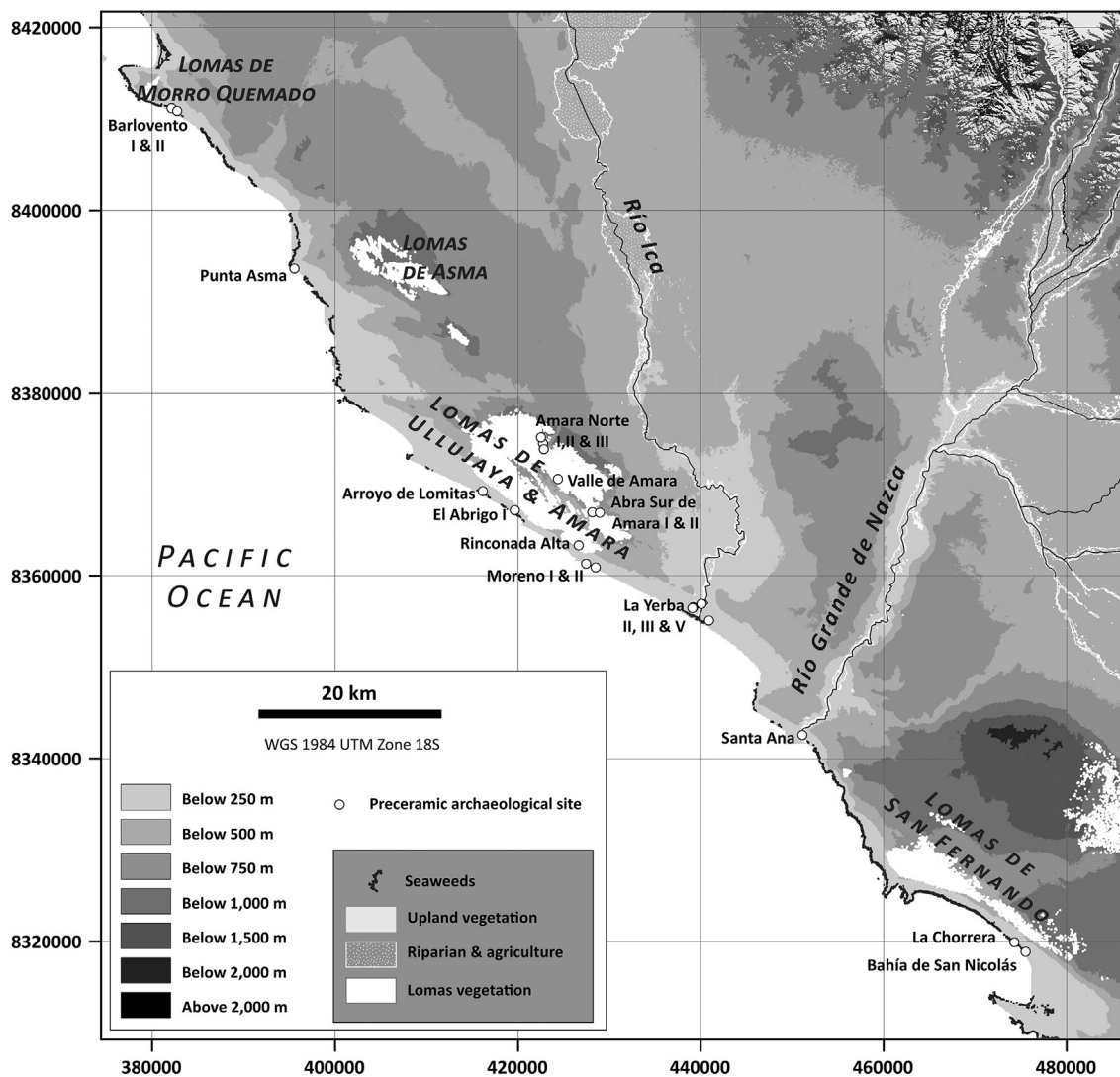
Fig. 1. Map of the south coast showing Preceramic archaeological sites together with lomas and other vegetation associations derived as described in Section 3.

vegetation maps to support conservation delimitation by Peru's Servicio Nacional de Áreas Naturales Protegidas por el Estado ('SERNANP').

Figs. 1 and 2 show vegetation maps derived from two sources: Landsat 8 imagery from March 2014 to March 2015 supplemented with GeoEye imagery (October/November 2011) for the San Fernando region. Landsat imagery was processed to give Normalised Different Vegetation Index (NDVI, Tucker, 1979) for each month, these were stacked and the maximum NDVI over this yearly period calculated. This maximum NDVI imagery was thresholded to pull though the herbaceous lomas and the *Tillandsia* vegetation. Vegetation in the San Fernando region did not show up in the Landsat imagery, probably because the seasonal lomas growth 2014–2015 was very poor. Thus lomas vegetation for the San Fernando region was derived from GeoEye imagery in the same way described for Landsat. These two vegetation maps were overlaid to give Figs. 1 and 2.

Fig. 2B shows a detail of the Amara lomas from a Near infrared false colour composite (NIR, red and green) image, showing high density of seasonal herbaceous lomas vegetation as dark grey, using GeoEye imagery from 10 February

2010, during an ENSO event entailing moderately increased sea surface temperature anomalies off the coast of Peru. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 3 shows the vegetation associations recorded across transect A (see Fig. 2) of the lomas de Amara. The relative extent of the vegetation units, bands or overlapping zones, is indicated with bars corresponding with the vegetation characterisation derived from herbarium voucher collections, drone flights, satellite imagery and other fieldwork including walked transects, seed analysis and root test pits. The figure also shows aggregated lomas resource values under a normal fog season and under El Niño and La Niña climatic modes.

2. Cambridge University's One River Project carried out new investigations of the Preceramic archaeology associated with the lomas of the south coast (Arce et al., 2013, 2015). We follow in the footsteps of Frédéric Engel (1981, 1991), whose seminal work here in the 1950's identified 14 Preceramic sites along the littoral between Morro Quemado and the Bahía de San Nícolas, eight of which he radiocarbon dated. As well as investigating many of these in much more detail and subjecting them to
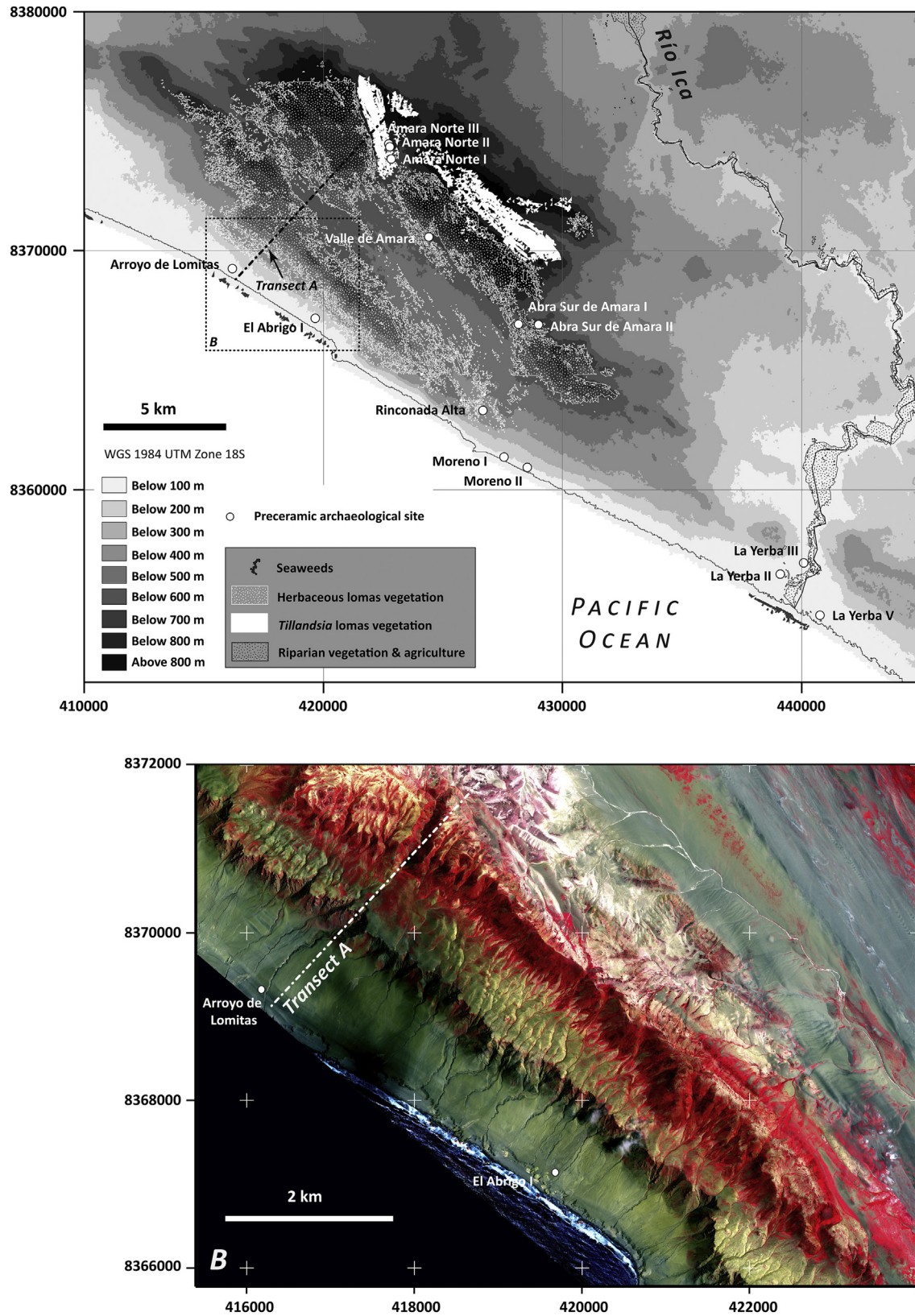
Fig. 2. Map of the lomas of Amara and Ullujaya showing Preceramic archaeological sites together with lomas vegetation associations derived as described in the text, and Transect A across which RBG Kew carried of systematic collections of herbarium vouchers in plots. Inset B shows a detail of the Amara lomas using NIR to show the high density of lomas vegetation as dark grey (red in online version) on 10 February 2010 during a moderate El Niño, as described in Section 3 (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

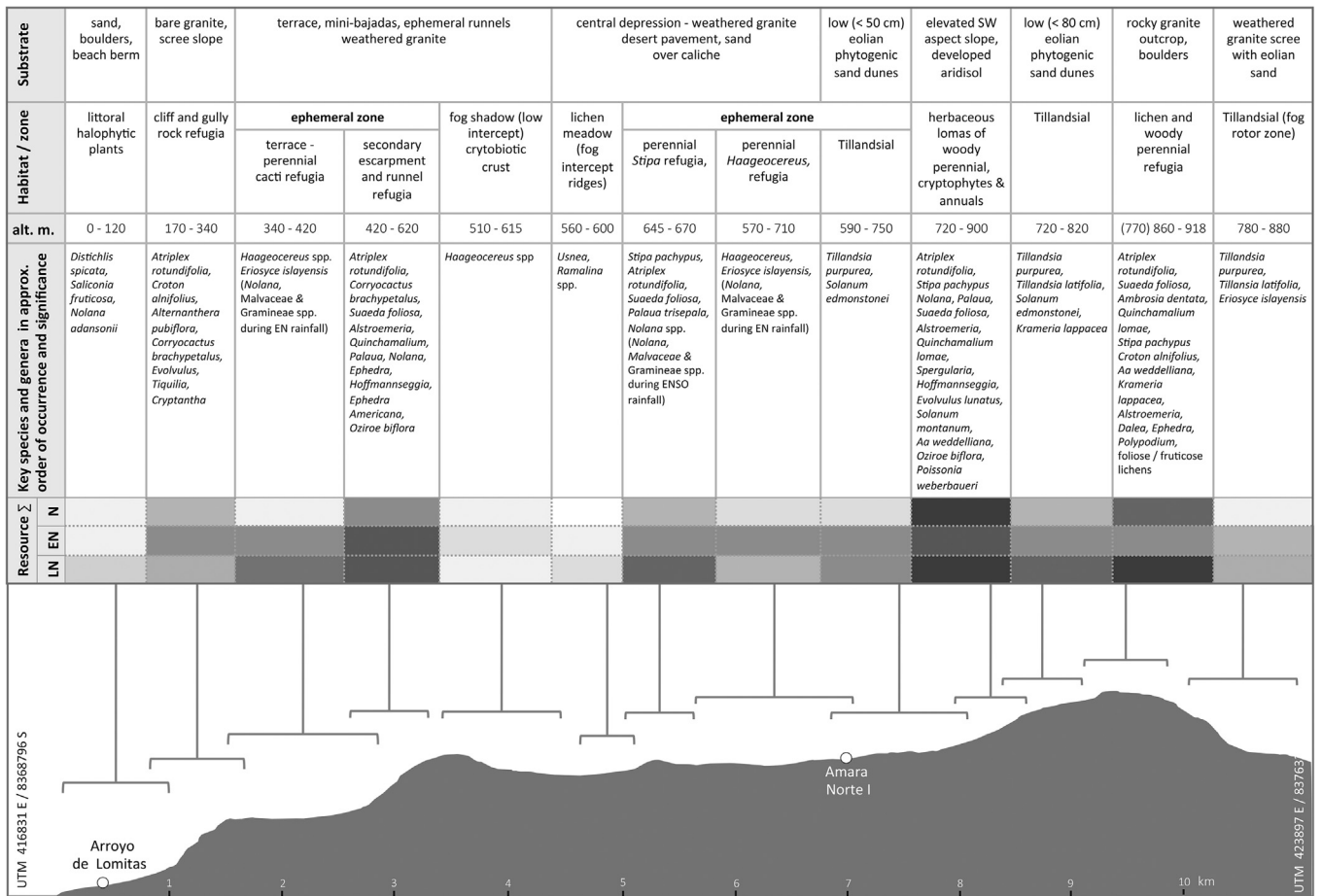| Substrate	sand, boulders, beach berm	bare granite, scree slope	terrace, mini-bajadas, ephemeral runnels weathered granite			central depression - weathered granite desert pavement, sand over caliche			low (< 50 cm) eolian phytogenic sand dunes	elevated SW aspect slope, developed aridisol	low (< 80 cm) eolian phytogenic sand dunes	rocky granite outcrop, boulders	weathered granite scree with eolian sand
Habitat / zone	littoral halophytic plants	cliff and gully rock refugia	ephemeral zone		fog shadow (low intercept) crytobiotic crust	lichen meadow (fog intercept ridges)	ephemeral zone			herbaceous lomas of woody perennial, cryptophytes & annuals	Tillandsial	lichen and woody perennial refugia	Tillandsial (fog rotor zone)
			terrace - perennial cacti refugia	secondary escarpment and runnel refugia			perennial *Stipa* refugia,	perennial *Haageocereus*, refugia	Tillandsial				
alt. m.	0 - 120	170 - 340	340 - 420	420 - 620	510 - 615	560 - 600	645 - 670	570 - 710	590 - 750	720 - 900	720 - 820	(770) 860 - 918	780 - 880
Key species and genera in approx. order of occurrence and significance	*Distichlis spicata, Saliconia fruticosa, Nolana adansonii*	*Atriplex rotundifolia, Croton alnifolius, Alternanthera pubiflora, Corryocactus brachypetalus, Evolvulus, Tiquilia, Cryptantha*	*Haageocereus* spp. *Eriosyce islayensis* (*Nolana, Malvaceae* & *Gramineae* spp. during EN rainfall)	*Atriplex rotundifolia, Corryocactus brachypetalus, Suaeda foliosa, Alstroemeria, Quinchamalium, Palaua, Nolana, Ephedra, Hoffmannseggia, Ephedra Americana, Oziroe biflora*	*Haageocereus* spp	*Usnea, Ramalina* spp.	*Stipa pachypus, Atriplex rotundifolia, Suaeda foliosa, Palaua trisepala, Nolana* spp. (*Nolana, Malvaceae* & *Gramineae* spp. during ENSO rainfall)	*Haageocereus, Eriosyce islayensis,* (*Nolana, Malvaceae* & *Gramineae* spp. during EN rainfall)	*Tillandsia purpurea, Solanum edmonstonei*	*Atriplex rotundifolia, Stipa pachypus Nolana, Palaua, Suaeda foliosa, Alstroemeria, Quinchamalium lomae, Spergularia, Hoffmannseggia, Evolvulus lunatus, Solanum montanum, Aa weddelliana, Oziroe biflora, Poissonia weberbaueri*	*Tillandsia purpurea, Tillandsia latifolia, Solanum edmonstonei, Krameria lappacea*	*Atriplex rotundifolia, Suaeda foliosa, Ambrosia dentata, Quinchamalium lomae, Stipa pachypus Croton alnifolius, Aa weddelliana, Krameria lappacea, Alstroemeria, Dalea, Ephedra, Polypodium,* foliose / fruticose lichens	*Tillandsia purpurea, Tillansia latifolia, Eriosyce islayensis*

Resource ∑	N													
	EN													
	LN													

UTM 416831 E / 8368796 S

UTM 423897 E / 83763

Arroyo de Lomitas

Amara Norte I

1   2   3   4   5   6   7   8   9   10 km

Fig. 3. Transect A across the Amara lomas (see Fig. 2) showing key vegetation associations and their altitudinal ranges, together with total lomas resource values (1–7 tonal values: light = low, dark = high), relative to both the climatic mode and other resources during a given lomas year (where N is a normal year, EN an El Niño year and LN a La Niña year), as described in Section 3.

modern sampling, we turned our attention also to the lomas hinterlands, in which we identify another seven previously unknown Preceramic sites. At many of these sites we carried out investigations of exposed profiles, new excavations and surface collections, during which we sampled for flotation to extract organic remains and heavy fraction components, geochemistry, monoliths for micromorphology, radiocarbon dating, etc.

Figs. 1 and 3 and Table 1, presents the results of this updated and augmented archaeological survey of the Preceramic landscape along the south coast between the Morro Quemado and the Bahía de San Nícolas, in which all radiocarbon dates are now presented calibrated using the ShCal13 curve (Hogg et al., 2013) in OxCal version 4.2 (Bronk Ramsey, 2009).

4. The potential of south coast lomas to Preceramic human ecology

The Preceramic archaeological patterning recorded on the south coast naturally reflects the differential distribution of many resources of food, fuel and raw material resources. Yet the first essential that dictates where people settle and move in such an extremely arid landscape is, of course, fresh water (e.g. Erlandson, 2001). What is most striking about the archaeological site distribution shown on Fig. 1 is that, while the largest and most visible Preceramic archaeological remains are, unsurprisingly, to be found

at the mouths of the Ica and Nazca Rivers, many Preceramic sites lie scattered far beyond the river courses: and yet always intimately associated with the coastal lomas formations. Indeed, as we will see, *all* of these Preceramic sites, regardless of their locations, contain significant lomas-derived resources.

4.1. Sites on river estuaries

The largest and most visible Middle Preceramic archaeological remains between Morro Quemado and Bahía de San Nícolas lie at the mouths of the Ica and Nazca Rivers. A number of sites on the Río Ica estuary date to early in the Middle Preceramic Period (Table 1), the largest and most visible of which are La Yerba II and La Yerba III. Their midden deposits are dominated by evidence of hunted and gathered marine resources: sea mammals, birds, fish and molluscs, particularly *Mesodesma donacium* surf clams that, until the 1997/98 El Niño, proliferated in vast beds just at the surf lines of the adjacent beaches. They also include many other organic components enjoying excellent preservation through desiccation, not least remains of plants: including, *inter alia*, seaweeds and Cyperaceae rhizomes; woven reeds and wooden posts in the vestiges of windshelters and houses; plant fibres spun and plied into lines and nets; and bottle gourd (*Lagenaria* sp., radiocarbon dated to 6936–6735 cal BP, see Table 1, OxA-29944) and both wild (*Vigna* sp.), and domesticated beans (*Phaseolus lunatus*, radiocarbon dated to 6270–5996 cal BP, see Table 1, OxA-32290): all presumably
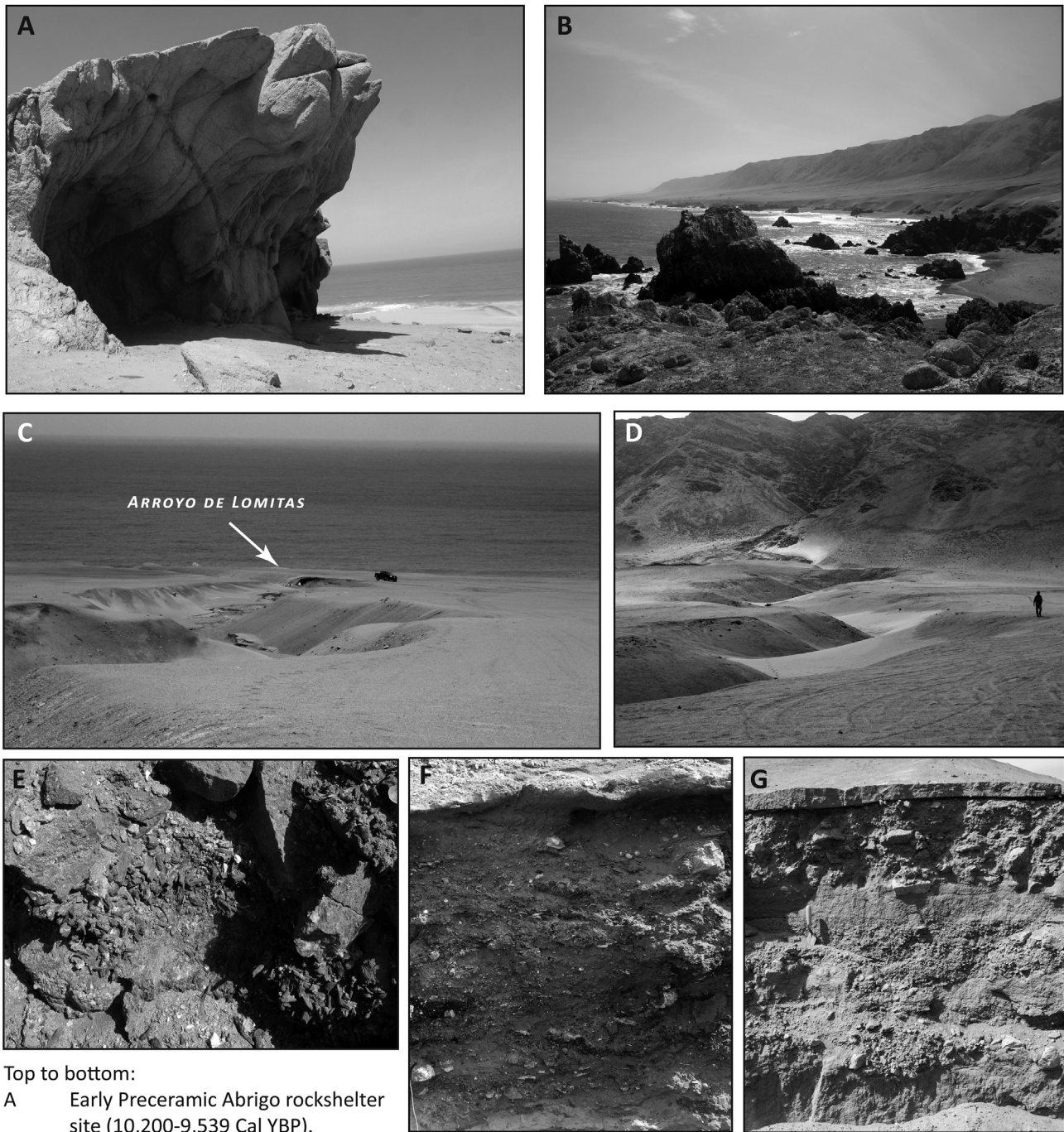
Top to bottom:

A   Early Preceramic Abrigo rockshelter
         site (10,200-9,539 Cal YBP).
B   View north along lomitas littoral with Lomas de Amara behind.
C&D   Views west towards ocean and east towards lomas de Amara, respectively, of watercourse alongside Middle
         Preceramic site of Arroyo de Lomitas (5,286-4,587 Cal YBP) under excavation.
E   Detail of charcoal in structured hearth at Arroyo de Lomitas.
F   Section of Arroyo de Lomitas showing Middle Preceramic midden and hearth deposits.
G   Sedimentary profile of Arroyo de Lomitas watercourse showing clastic deposits and alluvium.

Fig. 4. Details of selected Preceramic sites along the Amara lomas foreshore.

cultivated on the river floodplain. We interpret these sites on the estuary to be the logistical basecamps (*sensu* Binford, 1980) of seasonally mobile hunter—gatherers, although there is significant evidence of increasing sedentism at La Yerba III. They are located at the confluence of different habitats: riparian woodland, river estuaries, sandy beach, rocky headlands and an ecologically diverse lomas mosaic. Each could provide seasonally abundant and predictable resources, accessed at different times of the year by different members of society (men, women and children), according to varying levels of energy expenditure and hazard.
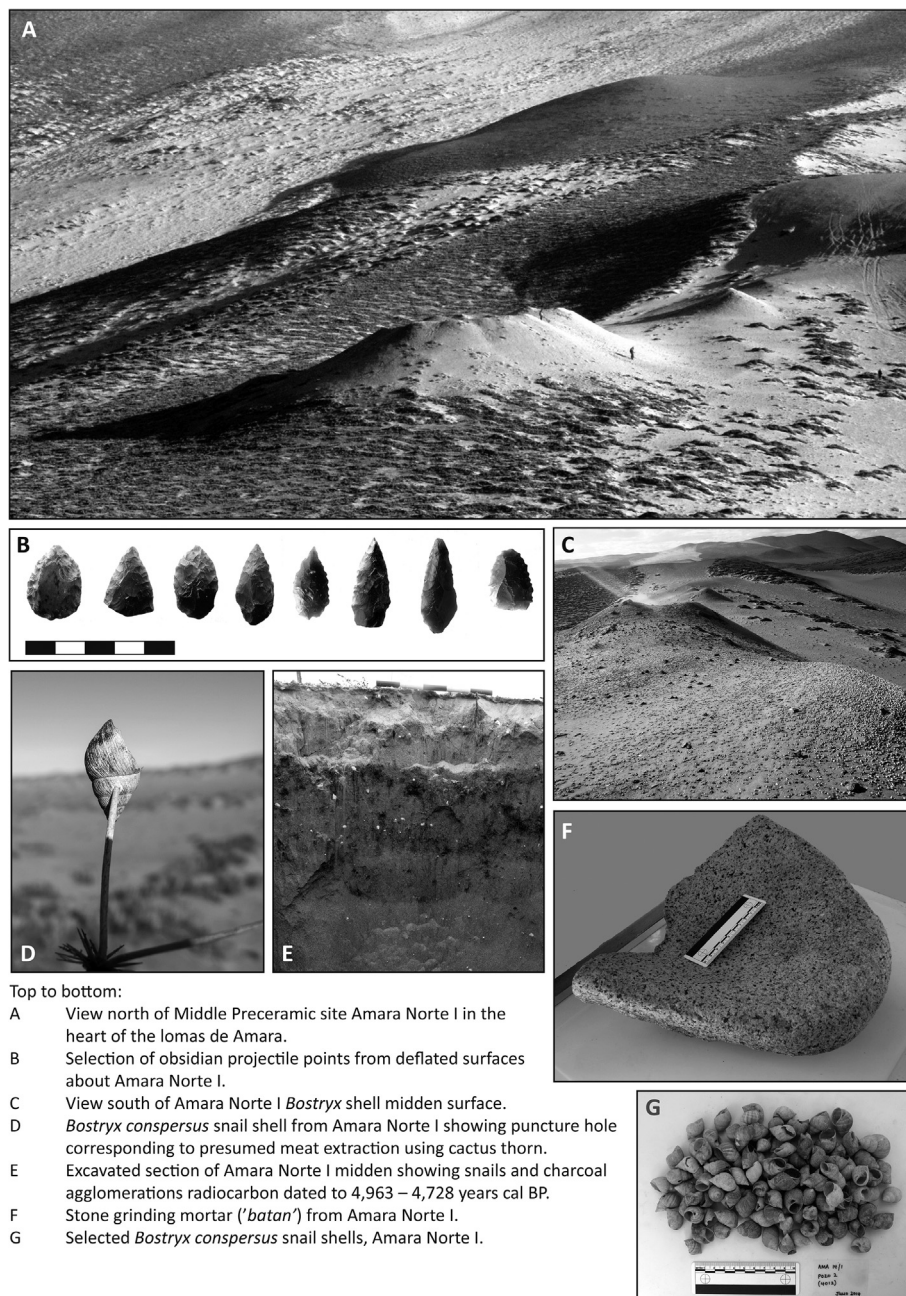
Top to bottom:
A View north of Middle Preceramic site Amara Norte I in the heart of the lomas de Amara.
B Selection of obsidian projectile points from deflated surfaces about Amara Norte I.
C View south of Amara Norte I *Bostryx* shell midden surface.
D *Bostryx conspersus* snail shell from Amara Norte I showing puncture hole corresponding to presumed meat extraction using cactus thorn.
E Excavated section of Amara Norte I midden showing snails and charcoal agglomerations radiocarbon dated to 4,963 – 4,728 years cal BP.
F Stone grinding mortar ('*batan*') from Amara Norte I.
G Selected *Bostryx conspersus* snail shells, Amara Norte I.

Fig. 5. Details of selected Preceramic sites in the Amara lomas.

Upstream of the river estuaries, few Middle Preceramic sites are reported on the south coast (Isla, 1990; Vogt, 2011; Gorbahn, 2013), though doubtless other remains have been obscured by subsequent agricultural and geomorphological changes. Far beyond the river courses, however, our investigations reveal other component parts of the Middle Preceramic landscape: all of which are directly dependent on lomas to provide key resources, not least water and fuel. These are of two general types.

4.2. Sites along the lomas littoral

The first group of Preceramic sites such as Arroyo de Lomitas, Abrigo I and Bahía de San Nícolas, all identified originally by Engel (1981, 1991), are located along the lomas foreshore, thereby simultaneously granting immediate access to marine and lomas resources (Figs. 1 and 4).

Our investigations of the dense, stratified midden deposits at Arroyo de Lomitas, including structured hearths (Fig. 4E and F) suggest that ground water sources here were sufficient to sustain small groups of hunter—gatherers for stretches of time. These middens are dominated by marine resources of the adjacent rocky littoral, particularly gastropods, mussels and seaweeds. Today itinerant fishermen call the site '*Agua Dulce*' (or '*Pozo de los Chilenos*' on the *Instituto Geográfico Nacional Peruano* map, Sheet 1741), and affirm that water here can always be obtained by excavating above the tidal margin where the arroyo emerges onto the beach. Indeed, *all* these Preceramic sites along the coast are associated with watercourses arising from in the lomas (Strong, 1957: 8, Engel 1981, 1991: 58).

The abrupt topography and impermeable granite massif of the

Top to bottom:
A   Lomas de Amara,
        August 2013.
B&C   Lomas de Amara tubers, *Oxalis* sp. and *Solanum montanum*,
        respectively.
D   Guanao (*Lama guanicoe*) footprints, lomas de Amara, August 2013.
E&F   Edible *Haageocereus* sp. cactus fruit, lomas de San Fernando.
G   Live *Bostryx conspersus* snail on Atriplex sp., lomas de Amara,
        August 2013.

Fig. 6. Selected south coast lomas resources.

Coastal Cordillera, rising out of the sea to over 1000 m, forms a vast and ideal surface for fog condensation and consequent run-off. Emerging from the seaward bluffs of the Amara and San Fernando lomas are multiple arroyos, deeply incised into the uplifted Holocene marine terrace, that stand testament to periodically significant surface flows. The range of clastic materials within the discrete water-lain deposits of these arroyos are evidence of erratic, high-energy flows perhaps during ENSO events (Fig. 4G). Yet layers of finer alluviums attest to water flows even during normal years (cf. Fontugne et al., 1999) and their courses are lined with perennial vegetation in the form of *Atriplex rotundifolia*, (Chenopodiaceae), *Croton alnifolius* (Euphorphiaceae) and *Tiquilia* spp. (Boraginaceae), a variety of small herbs such as *Alternanthera* sp. (Amaranthaceae) and *Parietaria debilis* (Urticaceae), and large relict stands of the cactus *Corryocactus* aff. *brachypetalus*, whose size is evidence of significant, if sporadic, water availability.

Unlike most coastal lomas contexts, wherein the two sources of water in this coastal desert, described in Section 2 above, are

Table 1
Preceramic sites associated with south coast lomas (between 14° 19′ and 15° 15′ S).

Site	Location (WGS84 18L)		Alt. (m)	Site code	Associated lomas formation	Site Ecotone	Radiocarbon dates				Reference
	Easting	Northing					^{14}C yr BP	Error (±)	Cal BP[a]	Lab key	
Barlovento I	382165	8411166	24	14b X − 205 A	Morro Quemado	Sandy littoral					
Barlovento II	382278	8411100	18	14b X − 203	Morro Quemado	Sandy littoral					
Punta Asma	395589	8393590	10	15a II-504	Asma	Rocky littoral					
Amara Norte III	422765	8374451	698	ORP-605	Amara-Ullujalla	Tillandsia lomas					
Amara Norte II	422808	8374327	693	ORP-610	Amara-Ullujalla	Tillandsia lomas					
Amara Norte I	422855	8373815	600	ORP-585	Amara-Ullujalla	Tillandsia lomas	4325	30	4963 4728	OxA-32350	
Valle de Amara	424436	8370553	720	ORP-611	Amara-Ullujalla	Atriplex lomas					
Arroyo de Lomitas	416205	8369229	37	15a VI-525	Amara-Ullujalla	Rocky littoral	4360	95	5286 4587	I-7774	Engel, 1991: 56
El Abrigo	419684	8367142	48	15a VI-550	Amara-Ullujalla	Rocky littoral	8835	145	10,200 9539	I-7772	Engel, 1991: 56
Abra Sur de Amara I	428183	8366898	547	ORP-609	Amara-Ullujalla	Atriplex lomas	–	–			
Abra Sur de Amara II	429011	8366874	649	ORP-602	Amara-Ullujalla	Herbaceous lomas	–	–			
Rinconada Alta	426689	8363298	340	ORP-619	Amara-Ullujalla	Atriplex lomas	–	–			
Moreno I	427500	8361271	25	15a IX-300	Amara-Ullujalla	Sandy littoral	–	–			
Moreno II	428550	8360900	25	15a IX-301	Amara-Ullujalla	Sandy littoral	–	–			
La Yerba I	439213	8356533	20	15b VII-50	Amara-Ullujalla	River estuary	7520	300	9015 7696	Birm-511	Engel, 1991: 56
La Yerba I (SU 1024)	439213	8356533	20	ORP-209	Amara-Ullujalla	River estuary	6375	39	7415 7165	OxA-30913	
La Yerba II	439123	8356430	21	15b VII-45 & 100	Amara-Ullujalla	River estuary	6470	110	7571 7030	I-7773	Engel, 1991: 56
La Yerba II (SU 1015)	439123	8356430	21	ORP-207	Amara-Ullujalla	River estuary	5988	33	6881 6674	OxA-29975	
La Yerba II (SU 1079)	439123	8356430	21	ORP-208	Amara-Ullujalla	River estuary	6029	32	6936 6735	OxA-29944	
La Yerba II (level 5)	439123	8356430	21	ICA-IN	Amara-Ullujalla	River estuary	5940	45	6944 6739	OS-60556	Carré et al., 2014: Table S2
La Yerba III	440115	8356906	25	15b VII-55	Amara-Ullujalla	River estuary	5430	140	6485 5893	Birm-513	Engel, 1991: 56
La Yerba III (SU 9020)	440115	8356906	25	15b VII-55	Amara-Ullujalla	River estuary	5381	33	6270 5996	OxA-32290	
La Yerba III (SU 9009)	440115	8356906	25	15b VII-55	Amara-Ullujalla	River estuary	5290	33	6179 5920	OxA-32291	
La Yerba V [b]	440924	8355047	10	15b VII-25	Amara-Ullujalla	Sandy littoral	6150	120	7264 6678	I-3560	Engel, 1991: 56
Santa Ana	451155	8342556	25	15b VII-8 & 19	Mainsa	River estuary	4720	120	5650 4983	–	Engel, 1981: 61
La Chorrera	474338	8319857	21	15b XI-50	San Fernando	Rocky littoral	–	–			
Bahía de San Nicolás	475573	8318822	25	16a II-40	San Fernando	Sandy littoral	5560	80	6694 6029	–	Engel, 1981: 59

Note
[a] 2σ OxCal v4.2.4 Bronk Ramsey, (2009); r:5 SHCal13 atmospheric curve (Hogg et al., 2013).
[b] Also called 'El Campo'. Its position, 'one kilometre south of the southern bank of the river, on a terrace found 8.5 meters above present sea level' (Engel, 1981: 20), is recorded differently in Engel, 1991: 155 (Fig. 127) and Engel, 1981: 122 (Fig. 43). We cannot find this site, despite much searching. Either its position is described erroneously, or it has been destroyed.

inevitably conflated, here, the *only* possible sources of fresh water beyond the river courses derive from condensing winter sea fogs. These fog-fed arroyo courses enabled Preceramic human habitation all along this arid littoral, far from its river courses, but in immediate proximity to both lomas and particular marine resources.

4.3. Logistical field camps within the lomas

While Engel successfully located those Preceramic sites along the coast, he failed to find a 'single human settlement' within the south coast lomas (Engel, 1981: 27, hardly surprising when the remote lomas de Amara alone cover some 400 km²). Yet such sites do exist, conspicuous largely as large accumulations of land snail shells (Figs. 1 and 5).

Preservation of other organic remains here is poor because of winter humidity. In lomas elsewhere Craig (1992) interprets similar accumulations of land snails to be natural death assemblages. Here, however, the Middle Preceramic anthropogenic origin of Amara Norte I is unequivocally revealed by stratigraphic contexts (Fig. 5E) also including remains of marine shell and sea urchin, grinding stones (Fig. 5F) and hearth charcoals radiocarbon dated to 4963–4728 cal BP (OxA-32350, Table 1). Moreover, these middens

are surrounded by scatters of obsidian projectile points (Fig. 5B) and flaking debitage from the later stages of lithic reduction such as the retouching of preforms, left lying exposed on the surface by wind deflation of these upland landscapes.

We identify three clusters of such sites deep within the lomas of Amara — at Amara Norte, Valle de Amara and Abra Sur de Amara (Fig. 2) — which we interpret to be logistical field camps (*sensu* Binford, 1980): the vestiges of multiple, short-term forays in winter to hunt game and gather lomas specific resources, particularly plant geophytes and land snails. Elsewhere in the archaeological record such sites are rare but not unknown (cf. Engel, 1981; Larrain et al., 2001).

Occult precipitation is sometimes sufficient to form seasonal standing ponds of water in the San Fernando and Amara lomas. In historical times atmospheric moisture has been 'harvested' within lomas by means of fabrics or nets and collecting vessels, yielding up to 10 L per day per m² of fabric (Klemm et al., 2012). There is no evidence that Middle Preceramic fabric technology allowed such water harvesting, but, during the foggy winter months — also the time when the lomas ecology is at its most productive — even fog drip collected from overhanging rocks eventually yields useful quantities of water (Larrain et al., 2001).

Doubtless drinking water was transported during the Middle Preceramic using bottle gourd and/or animal skins, both in evidence at the logistical basecamps on the river estuaries. Nonetheless, our observations of today's lomas hydrology, together with a pattern of substantial Middle Preceramic archaeological deposits (see Figs. 1 and 2), at locations very widely dispersed from the river courses (Figs. 4F and 5A), strongly suggest that, fresh water derived entirely from coastal fog ecosystems was sufficient, at least seasonally, to sustain small groups of hunter–gatherers. We next assess the potential of other lomas resources to Preceramic hunter–gatherers, in the light of our ecological and archaeological investigations of the south coast lomas.

4.4. Lomas faunal resources

Today, despite the depauperate or ephemeral nature of much of its vegetation, the south coast lomas formations sustain a remarkably rich animal life including larger mammals such as wild guanaco camelids (*Lama guanicoe*, Palomino, 2006), two species of desert fox (*Lycalopex* spp.), many rodents, lizards and birds, and invertebrates including insects and snails. Indeed, snails are the single most conspicuous and ubiquitous element of lomas resources found in the Middle Preceramic archaeological contexts of the south coast: evidence of their importance to human diet.

There appear to be two species of snail today found on Ica's lomas formations, the most common of which, we tentatively identify as *Bostryx reentsi* (Philippi, 1851; Bram Breure, personal communication). These snails are only active during the lomas growing season (Fig. 6G), aestivating in groups during the dry

months (Ramírez, 1988; Ramírez et al., 2003). We observe live snails in numbers grazing on the lush herby lomas vegetation during the fog season, but also in transition belts, eating algae that grows on *Tillandsia* and aestivating on their stems or beneath their roots (Craig, 1985).

Archaeological sites such as Amara Norte I and Abra Sur de Amara I, amidst these *Tillandsia* transition belts in the lomas de Amara, between 550 and 700 m asl, have middens dominated by snail shells (Fig. 5C and D). Meanwhile, sites along the littoral such as Arroyo de Lomitas, Abra I and La Yerba II, otherwise full of the evidence of marine resources, also all contain lomas snails, in some contexts in considerable quantities (Fig. 8F).

In Mesolithic contexts worldwide snails have made a significant contribution to daily calorific and protein requirements (e.g. Rizner et al., 2005). Clearly this was the case during the Middle Preceramic in the lomas of the south coast of Peru. Relative to marine molluscs individual *Bostryx* yielded little, difficult to extract, meat; yet they were easily gathered in great quantities during winter months and could then — unlike marine molluscs — be stored fresh for months because of their ability to aestivate through sealing their shells with a mucus epiphragm (Ramírez, 1988). The significance of snails to Preceramic diets may well have varied therefore according to the seasonal availability of other resources, particularly during periodic collapses in marine resources induced by El Niño.

Most of the land snail assemblages in these contexts are whole and show little evidence of heat alteration. But many shells in the Amara Norte I middens show fine puncture holes suggesting that their meat was extracted using cactus thorn inserted through the epiphragm, or through the thin shell itself (see Fig. 5D). Since the
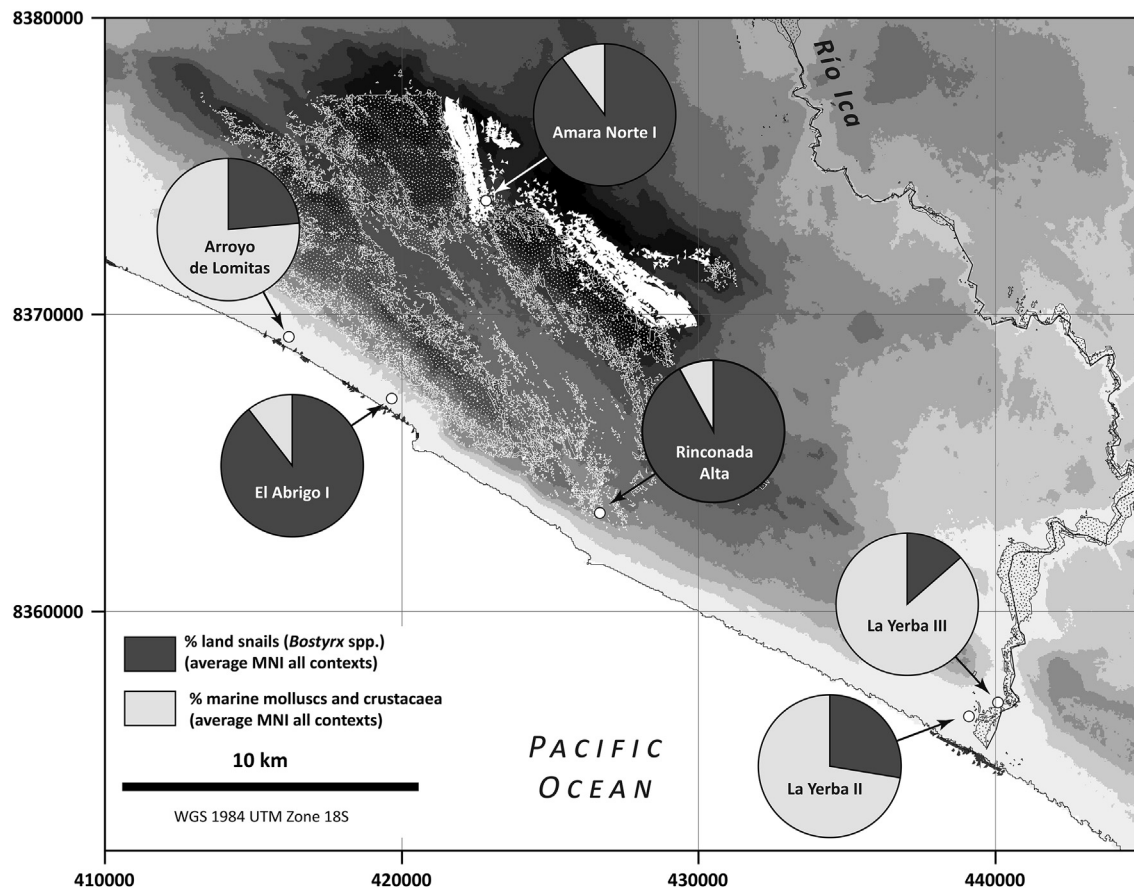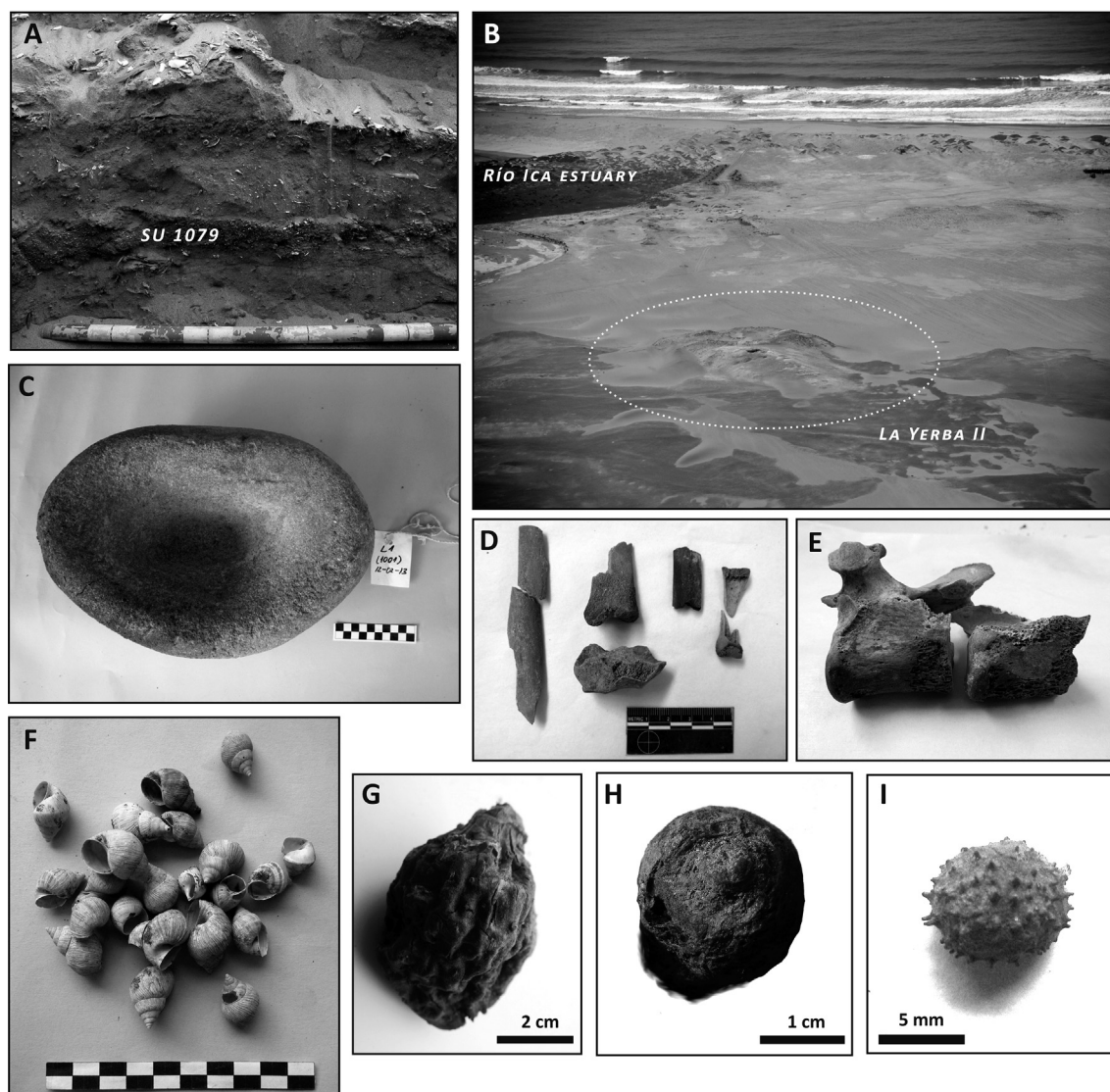

Fig. 7. Land snails (*Bostyrx* spp.) as a proportion of total mollusk and crustacean assemblage (by average Minimum Number of Individuals 'MNI') across various south coast Middle Preceramic archaeological sites.

Top to bottom:

A   Middle Precamic contexts, Trench 3, La Yerba II. Occupation layer SU 1079 dated 6,936 – 6,735 Cal YBP.

B   La Yerba II under excavation, 2013.

C   Stone grinding mortar ('batan'), La Yerba II, SU 1001, presumably for processing starchy plant foods.

D   Examples of butchered grey deer (*Odocoileus virginianus*) bone, La Yerba II, SU 1001.

E   Examples of butchered, charred camelid vertebra, presumably guanaco, (*Lama guanicoe*), La Yerba II, SU 1001.

F   Examples of *Bostryx* sp. land snails, La Yerba II, SU 1005. Snails comprise 28% (by NMI) of the total mollusc and crustacean assemblage at La Yerba II..

G   Desiccated *Haagocereus* sp. cactus fruit, La Yerba II, SU 1072.

H   Desiccated *Oxalis* sp. tuber fragment, La Yerba II, SU SU 1079.

I   Desiccated *Krameria* sp. seed, La Yerba II, SU 1072.

Fig. 8. Selected lomas resources in Preceramic archaeological contexts at the site of La Yerba II, on the Río Ica estuary, south coast Peru.

taphonomies of terrestrial and marine molluscs in such ancient archaeological contexts should be similar — relative to those of other classes of organic remains — we use the proportion one to the other, measured by minimum number of individuals ('MNI'), as a proxy measure of the relative importance of lomas resources in particular contexts. Thus averages of such measures offers a useful, albeit crude, way to compare the use of lomas resources between individual site locations during the Middle Preceramic (see Fig. 7).

Meanwhile, the importance of other lomas faunal resources to south coast Middle Preceramic hunter–gatherers can be inferred from direct evidence such as animal bone — though with considerable taphonomic bias between different sites — but also from indirect evidence in the form, for instance, of the stone tools used to hunt and process animals.

Today tiny relict populations of guanaco still live in the south coast lomas of San Fernando and Amara (Fig. 6D). They are shy and more or less constrained to particularly remote parts. In the past these animals, catholic feeders on either browse or graze, may have

moved more freely between the winter lomas and summer river valley oases, which may, in turn, have determined rounds of hunter–gatherer transhumance (Custred, 1979). Alongside predators such as puma (*Puma concolor*), guanaco and grey deer (*Odocoileus virginianus*) were once far more numerous in the lomas and the formerly wooded valleys of the Peruvian coast (Baied and Wheeler, 1993; Wheeler, 1995; Wheeler et al., 2011; Beresford-Jones, 2011). Today there are no deer on the south coast of Peru, outside of captivity. Yet the Middle Preceramic archaeological record here includes evidence of both deer and camelids (presumably guanaco), together with many other vestiges of the attendant hunting activities in the lomas (Lavallée and Julien, 2012).

Before the development of woven textile technologies in the Late Preceramic, these lomas mammals would have provided skins and tendons vital for clothing and bindings. Guanaco hides were much esteemed for clothing by Yaghan hunter–gatherers of Tierra de Fuego because, unlike the hides of marine mammals – the more common prey of both Yaghan and Middle Preceramic hunters – guanaco skin is thin and flexible, so that it conforms readily to the contours of the human body, and has heavy hair, making it is far better for shedding water and keeping out the cold (Lothrop, 1928). The La Yerba II contexts contain good evidence for hide preparation in the form of numerous scraper tools made of *Choromytilus* shell and plants potentially used for curing leather (see below).

Preservation conditions at sites within the lomas itself are poor, though a few fragments of ungulate bone were recovered from Amara Norte I. At La Yerba II, 17% (by MNI) of an animal bone assemblage dominated by marine mammals and birds, are camelid and deer. Whereas all parts of deer were recorded, camelid bones were mostly (85%) of meatier hind leg parts, suggesting that these large animals were butchered off-site, perhaps near the kill sites within the lomas.

Obsidian and other stone tools, dominated by projectile points prepared for hafting, are found throughout the lomas of the south coast. Small stone structures high on bluffs in the lomas and near guanaco trails today, such as Abra Sur de Amara II, may represent hunting stands (cf. Larrain et al., 2001). Indeed, sites deep within the lomas associated with the gathering of snails such as Amara Norte I, are surrounded by scatters of obsidian lithics including many projectile points, presumably for hunting game (Fig. 5B).

The variety of obsidian points found in the lomas, are likely a palimpsest of hunting activities over time. Different lithic morphologies may also represent different target species, or hunting strategies. We suggest, however, that the majority of this lithic activity dates to late in the Middle Preceramic because those sites on the coast that date to that period, such as La Yerba III and Amara Norte I, have abundant, comparable obsidian lithic remains within stratified deposits, whereas earlier sites such as La Yerba II, contain only a few small obsidian flakes.

4.5. Lomas flora as food resources

The importance of plant foods to hunter–gatherer diets outside extreme latitudes has long been recognised (e.g. Cordain et al., 2002). As noted above, many lomas perennials have evolved to cope with cycles of long aridity followed by intensive, growing seasons through underground storage organs (geophytes), several of which would have provided a valuable source of edible starch for the hunter–gatherers of the Middle Preceramic (Engel, 1987). Significant examples we have recorded in the lomas of the south coast include: the tuberous roots of *Aa weddelliana* (Orchidaceae), only recently recorded elsewhere on the Peruvian coast (Trujillo and Delgado Rodríguez, 2011); the roots of *Alstroemeria* sp. (Alstroemeriaceae), several closely related species of which are recorded as providing food for humans in the lomas of Chile where they are

known as 'chuño' (Puga, 1921; Muñoz-Schick and Moreira-Muñoz, 2003); and the corms of various *Oxalis* (Oxalidaceae) species including *O. lomana* (Stafford, 1939, reports them tasting like cobnuts, Fig. 6B). Several varieties of true and wild potatoes are found in lomas vegetation elsewhere in Peru (Sandra Knapp, personal communication) although only *Solanum montanum*, a highly variable species distantly related to potatoes (Bennett, 2008), is recorded today in the lomas of the south coast (Fig. 6C). Like all Solanaceae tubers, these are bitter and must be processed, but are recorded as a minor food source in historical times (Hooker, 1827). Edible lomas geophytes are at their most nutritious both before and after periods of active growth but remain available all year round, and are easily collected because plants such as *S. montanum* occur in concentrated patches and are not deeply rooted (Cohen, 1978a; Ochoa, 1998).

Edible seeds, greens and fruits of lomas plants likely provided seasonal sources of important vitamins and micronutrients. In particular almost all lomas cacti species produce palatable fruit and likely contributed significantly to diet for parts of the year (Cadwallader et al., 2012). *Corryocactus brachypetalus* which, uniquely, grows on the rocky seaward bluffs of the lomas has the largest fruit, with a pale pulp tasting not unlike apple or gooseberry. Two species of *Haageocereus* cactus (*decumbens* and aff. *tenuis*), generally found in the transitional vegetation belts of the inter lomas plain in Amara (Fig. 6E and F), both produce crops of sweet juicy fruit in January once the winter fogs have receded, whilst the fruit of *Cumulopuntia sphaerica* and *Eriosyce islayensis* are edible but somewhat less palatable.

In the desiccated conditions of the La Yerba II Middle Preceramic occupation contexts at the Río Ica estuary evidence for the use and consumption of lomas plants include *Oxalis* sp. tubers, and cactus fruit and seeds (cf. *Haageocereus* spp., Fig. 8G). Indirect evidence for the processing of starchy plant foods include stone grinding mortars ('batanes') both at La Yerba II and III (Fig. 8C), and also at Amara Norte I in the heart of the lomas (Fig. 5F), where plant remains themselves are only preserved through charring. Undifferentiated charred parenchyma tissue suggestive of starchy plant foods is evident in the contexts of all these Middle Preceramic sites. *Haageocereus* spines found at La Yerba III in carefully tied bundles, were presumably for used for making fishhooks (cf. Engel, 1984).

A range of lomas plants are also known today for their antibacterial or other medicinal properties including *Ephedra* spp. and *Plantago* spp. (Villagrán and Castro, 2003) and the astringent *Krameria lappacea*, used for treating inflammation, gastrointestinal illnesses and other medical purposes (Simpson, 1989; Brack Egg, 1999). *Krameria* also has a very high tannin content so that it is sometimes used today for curing animal hides. Its remains are identified in the Middle Preceramic contexts of La Yerba II (Fig. 8I). Most of these archaeological contexts also contain many pale, finely-spun fishing yarns and net fragments. Engel (1973) suggests, before cotton, such yarns may have been spun from that the downy seed head fibres of *Tillandsia* sp.

Many of these lomas plants are also important to the diet of the animals hunted here during the Preceramic. Guanaco graze on leguminous herbaceous lomas plants such as *Astragalus*, as well as the roots and tubers of perennial plants that they dig up, grasses, cacti and cacti fruit. In both winter and summer they can also persist on lichens and the *Tillandsia* that dominate such large parts of the south coast lomas (Raedeke and Simonetti, 1988; Reus et al., 2009).

4.6. Lomas flora as fuel resources

Fuel would have been required at these Preceramic sites for cooking, opening clam shells in bulk (Waselkov, 1987: 100), curing

animal skins, roasting to make certain lomas tubers edible and indeed for warmth because, though in the tropics, the south coast of Peru is remarkably chilly in winter, when temperatures fall into single figures and strong winds blow cold, damp fogs inshore off the Pacific. Our data loggers record a minimum temperature during winter in the south coast lomas of 7 °C.

The evidence from Middle Preceramic sites such as La Yerba II and III, adjacent to the river, suggest the use of estuary and woodland species as fuel. But lomas vegetation must have been the primary source of fuel at those sites that are distant from the vegetated river courses, because ethnographic studies suggest that heavy expendable resources like fuel wood are almost always gathered within a radius of not more than two hours walking (Willis and Van Andel, 2004: 2371) Substantial fragments of wood charcoal are evident in the structured hearths at Arroyo de Lomitas (Fig. 4E). Although driftwood might have contributed to the overall fuel economy, today it is scare along this rocky shore. More exposed sites within the lomas such as Amara Norte I have poorly preserved microcharcoal remains, but blackened and fire cracked hearthstones here are evidence of repeated fires.

Today there are no trees and few woody perennial shrubs on the south coast lomas. Those few that do persist, such as *Ephedra americana*, *A. rotundifolia* and *C. alnifolius*, are like all lomas woody species, slow growing, yielding high calorific value fuel, but making them prone to overexploitation. Elsewhere, Preceramic charcoal assemblages have been taken as suggesting such overexploitation (Weir and Derring, 1986). Certainly, the charcoals in the hearths of Preceramic sites such as Arroyo de Lomitas, suggest that the south coast lomas once supported more woody vegetation. Large areas of these lomas are today dominated by *Tillandsia* spp., which, elsewhere, has been noted as a fuel in the Preceramic (Moseley and Willey, 1973; Weir and Derring, 1986; Quilter, 1991). Its downy seed head fibres would also have made effective tinder (Pullen, 2005). Yet most *Tillandsia* too are slow-growing (Craig, 1985) and their removal may have promoted destabilisation of dune systems (Hesse, 2012: 35), evident in landscape deflation about sites such as Amara Norte I.

Although the story of Middle Preceramic human ecology in the lomas of the south coast is one of continuity over millennia, change through time is also evident in this archaeological record. We turn next to what that evidence might contribute to the vexed question of what caused such changes.

5. Change through time

Lomas environments, like other arid area ecologies, are fragile and peculiarly sensitive to even mild climatic perturbations (Masuda, 1985), and to human impact (Dillon et al., 2003).

As discussed, the climatic factor of proximate relevance to lomas is the periodic perturbations along the Pacific coast of Peru of the El Niño Southern Oscillation ('ENSO') phenomenon. ENSO is defined by sea surface temperature ('SST') anomalies, described recently according to two spatial modes of variability: maximum SST anomalies localized in the central Pacific ('CP' mode), entailing negatively skewed SST anomalies off the coast of Peru and strong 'La Niña' events; or, maximum SST anomalies localized in the eastern Pacific ('EP' mode), entailing strong 'El Niño' events (e.g. Carré et al., 2014).

A long-standing model of ENSO history based on proxy data from archaeological sites on the north coast of Peru (Sandweiss et al., 1996; Sandweiss and Kelley, 2012; Etayo-Cadavid et al., 2013) suggests, for north of 12^0 S, some four millennia of ENSO suppression during the Early Holocene, between c. 9000 and 5800 BP; after which there was a low-frequency of *El Niño* until 3000 BP, when the modern, higher frequency *El Niño* regime

became established (cf. Rodbell et al., 1999; Moy et al., 2002; Loubere et al., 2013).

Recently, however, refinements specific to the south coast have been proposed to this model based on $\delta^{18}O$ as a proxy for sea surface temperature recorded in surf clam shells in archaeological deposits, including from La Yerba II (Carré et al., 2012, 2014), central Pacific corals (Cobb et al., 2013) and Galapagos foraminifera (Koutavas and Joanides, 2012). Together these suggest that for over five millennia, between 9600 and 4500 BP, mean annual SSTs were significantly lower than today, especially in southern Peru; that before around 8000 BP ENSO variance was skewed towards El Niño (EP mode), whereas between 7500 and 6700 BP variation was skewed towards CP mode with more frequent and intense La Niña events; and that there was a period of substantial reduction of ENSO variance was between 5000 and 4000 BP. How then might this revised model of ENSO history have impacted upon the south coast lomas and is it reflected in its archaeological record?

Variances in ENSO spatial mode and amplitude affect relative land and sea temperatures that drive convection wind regimes and govern other sea–atmosphere interactions, such as the production of aerosols and condensation nuclei, and thereby the production, intensity (water droplet size) and duration of occult precipitation in lomas. In northern and central Peru El Niño years prompt 'enormous blooming events' (Muenchow et al., 2013: 564) and population explosions of snails (Ramírez et al., 2003) in lomas (see also Dillon et al., 2003). Further south too they bring increased lomas vegetation, due to 'advection fog with a higher moisture content' over warmer waters (Eichler and Londoño, 2013: 1, see also Muñoz-Schick et al., 2001; Manrique et al., 2010; Manrique, 2011). Dillon (2011) and Manrique (2011) record increases in the primary productivity of southern Peru's lomas, measured by plant density and cover, by thirteen times, during the very strong 1997–98 El Niño event, and three times during the moderate 2010 event, respectively. Moreover, El Niño effects usually fall in the austral summer, so producing continuity between the phases of normal lomas winter florescence.

The effects of La Niña events on Peruvian lomas formations are less straightforward. Inland, colder oceanic conditions during La Niña produce dryer conditions. Yet, immediately along the coast, La Niña creates more persistent fogs (Garreaud et al., 2008; Manrique et al., 2010; Muenchow et al., 2013; Eichler and Londoño, 2013), because the cooler humid air masses that it brings are more prone to condensation (McPhaden et al., 2006). Muenchow et al. (2013: 564) record 'abundant blooming events, high species diversity and high species coverage', albeit during a single La Niña year, in Casma. Nonetheless, the relationship between increased fog and lomas vegetation is far from simple, not least because it is governed also by changes in the altitude and temperature of the fog layer (Manrique et al., 2010; Eichler and Londoño, 2013; Muenchow et al., 2013). Consequently lomas plant species have evolved into these moisture regimes and topographically delimited niches to form a complex mosaic of vegetation. Persistent La Niña conditions may, for instance, promote xerophytic species and widen transitional vegetation belts at the expense of herbaceous fog meadow (Latorre et al., 2011).

Figs. 3 and 9 shows that for the lomas of the south coast the impact of ENSO on lomas resources is bimodal: El Niño tending to produce a higher above ground biomass in ephemeral zones, while La Niña tend to produce a higher below ground biomass in fog zones in the form of geophytes. In sum we infer that past multicentennial periods of increased ENSO variance and intensity – of either La Niña or El Niño – would have bolstered the extent, volume and fog trapping height of lomas vegetation, thereby positively influencing lomas hydrology and producing a self-sustaining
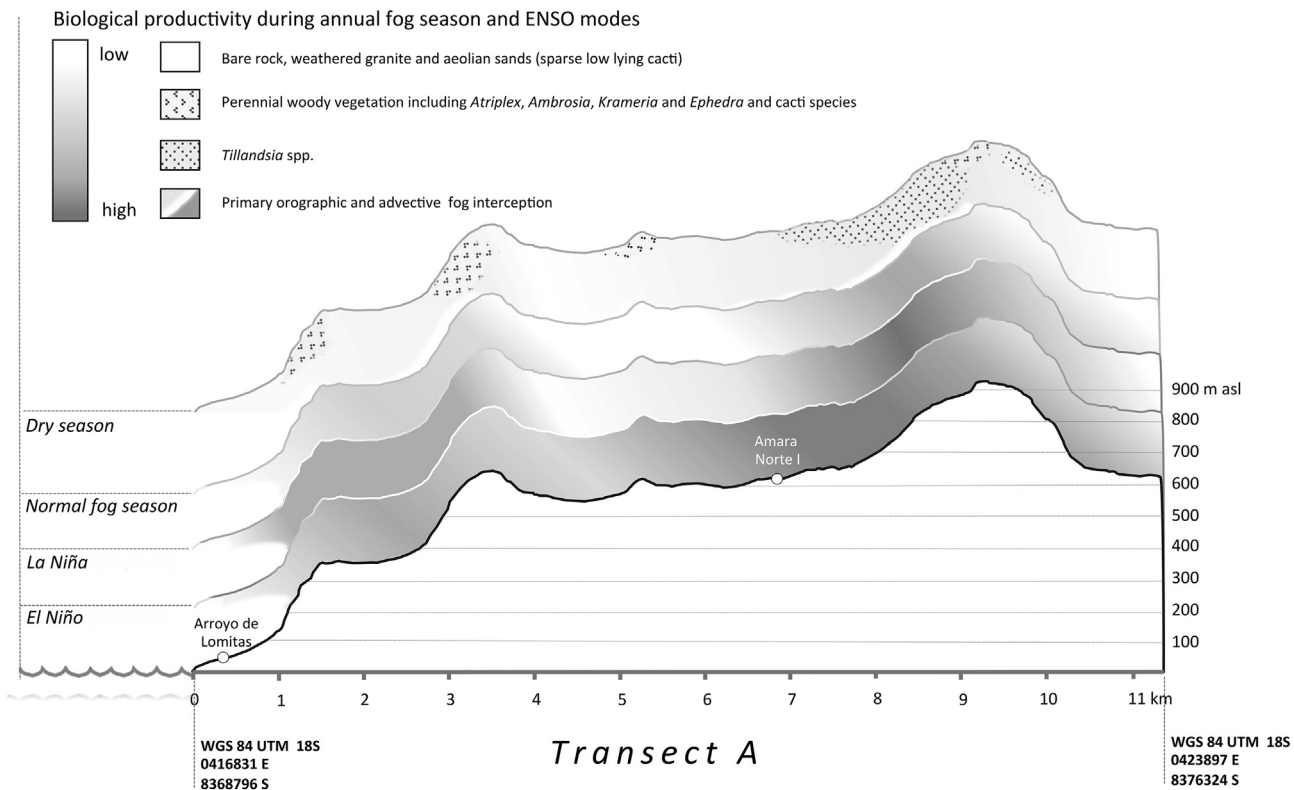
Fig. 9. Conceptual model of lomas biological productivity across Transect A in Amara lomas, showing: (i) **Dry season** (January–June) – when seed, stem and root storage provide resources; extant woody and herbaceous perennial lomas ('WHPL') and *Tillandsia* dominated vegetation (ii) **Normal fog season** (occurring annually or biennially, July–December) – occult precipitation stimulating plant growth and reproduction in high diversity annual and WHPL species. (iii) **El Niño** – rare rainfall events triggering non-seasonal ephemeral herbaceous species of low diversity to expand across open pampas into *Tillandsial* spp. areas and merging refugia (iv) **La Niña** – sustained fog and lower temperature (reducing evaporation) increasing growth and expanding margins of WHPL.

microclimate. This, in turn, would have greatly augmented the biomass of both the floral and faunal resources exploited therein by Preceramic hunter–gatherers. Different ENSO modes would promote different parts of the lomas ecosystem and so entail different subsistence strategies, for instance, by focus on hunting guanaco and gathering snails as their populations soared due to expanded herbaceous lomas vegetation during periods of increased El Niño variation, or, by focus on gathering the starchy geophytes of lomas perennials when they thrived thanks to the more persistent fogs in epochs of increased La Niña variation.

By contrast, long durations of suppressed ENSO variance would be inimical to lomas ecosystems. Indeed, without regeneration through periodic ENSO events, certain lomas species may disappear completely over time (Dillon, 2011). It would also increase their vulnerability to human impact. Vegetation in lomas acts overall, not as a water consuming, but as a water-*producing* factor because of the greatly enhanced surface area it provides for the condensation of fog water. This is particularly true of taller woody shrubs and trees which increase fog condensation in lomas by up to six-times (Ellenberg, 1958) so that their removal, say for fuel, acts in self-enhancing feedback to reduce lomas hydrology and soil humidity, and thus the growth and germination of other herbaceous plants and the entire lomas biomass (Engel, 1973; Walter, 1973; Oka, 1986; Muenchow et al., 2013).

Fig. 10 brings together the archaeological record for the south coast lomas (Table 1) and the latest ENSO climate history data for the same region, as synthesised by Carré et al. (2012, 2014). We make five observations from this combination of data, in light of the ecological information already presented.

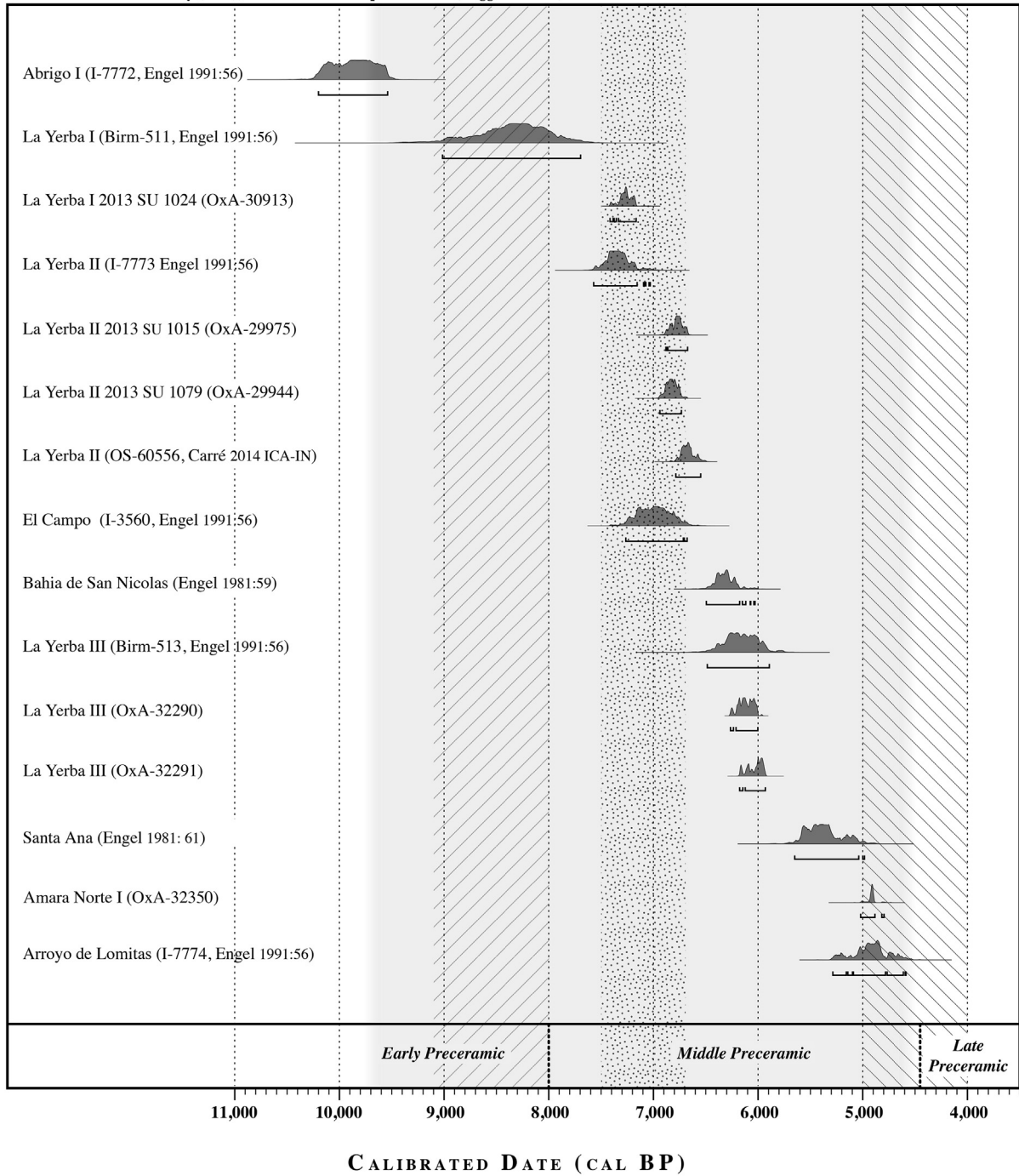Firstly, Fig. 10 shows that, over the broadest scale, all the

Preceramic archaeological sites[1] intimately associated with the south coast lomas were occupied during five millennia in which, as Carré et al. (2014: 1045) summarise, 'mean annual SST was significantly lower … than today, especially in southern Peru ~3 °C cooler [implying] an increase in the intensity of coastal upwelling'. It was this that underpinned conditions of higher oceanic productivity, and augmented lomas hydrology and biomass due to more persistent fogs (e.g. Carré et al., 2009), which sustained hunter–gatherers in Engel's (1984) 'fog oasis situation' for this enormous stretch of time on the south coast.

Secondly, there was, seemingly, a millennia of increased El Niño (EP mode) before 8000 BP and the start of the Middle Preceramic Period, which would have expanded lomas vegetation extent and biomass, but simultaneously inflicted persistent shocks upon certain marine resources critical to Preceramic subsistence. Only one site at the estuary, La Yerba I, is dated by Engel (1991: 154) to

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[1] The Early Preceramic rock shelter site of Abrigo I (10,200–9539 Cal yrs BP), was occupied before this period but it serves to highlight another factor governing the distribution of past lomas formations: that of relative sea levels (Dillon, 2011). At that time, eustatic sea levels were around 35 m lower than today, causing considerable shoreline alterations for those parts of the coast with a shallow-sloping continental shelf, and thereby for the visibility of Early Preceramic archaeological sites (e.g. Richardson, 1998; Sandweiss, 2009). Such changes also have implications for extant lomas distributions since these are defined principally by altitude. Along the south coast, however, a steep and narrow coastal shelf meant that there was much less horizontal shoreline displacement as eustatic sea-levels reached high stand conditions around 7000 BP, and then stabilised (Sandweiss et al., 1996). This has important implications for the archaeological visibility of older sites along this littoral, such as Abrigo I, which otherwise would have been inundated by the sea.

OxCal v 4.2.4 Bronk Ramsey (2013); r:5 SHCal13 atmospheric curve (Hogg et al 2013)

C A L I B R A T E D D A T E (C A L B P)

Key – Historical reconstructions of sea surface temperatures (SST's) for south coast Peru

Mean sea surface temperatures ~ 3°C cooler than today (Carré 2014: 1045).

Strong ENSO activity dominated by EP mode (strong El Niño events, positively skewed distribution of SST anomalies, Carré 2014: 1046).

Strong ENSO activity dominated by CP mode (strong La Niña events, negatively skewed distribution of SST anomalies, Carré 2014: 1047).

Substantial reduction of ENSO variance (Carré et al. 2014: 1047, Cobb et al. 2013, Koutavas & Joanides 2012).

Fig. 10. Comparison of ENSO history (after Carré et al., 2014) with dates of Preceramic archaeological sites on the south coast of Peru, all calibrated using the ShCal13 curve (Hogg et al., 2013) in OxCal version 4.2 (Bronk Ramsey, 2009).

this epoch, and following calibration, entails a margin of uncertainty of almost a millennia (9015–7696 Cal yrs BP, see Table 1, Fig. 10). Engel provides few details and our own investigations of the same site — so far as that can be ascertained — suggest that both its date and archaeological assemblage are, in fact, similar to the adjacent site of La Yerba II (see Table 1, Fig. 10, Arce et al., 2013). If so, there is little visible archaeological evidence of human occupation of the south coast during this period, though that also entails factors of eustatic sea-level change and stabilisation, germane to our next observation.

Thirdly, within the broad sweep of five millennia of colder seas, the start of the Middle Preceramic period is marked by the founding of several highly visible archaeological sites, most notably La Yerba II (7571–7030 Cal yrs BP) on the Río Ica estuary. This coincides with a multi-centennial period of enhanced La Niña activity (see Fig. 10), entailing even colder seas and foggier lomas: conditions reflected in the particularly cold-water ecology of parts of the La Yerba II mollusc assemblage, such as *Tegula atra* and *Choromytilus chorus*. Also, at this time eustatic sea levels stabilised, after which shoreline progradation began forming the sandy beach habitat of the easily gathered *Mesodesma* surf clams that so characterise the La Yerba II middens. It is surely no coincidence then that the establishment of the Middle Preceramic way of life here apparently takes place during an epoch of abundant and predictable oceanic and lomas resources.

Fourthly, over the five hundred years to around 6000 BP, the archaeological sites on the river estuaries show evidence of increased sedentism and a broadening of the resource base along a spectrum of mixed hunting-farming subsistence (cf. Gorbahn, 2013). Whereas sites like La Yerba II are characterised by temporary areesh wind-shelters made of reeds (cf. Quilter, 1989), later-dated sites at the river estuaries, such as La Yerba III and Santa Ana (6281–6006 Cal yrs BP and 5650–4983 Cal yrs BP), have evidence of more permanent and substantial villages and structured mortuary deposition (see Engel, 1981: 20–21, 1991: 157, cf. the 'Encanto phase' elsewhere, see Lanning, 1963; Patterson and Moseley, 1968). These later sites have much greater quantities of obsidian, indicating far wider spheres of interaction since the nearest sources are 250 km away in the highlands, notably at Quispisisa (Tripcevich and Contreras, 2011). They also have the first evidence here for food agriculture, grown in the seasonally humid silts of the adjacent river floodplains. We recover fully domesticated lima beans (*Phaseolus lunatus*), while Engel (1981: 20) reports both *Phaseolus* beans and jícama (*Pachyrhizus tuberosus*), in the contexts of La Yerba III.

Last, but not least, Fig. 10 suggests that as the long epoch of cooler sea temperatures ended around 4500 BP, synchronous with a Holocene minimum of ENSO variance lasting a thousand years to 4000 BP: each inimical to lomas ecosystems and to water sources they fed along the littoral, so too did a Middle Preceramic way of life that had turned for millennia here about the lomas seasons and their rich ocean littoral — the 'fog oasis situation' — draw to a close.

Indeed, the significance of lomas resources to human settlement here is made stark by the observation that there are *no* Preceramic archaeological sites along the coast between Morro Quemado and Bahía de San Nícolas dated to after 4450 BP, the date more widely construed to mark the end of the Middle Preceramic Period elsewhere in Peru (Quilter, 1991). For there seems little reason to suppose that a shift to an average sea temperatures akin to modern conditions, together with suppressed ENSO activity, would have been greatly detrimental to many marine resources, not least *Mesodesma* clams, long a key dietary component here. And yet, even at the river estuaries, the archaeological record appears silent for the subsequent Late

Preceramic Period[2]. Following the demise of the 'fog oasis situation', therefore, we speculate that increased reliance upon agriculture in the Late Preceramic necessitated relocation of settlement inland, into the riparian basins of the south coast rivers.

Elsewhere, on the north and central coasts of Peru this critical change heralded the florescence of greater population densities and monumental civilization after 4500 BP (e.g. Dillehay et al., 2004). This did not happen on the south coast, probably because of is distinctive geomorphological configuration. For unlike the river valleys to the north, with their broad alluvial deltas and wide ocean frontages granting easy access simultaneously to rich marine and agricultural resources, the river systems of the south coast comprise scattered riparian basins down long river courses, diverted and separated from the sea by the same coastal lomas formations that had been the prime theatre of human ecology during the Middle Preceramic.

Those lomas environments continued to be exploited seasonally for snails, plants and game and for grazing domesticated animals throughout later archaeological time periods and indeed, well into historical times (Rostworowski, 1981; Masuda, 1985; Larrain et al., 2001; Beresford-Jones et al., 2011). Paths through the south coast lomas were still traversed for access to marine resources along the littoral (see coastal surveys by Engel, 1981, 1991; Carmichael, 1991). Yet it also seems clear that for those later times, lomas and marine resources were strictly supplementary (Cadwallader et al., 2012; Carmichael et al., 2014), never again dictating the rounds of human existence as they had during the Middle Preceramic Period.

6. Conclusions

Plainly it was the cold, upwelling ocean, with its bounty of almost inexhaustible protein sources, that chiefly sustained the Middle Preceramic hunter–gatherers of the south coast of Peru. Yet because those marine resources were distributed in hotspots all along this littoral, it was in fact the lomas formations on the granite coastal massif, and their fresh water sources, that defined the setting of human ecology at this time and thereby the patterning of human occupation and corridors of movement along the south coast between Morro Quemado and Bahía de San Nícolas: Engel's (1981: 24) 'fog oasis situation' (see Fig. 1). The south coast lomas offer unique insight into the capacity of past lomas ecosystems to support seasonal hunter–gatherer occupation because of their separation from the resources and water sources of the Andean foothills.

Lomas fauna and flora provided significant (Fig. 7), and seasonally critical, components of Middle Preceramic diet, most notably plant tubers, ungulates and storable land snails. Moreover, lomas provided critical fuel, medicinal and raw material resources. Our findings refute any view that lomas environments were not important 'could never have been important to man', or that they have not altered much through the course of the Holocene. Indeed, given that lomas ecosystems include wild relatives of the Andean potato and tomato (*Solanum* spp.) and papaya (*Carica* sp.) together with guanaco, the wild relative of llama and alpaca camelids, we suggest that the role of lomas in key Andean domestication processes merit more consideration than has hitherto been the case, not least because those processes for camelids and tubers have often been seen as going hand in hand (e.g. Pearsall, 2008: 113).

Setting the latest model for ENSO variance based upon $\delta^{18}O$ isotope records (Carré et al., 2014), alongside the archaeological

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[2] The closest Late Preceramic sites that we are aware of lie north of the south coast lomas, at Otuma and on the Paracas peninsula, strikingly both associated with shallow, presumably warmer water, lagoon contexts (Engel, 1991).

patterning here, now defined with greater chronological precision, shows striking correlation between the Middle Preceramic occupation throughout the south coast lomas and a long epoch of significantly colder seas, with implications for increased intensity of coastal upwelling and more persistent lomas fogs. These include logistical field camps spread far along the lomas littoral alongside fog-fed arroyo watercourses, and previously undiscovered sites targeting gathered and hunted resources deep within the lomas itself.

Within that five millennia of colder seas, the first Middle Preceramic occupations were founded at the river estuaries during a multi-centennial period of enhanced La Niña activity, entailing even more abundant ocean and lomas resources, and coinciding too with the time at which eustatic sea-levels stabilised and shoreline progradation began to form the beach habitat necessary for abundant, easily collected *Mesodesma* clam resources that dominate the middens of these sites. These logistical basecamps at the river estuary offered complex hunter–gatherers access to a mosaic of diverse, highly productive environments[3].

Eventually, the millennia of Middle Preceramic existence defined by the 'fog oasis situation' and the epoch of colder seas drew to a close, during a Holocene minimum of ENSO variance inimical to lomas ecosystems and the water sources they sustained. Thus this latest data from the south coast upholds Lanning's (1963: 369) perspicacious assertion, made half a century ago now, that climate change – specifically linked to alterations in oceanic circulation (i.e. ENSO) – accounts for significant change in the resource potential of lomas ecosystems through the Holocene, and indeed, for why human ecology shifted out of the 'fog oasis situation'.

Yet compelling though this vision of climate-induced change in human ecology during the Middle Preceramic is, it does not preclude other factors from explanations of why the 'fog oasis situation' came to be abandoned, not least human impact, to which such climate changes would have exposed lomas ecologies. Indeed, since vegetation in lomas environments, and in particular its slow-growing, easily over-exploited woody vegetation, acts to catalyse fog condensation, such perturbations and human impact each precipitate the effects of the other. Today there are no trees and few woody species in the south coast lomas. Yet charcoal in Middle Preceramic hearths throughout this fog oasis situation attest to this not having been the case in the distant past. More importantly still, this model of climatically-induced lomas resource depression at the close of the Middle Preceramic does *not* seem to explain the emergence of agriculture in the Andes, as Lanning and others had also proposed.

Over the five hundred years between La Yerba II and III, the archaeological record of the south coast shows evidence for many of those changes widely recognised to precede the emergence of agriculture in many parts of the world, for which Flannery (1969) coined the term 'Broad Spectrum Revolution'. These include more permanent architecture, structured mortuary deposition perhaps denoting territoriality, much more extensive trade or exchange networks implied by obsidian quantities, and a widening use of resources to include floodplain farming of high-protein *Phaseolus* beans. Yet throughout this time, the 'fog oasis situation' still prevailed (Fig. 10).

We conclude therefore that on the south coast of Peru a Broad Spectrum Revolution unfolded, *not* through population pressure in deteriorating environments (e.g. Patterson and Moseley, 1968; Cohen, 1978b), but rather as an outcome of resource *abundance* prevailing in the 'fog oasis situation' throughout the Middle Preceramic Period. Just as is now envisaged for many parts of the world (Arnold, 1996: 98; Zeder, 2012: 258), it was a combination of abundance and seasonal predictability that enabled increasingly complex Middle Preceramic hunter–gatherers here to reduce mobility by settling in logistically optimal locations at the confluence of multiple eco-zones at the river estuaries.

Acknowledgements

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.quascirev.2015.10.025.

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