THE RÔLE OF *PROSOPIS* IN ECOLOGICAL AND LANDSCAPE CHANGE IN THE SAMACA BASIN, LOWER ICA VALLEY, SOUTH COAST PERU FROM THE EARLY HORIZON TO THE LATE INTERMEDIATE PERIOD

David G. Beresford-Jones, Susana Arce T., Oliver Q. Whaley and Alex J. Chepstow-Lusty

DO NOT CITE ANY TEXT WITHOUT PERMISSION OF THE AUTHORS

David G. Beresford-Jones. Corresponding author. Department of Archaeology, University of Cambridge, Downing St., Cambridge CB2 3DZ (dgb27@cam.ac.uk).

Susana Arce Torres. Museo Regional de Ica (INC-Ica), Avda. Ayabaca s/nº Cuadra 8, Urbanización San Isidro, Ica, Perú (susarceto@yahoo.com)

Oliver Q. Whaley. The Herbarium, Royal Botanical Gardens Kew, Richmond, Surrey TW9 3AE, UK

Alex J. Chepstow-Lusty. Centre de Bio-Archéologie et d’Ecologie (UMR 5059-CNRS/UM2/EPHE), Institut de Botanique, 163, rue Broussonnet F-34090, Montpellier, France; and, Département Paléoenvironnements (ISEM/CNRS), Université de Montpellier II, F-34095 Montpellier Cedex 05, France.
The lower Ica Valley on the hyperarid south coast of Peru is today largely depopulated and bereft of cultivation. Yet its extensive archaeological remains attest to substantial prehispanic populations. This paper describes archaeological investigations aimed at reconstructing geomorphological, ecological and land-use changes in Samaca, one of the riparian oasis basins of the lower Río Ica to address the questions of when, how and why change took place in the basin. Archaeological interpretations of culture change in the region often invoke the impacts of major ENSO perturbations (El Niño). Whilst our investigations confirm that major El Niño events occurring around the end of the Early Intermediate Period are a likely part of the explanation for marked landscape change in the Samaca Basin, we also demonstrate the significance of more gradual human-induced processes of Prosopis pallida (huarango) riparian dry-forest deforestation, which culminated during the Middle Horizon. Huarango is a remarkable leguminous hardwood that lives for over a millennium and provides forage, fuel, and food. Moreover it is crucial to the integration of fragile desert ecosystems, enhancing soil fertility and moisture, accomplishing desalination and microclimatic amelioration. Thus we argue for a much more complete incorporation of Prosopis-human ecological relationships into south coast archaeological interpretations.
El valle bajo de Ica en la hiperárida costa sur del Perú se encuentra actualmente largamente deshabitado y privado de cultivo. Sin embargo de manera contraria, la vasta presencia de sus restos arqueológicos da testimonio de la existencia de considerables poblaciones prehispánicas. En el presente artículo describimos las investigaciones arqueológicas dirigidas a reconstruir los cambios geomorfológicos, ecológicos y de uso de la tierra en Samaca, una de las cuencas de oasis ripario del valle bajo de Ica, con el fin de averiguar cuando, como y por qué se sucedió este gran cambio en el valle. Las interpretaciones arqueológicas referentes al cambio cultural en la región a menudo invocan el impacto de eventos ENSO (El Niño) de gran magnitud. Si bien nuestras investigaciones confirman que tales eventos ocurridos aproximadamente al final del Período Intermedio Temprano forman muy posiblemente parte de la explicación, éstas demuestran además la relevancia de la deforestación del bosque seco ripario de Prosopis pallida (huarango), un proceso mas gradual y de origen humano que culminó durante el Horizonte Medio. El huarango, notable leguminosa de madera dura capaz de vivir más de mil años, no sólo provee forraje, combustible y alimento sino que además es crucial en la integración del frágil ecosistema desértico, mejorando la fertilidad y humedad del suelo y logrando desalinización y mejora microclimática. Nuestros resultados abogan en favor de una incorporación mucho más completa de las relaciones ecológicas entre el Prosopis y el ser humano en las interpretaciones arqueológicas de la costa sur.
The lower Ica Valley, on the hyperarid south coast of Peru is today largely depopulated and bereft of cultivation. Yet its extensive archaeological remains attest to substantial prehispanic populations and present a *prima facie* case for changed ecological and landscape conditions (Strong et al. 1943, Massey 1991, Cook 1999). This paper describes work conducted in the Samaca Basin of the Río Ica to investigate this landscape change with particular focus upon the ecological keystone species of the region: trees of the genus *Prosopis*.

As Wells and Noller (1999) point out the archaeological record of the Peruvian south coast is usually interpreted against the constraints of an effectively static arid landscape, impacted periodically by catastrophic *El Niño* events. Whilst recognising the importance of these so-called punctuated equilibrium events, we need also to attempt to distinguish their effects from more gradual changes, many of which in the lower Ica Valley were, we will argue, human-induced.

*Prosopis* is a remarkable leguminous hardwood tree, capable of living for over a millennium and providing timber, forage, fuel, and food. Trees of the genus are known in Quechua as *Thaccu*, meaning simply ‘the tree’, or ‘the one’ (Yacovleff and Herrera 1934): indicative of their importance and cultural antiquity. However its mention in archaeological literature is almost inevitably in reference to its use as construction material or fuel. We will argue that its importance to archaeological interpretation should go far beyond an appreciation of its value as a human resource.

On the south coast the genus is represented by *Prosopis pallida* forma *pallida*, or *P. limensis* (Ferreyra 1987, Díaz Celis 1995, Pasiecznik et al. 2001, Mom et al. 2002), known locally as *huarango*, or *guarango*. *Prosopis* is crucial to ecological integration and biodiversity in fragile desert ecosystems. The riparian dry forests of
the south coast of Peru are today almost gone. The implications for the region’s landscape can only be appreciated in the context of an understanding of the biology and ecology of *Prosopis*, its importance in modifying desert environmental extremes and in maintaining the complexity of its sensitive ecosystem; including human participants. Our focus here upon human ecology does not necessarily make interpretations derived environmentally deterministic. On the contrary, it may allow for more informed discrimination between human agency and environment response.

Archaeological investigation, comprising geomorphological survey, archaeological survey and excavation and archaeobotanical analysis, concentrated upon a c. 50 ha area of the upper Samaca Basin, known as ‘H-13’ (Cook 1994), which exhibits evidence of environmental degradation and diminished land use over time. We aim to answer the following questions: was H-13 once a productive and vegetated landscape, and if so, when and how did change take place, and why did it occur?

**The Study Area**

The Peruvian south coast is one of the oldest and driest deserts in the world. Its topography is typical of ‘Basin-range’ deserts, characterised by enclosed drainage systems (Cooke et al. 1993). These riparian basins were the locus for human settlement since at least the Early Horizon (Cook 1999, Figure 1). Samaca is one of several basins that constitute the course of the lower Ica River Valley, cut into the *Tablazo de Ica* - a tertiary sedimentary rock plateau (Figure 2). It is a well-defined and convenient landscape unit within which to consider particular human-environment interactions (French 2003). The climate is hyperarid with an average annual precipitation of only 0.3 mm per year (ONERN 1971). In this environment
there are only two natural geomorphological agents acting within the Samaca basin in opposite directions: the wind and the river.

Surface flow in the Río Ica is erratic and seasonal, arising from summer rainfall in the distant Andean highlands and lasting for only around three months per year. Annual discharge since 1922 has oscillated widely (standard deviation of over 150) about a mean of 257 million m$^3$. It has experienced annual flows of over 800 million m$^3$, which can be correlated with perturbations in the Southern Oscillation Index or *El Niño* (Beresford-Jones 2005), and many years with practically no surface flow (SENAMHI-Ica 2002).

The wind regime of the lower Ica Valley is extraordinarily strong and unimodal from the south. Mega-yardangs hundreds of meters high etched upon the surface of the *Tablazo de Ica* (Figures 2 and 5), are testimony to stability of this wind regime over great time depths (McCauley et al. 1977, Beresford-Jones 2005). The average monthly wind velocities in the Samaca Basin, measured continuously by Davis cabled weather station over seven months, varied between 32.3 km/h (for October 2004) and 27.1 km/h (for December 2004). Maximum gusts recorded varied between 115 km/h and 82.1 km/h respectively (Personal communication. Ing. Alberto Benavides).

H-13 lies on an area of c. 60 hectares of relict river terrace standing around 5 m higher than the floodplain and 10 m higher than the current Río Ica thalweg. It is entirely barren of vegetation. Within this area are numerous archaeological remains including the foundations of stone enclosures, heavily looted cemeteries, and agricultural features such as relict canal courses. Over parts of the surface are various, occasionally dense, scatters of midden materials, ceramic fragments and lithics (Figure 2). Cemented CaCO$_3$ duracretes, known locally as *caliche*, are the defining
characteristic of the H-13 relict terrace and they have a profound effect upon its extant land surface. The high, unvegetated relict terrace is exposed to the region’s extraordinary wind regime. The effects of aeolian deflation of the H-13 landscape are evident in frequent palimpsests of multiperiod surface scatters of ceramic sherds, and complex second-order landforms created by a classic inversion of relief, whereby features such as canals, once cut into the land surface, are preserved by calcrete enrichment as upstanding features above the deflated surrounding landscape (Figure 6), (Maizels 1988, Cooke et al. 1993, Beresford-Jones et al. 2007).

Was Samaca H-13 a Productive Landscape?

54 wind-abraded relict *Prosopis* trunks were identified across the barren expanse of H-13 in survey and excavation, seemingly rendering this first question rhetorical (Figure 3). The highest (T15, Figure 2) was recorded at 233 m asl, 24 m above the groundwater level in April 2002. However, *Prosopis* is a phreatophyte with deep roots and isolated individuals can grow high upon relict terraces, dunes or even rock outcrops, above and beyond the extent of other riparian vegetation.

Many other *Prosopis* fossils were also recorded across H-13. These included expanses of duracrete with dominant calcite rhizoliths and leaf litter (or *poña*) pseudomorphs (Figure 3); desiccated roots, leaf litter, seeds, pods (Figure 7) and masticated pod fragments in human coprolites in flotations of various contexts; and *Prosopis* pollen. Indeed, *Prosopis* macro and microfossils were the single common denominator of the Samaca H-13 excavations.

All these fossils likely represent trees growing at various time intervals. Nevertheless, since the lifespan of *Prosopis* can exceed 1,000 years, they each
represent elements of vegetation potentially covering considerable and overlapping periods of time. The dimensions of some of the relict tree trunks indicate that they existed on H-13 for many hundreds of years, encompassing entire cultural periods. Thus, in respect of their implications for ecological change, the occurrence of *Prosopis* fossils effectively ‘compresses time’.

The total number, local groupings and varied sizes of the many relict tree trunks and copious other *Prosopis* fossils across H-13, are thus, taken together, highly suggestive that it was once vegetated with more than isolated *Prosopis* individuals.

Above groundwater levels organic remains enjoy remarkable preservation conditions in these hyperarid conditions and many other plant macro and microfossil assemblages were identified from excavation contexts across H-13 (Beresford-Jones 2005). These included many plants from the riparian dry forest ecosystem, agricultural and disturbed areas and even of obligate wetland status in Test Pits 1, 1/030, 1/031, 2, 4, 5 (Figure 2). Some of these were from anthropogenic midden contexts whose remains do not necessarily reflect the ecology of their immediate surroundings. However, specific elements of these (such as the dominant quantities of desiccated *poña* beneath midden contexts in Test Pit 5 in mound feature No. 23) do likely represent local vegetation cover.

Geomorphological data corroborate the picture of landscape change presented by archaeobotanical remains. A steep 5 m embankment incised by the river marks the edge of the H-13 relict terrace. This profile (Section 1/013) was cleaned and analyzed because it represents the terrace history prior to the deposition of the archaeological remains on its surface. Grain size profiles down this section suggest radically altered environments of deposition in those deeper time contexts, both from its upper stratigraphic unit proximate to the H-13 archaeological remains, and from those that
persist today. In view of the relict canal system recorded across the surface of H-13 this distinction is interpreted as the result of the imposition of human control, agriculture and pedogenesis upon the energies of episodic clastic sediment regime of the underlying river floodplain (Beresford-Jones et al. 2007).

Preserved surfaces dating to archaeological time periods are scarce across H-13 due to the effects of wind deflation. However, they are encountered buried and sealed beneath the deposits of the climbing dune anchored along the western flank of the Samaca Basin by its unimodal wind regime. Micromorphological analysis demonstrates the occurrence of buried soils in contexts from Test Pits 1 and 1/030 (Figure 4), beneath these dune deposits (ibid). Today, these once organic soil horizons lie over half a kilometer west, and about 5 m above, the edge of the current riparian Río Ica floodplain, in the midst of a barren landscape (Figures 2 and 4). As the unconsolidated aeolian deposits were removed during the excavation of Test Pit 1, a remarkably preserved print of an individual’s left foot was found on the underlying, hard silt-loam surface (Figure 4), providing clear and rather poignant evidence of a once moist surface now sealed under the climbing dune, and thus of the extent of landscape change across H-13.

When was Samaca H-13 a Productive Landscape?

Archaeology provides a means of approximately dating the various elements of the H-13 landscape change. Many hundreds of ceramic fragments covering time periods from the Early through to Middle Horizon were encountered in survey and excavation of H-13 contexts. Although aeolian deflation has destroyed most of the original stratigraphy of H-13, it has also in effect excavated vast expanses to leave
heavier archaeological materials scattered in multi-period palimpsests upon today’s land surface.

An important observation of the H-13 archaeological remains is the conspicuous absence of almost any material from the Late Intermediate or Late Horizon periods, despite the presence of two large habitation sites ‘H-8’ and ‘H-9’ (Figure 5), from those periods in the lower Samaca Basin (Cook 1994). We thus conclude that H-13 was an abandoned landscape prior to those periods. Further archaeological data refine this conclusion.

The precise dating of features such as canals in use over time is problematic. Nevertheless, ceramic finds obtained during excavation (of Test Pits 2 and 4 in relict canals Features 40 and 33 respectively) and survey indicate that the H-13 relict canal fragments were once part of a contemporary system, dated *terminus ante quem*, to the end of the Early Intermediate Period (Beresford-Jones et al. 2004, Beresford-Jones 2005). Calcite cementation to more than 3 m beneath their courses is evidence that these canals were in operation for considerable periods of time (Figure 6).

The occurrence of the relict *Prosopis* trunks mapped across H-13 is clearly associated with areas of duracrete exposed by wind deflation (Figure 2): the great majority were surveyed within a narrow altitudinal range between 220.0 and 220.5 m asl, corresponding to that surface. Ceramic fragments from later Ocucaje phases and Nasca phases covering some 800 years of time depth were encountered in mixed scatters upon these deflated duracrete surfaces (Beresford-Jones 2005). The relict trunks show the effects of long wind abrasion (Figure 3). *Prosopis* wood is very dense and harder than oak or teak (Ibrahim 1992, Rogers 2000, Pasiecznick et al. 2001). In these hyperarid conditions it can be preserved over millennia (Kroeber 1944, Strong and Evans 1952, Kroeber and Collier 1998). The extant forms of the H-13 relict
trunks are nonetheless quite distinct from *Prosopis* posts (*horcones*) in the Late Intermediate to Late Horizon site of H-8, exposed to the same wind regime, but which exhibit far less wind erosion effects. These relict trunks in the H-13 duracrete are therefore interpreted as living trees, which met their demise at some time prior to the Late Intermediate Period.

Finally, the predominant mound in the H-13 landscape, Feature 23, was excavated by Test Pits 5 and 6. Its upper contexts comprised diverse Middle Horizon midden materials (Figure 4). Below these, its character at depth with tree throws and aeolian contexts dominated by *Prosopis* leaf litter, established Mound 23 as a relict nabkha, or phytogenic mound, formed by wind deposition about a large tree(s). The extant form of the mound, amid its surrounding deflated duracreted landscape covered with mixed ceramic fragments from earlier epochs, is interpreted as a consequence of its later age; the binding effects of nabkha formation and the density of heavy ceramic and lithic midden materials on its surface.

Flotations of Mound 23 midden contexts yielded a well-preserved desiccated plant assemblages, which included, *coca* seed (*Erythroxylum* sp.) together with leaf fragments of *Inga feuillei* (*pacay*), and *Psidium guajava* (*guava* or *guayaba*). *Coca* leaf, the useful part of the plant, first becomes visible in the south coast archaeological record from Late Nasca phases to the Middle Horizon (Silverman and Proulx 2002, Piacenza 2002). The presence of its seeds in this conjunction of plant remains is noteworthy because of historical evidence of coastal *coca* plantations under *pacay* and *guayaba* shade trees (Rostworowski 1989). Regardless, these archaeobotanical remains suggest dramatically altered ecological conditions in a wider context beyond H-13 because neither *coca*, nor the large, simple-leafed fruit
trees of *pacay* and *guayaba*, can persist anywhere today in the wind regime of this
part of the lower Ica Valley.

Together these data suggest that Samaca H-13 was vegetated until the Middle
Horizon Period, but that it had become barren and abandoned prior to the Late
Intermediate Period.

**How did Change Occur on Samaca H-13?**

*Punctuated Equilibrium*

A characteristic of Andean archaeological interpretation has been its emphasis
upon catastrophic events in the form of *El Niño* flood and/or *La Niña* drought events
(or perturbations in the Southern Oscillation Index, ‘ENSO’). Ice-core records from
the Quelccaya ice cap (Thompson et al. 1985) have been used to postulate correlations
of major climatic perturbations with episodes of so-called ‘punctuated equilibrium’
evident in the archaeological record throughout the Peruvian coast (Shimada et al.
important to archaeological interpretation is demonstrated by some of the H-13 data.

Excavation of Test Pit 4 (Figure 8) revealed a thick fluvial layer (Stratigraphic
Unit 19). This was one a several remaining fragments of a sheet flood deposit (known
locally as *yapana*), up to 60 cm thick, that once covered much of the area of a second
relict river terrace lying below H-13, also now barren of vegetation and deflated by
wind erosion (Figure 2). The significance of this layer is due to its position and
approximate dating: S.U. 19 directly caps midden contexts containing Nasca 2/3 Early
Intermediate Period ceramic fragments.
The effects of any ENSO event vary in different coastal valleys. The 1997/98 El Niño was particularly severe in the Ica Valley. It flooded the city of Ica to a depth of over 2 m and downstream in the Samaca Basin destroyed most of a substantial Late Intermediate/Late Horizon archaeological site recorded as ‘H-9’ (Figure 5, Cook 1994). This was therefore the greatest flood in the lower Ica Valley for at least the last 500 years.

And yet this flood appears relatively minor in its spatial effect upon the upper Samaca Basin in comparison to the event that deposited S.U. 19. The surveyed altitudes of preserved fragments of S.U. 19 conservatively imply a sheet flood some 4 m higher than the maximum river level during the 1997/98 El Niño, across the equivalent profile in the Samaca Basin. This is illustrated in Figure 8 below, which uses a digital elevation model (DEM) of the Basin’s current topography to project a theoretical sheet flood at the level of the S.U. 19 deposit. Indeed, there are some notable correlations between the projected extents of the S.U. 19 event and the extant form of archaeological and landscape features of H-13.

The original primary canal operating across H-13 during the Early Intermediate Period is today preserved in two fragments, Features 40 and 34, separated by the incursion of the river floodplain, which coincides precisely with the simulated incursion of the S.U. 19 flood into H-13. A secondary relict canal, Feature 33 was completely submerged by this flood event (Figure 8). The edge of the terrace H-13 is defined for much of its extent parallel to the river direction where the erosive force of the river would have been at its strongest during the postulated flood by a steep embankment some 5 m high: the result of river incision (e.g. Section 1/103, Figure 8). Downstream from this embankment edge there are a series of 2 m high
relict braided channel banks composed of large, sub-rounded river cobbles deposited by the river in spate (Feature 18, Figure 8).

This presents evidence of a major flood event, occurring at some time towards the end of the Early Intermediate Period, that spread a deep fluvial layer across the upper Samaca Basin, caused some 5 m of river incision into its floodplain and which had catastrophic effects upon the H-13 canal system. Thus our data reflects those wider observations of the likely catastrophic effects major El Niño events have had along the coast of Peru.

However, it would be simplistic merely to posit Figure 8 as the answer to the question of how change occurred on Samaca H-13. The projection of the S.U. 19 event shown has been carried out upon the Basin’s existing topography. This conceivably conflates the effects of several high-energy flood events. More certainly, it renders the topographical basis upon which the comparison between the relative magnitudes of the 1997/98 El Niño and S.U. 19 flood events, quite unalike. A more complete interpretation thus requires consideration of two related factors: riparian vegetation changes and river down cutting.

**Riparian Vegetation**

Cooke et al. observe:

‘It is a mistake to assume that because riparian vegetation is generally less dense in deserts than elsewhere, it is of no consequence. In fact phreatophytes … significantly influence channel geometry by increasing
bank resistance to erosion, inducing deposition and increasing roughness’ (1993: 153).

The pre-eminent native phreatophyte of arid American riparian ecosystems is the genus *Prosopis*, which has one of the deepest and most laterally extensive root systems of any tree in any environment (Stone and Kalisz 1991). *P. pallida* roots in Peru are typically 2 to 3 times the diameter of the tree’s crown, frequently access water tables 25 m deep and are recorded at well over 60 m in length (Díaz Celis 1995, Galera 2000). This deep *Prosopis* root architecture ‘underpins’ floodplain and river meanders, providing the edaphic conditions for a river bank species assemblage, which, on the Río Ica comprise, in order of distance from the water’s edge, *Phragmites* sp., *Tessaria intergrifolia*, *Baccharis lanceolata*, *Salix humboldtiana*, *Acacia macracantha* and *Tecoma fulva*. The combined, heterogeneous root architecture and vegetation cover of this riparian assemblage constitutes a robust erosion resistant system (Galan De Mera 1996, 1999, Whaley 2004)

Studies of the effects of changes in the density of riparian vegetation in the Gila River drainage of the southwestern United States demonstrate how channel width decreases, and channel sinuosity increases, with increasing phreatophyte density, because of the effects of their root systems (Graf 2002). The corollary of these influences upon channel form are increased opportunities for irrigation intakes, infiltration or riverbank breaches during flood events, giving rise to standing flood deposits like those represented by S.U. 19. Therefore, the much greater extent of the S.U. 19 flood as compared with that of the 1997/98 *El Niño* event may not be a reflection of actual differences in river discharge between the two events, but rather of much greater riparian vegetation density in the floodplain when the S.U. 19 event
occurred. The other factor of topographic change, intimately related to riparian vegetation cover, is river down cutting.

**River Down cutting**

The preservation of desiccated plant macrofossils in Test Pit 4 contexts beneath S.U. 19 was excellent, making it likely that the S.U. 19 flood was a rare or perhaps unique inundation at this point in the landscape. It is also difficult to see why the Early Intermediate Period inhabitants would have gone to the trouble of constructing canal 33 perpendicular to the river direction *within* the usual, active river floodplain, or indeed that any remnant of it would remain today if they had. The Río Ica is therefore unlikely to have significantly altered its course laterally since the S.U. 19 event. That it has incised *downwards* however by at least some 5m is evidenced by the terrace embankment described as Section 1/013. River incision will diminish its floodplain area, changing the relationship between river flood volume and the extent of the resulting sheet flood and thus undermining any comparison between the S.U. 19 and the 1997/98 events.

Moseley et al. (1983) note river floodplain incision as the cause of progressive abandonment of canal systems in the Moche Valley on the north coast. To maintain a given area under canal irrigation following incision canal intakes have to extended further upstream. Water loss in unlined canals exposed to high evaporation limits the extension possible, thereby causing abandonment. They postulate tectonic uplift as the cause of this entrenchment, based upon the occasionally uphill course followed by the Chicama-Moche inter-valley canal. However the Chicama-Moche canal system never actually carried water along its whole length and its sometime uphill course has since
been interpreted as engineering failure rather than subsequent tectonic uplift (Pozorski and Pozorski 2003). Furthermore, there is little geomorphological evidence that the Andean north coast has experienced significant uplift during archaeological time periods (Cooke et al. 1993, Wells and Noller 1999). Indeed, Moseley et al. explicitly recognize another possible explanation, noting that, ‘In theory, if such land supported a more erosion-resistant vegetation cover when under irrigation than when left abandoned, then a corollary of highland irrigation collapse could be “deforestation” and consequent erosion that could exacerbate river down cutting, leading to intake stranding of the coastal canal systems’ (1983: 323). The ‘erosion resistance’ of *Prosopis* has been discussed above.

In the 1920’s, the geomorphologist Kirk Bryan was noting the rapid degradation in the Gila River Basin that had been taking place since the 1870’s, particularly through the phenomenon of ‘arroyo’ formation. This had catastrophic consequences for the landscape and for irrigation and floodwater farming in the region (Nabhan 1986). Hackenberg (1983) summarizes:

‘The major environmental damage occurs through loss of vegetation whose root structures formerly held the banks of streams and rivers in place… Widened channels are cut deeper by subsequent rapid runoff, and the result is an arroyo, a deep trench cut to a depth of 50 feet or more into the terrain. These trenches, in turn’ lower the groundwater level by draining soil moisture from the adjoining terrain’ (1983: 162).

The phenomenon of arroyo cutting (Cooke and Reeves 1976, Graf 2002, Cooke et al. 1993) involves complex interplay between what Cooke et al. term, ‘self-

We suggest that analogous to the North American Southwest, the river entrenchment noted in the Samaca Basin and perhaps elsewhere on the Peruvian coast is the result, not of tectonic uplift, but of ongoing diminution of riparian vegetation in the river floodplain and in particular of *Prosopis*.

Thus, the difference between the extent of the S.U. 19 event and the 1997/98 *El Niño* flood event in the upper Samaca Basin could be the result of: (i) much greater riparian vegetation in the river floodplain in the past; and, (ii) the result of river entrenchment during the S.U. 19 event and subsequent flood events, caused by gradual, ongoing removal of riparian vegetation from the floodplain.

S.U. 19 nevertheless represents an enormous flood event, likely the result of a so-called ‘super’ *El Niño*, comparable to that of 1997/98 (Bendix et al. 2002). It demonstrably damaged and submerged parts of the Early Intermediate Period canal system. Grodzicki identifies roughly contemporary effects of major *El Niño* impact, including river down cutting and a narrowing of the vegetated floodplain, at the major Nasca period site of Cahuachi on the Río Nazca (Orefici and Drusini 2003). The point here is not to deny the significance of these chaotic fluctuations in the biophysical environment, but to observe that their effects would be *precipitated* by ongoing processes of gradual change, causing them to breach critical desert geomorphic thresholds, particularly through river entrenchment. A more complete picture of how change occurred on Samaca H-13 thus requires the superposition of gradual processes
of change, upon the punctuated equilibrium of El Niño/drought impacts. Our data also provide evidence that the H-13 relict terrace did not suddenly become denuded of vegetation following or until long after, the S.U. 19 event.

**Gradual Change**

Pollen data interpreted according to context, taphonomic considerations and comparisons with plant macrofossil data, help elaborate the history of gradual change on H-13 (Beresford-Jones 2005). There are rather few precedents for successful pollen extractions from Peruvian coastal locations (Weir and Eling 1986, Wells and Noller 1999), although good pollen preservation has been reported from other arid environments (Fish 1985, Gilbertson et al. 1994). Some H-13 contexts yielded good pollen concentrations of between 15,200 and 99,300 pollen grains per cm³, most notably a sequence of contexts in Test Pit 1/031 from its layer 76-80 cm downwards (Figure 2). Early Intermediate Period Nasca Phase 2/3 ceramic fragments in that layer provide the sequence with a rough time framework.

Grain size and other geomorphological analyses establish the 1/031 context sequence as aggrading surfaces, above the ancient water table on the basin’s western flank, upon which aeolian materials were deposited with progressively increasing energy by the unimodal Samaca wind regime (Beresford-Jones et al. 2007). This location was an effective trap for wind-borne pollen blown across H-13 and for entomophilous (insect pollinated) taxa in its close vicinity (such as Prosopis and most other riparian arboreal species), with limited possibilities for non-local contamination (see Figure 5 and minor %’s of exotic pollen in Figure 10). The sequence was eventually buried and sealed by graded sand aeolian deposits of the climbing dune.
Figure 10 shows the pollen sequence from 1/031 compared with: (i) pollen preparations from the adjacent Test Pit 1/030 33-46 cm associated with Middle Horizon archaeological materials; and (ii) the average of preparations of modern samples taken from the floor of an old-growth woodland fragment in Quebrada Usaca on the Río Poroma in the Río Grande de Nazca drainage (Figure 9), because it represents a partial and last-remaining modern analogue for the riparian forests that we argue were formerly extensive on the south coast of Peru.

The sequence shows a gradual replacement of *Prosopis* woodland with cultivation and anthropogenic disturbance on H-13. The rich, *Prosopis* dominated (70%) pollen assemblage recorded for layer 140-190 cm at the bottom of the sequence is almost directly comparable to those observed on the modern forest floor of the Usaca fragment. Desiccated *Prosopis* leaf litter macrofossils also dominated these contexts. Both provide evidence that trees were growing close to this location, today far from the vegetated river floodplain (Figures 2 and 5).

*Prosopis* pollen and poña macrofossils decline steadily up the sequence as pollen from domesticated plants such as cotton (Fam. Malvaceae cf. *Gossipium* sp.), maize (*Zea mays*) and possibly beans (Fam. Papilionaceae) appear and increase. Self-pollinating maize produces very low pollen rain and does not disperse far because of its large pollen grains (Martin 1963, Weir and Eling 1986). Hence, its apparently modest occurrence here indicates plants or anthropogenic processing in the immediate vicinity. Maize pollen reaches a maximum in the Early Intermediate Period layer of 76-80 cm: the same period in which the canal system on H-13 was in operation and, as observed in the geomorphological record of Section 1/013, imposing a controlled energy regime of deposition quite distinct from the preceding, episodic floodplain clastic deposition.
As *Prosopis* pollen declines up the 1/031 sequence, Chenopodiaceae-Amaranthaceae (Cheno-Ams), those halophytic pioneers of open ground that are markers of anthropogenic disturbance and also of degraded riparian vegetation, increase. Their anemophilous pollen indicates wider scale ecological change in the Basin. In the Middle Horizon contexts of 1/030 Cheno-Ams dominate entirely the pollen assemblage and *Prosopis*, other arboreal species, and maize and cotton have practically disappeared. The pollen assemblages of 1/030 also show notable similarity not only with the plant macrofossil assemblages extracted by flotation from those contexts, but also with the plant macrofossil assemblage from the midden contexts of the Middle Horizon Mound 23 (with the exception of *Prosopis*, which serves to emphasize the identification of that mound as an isolated nabkha). These anthropogenic midden contexts contain copious marine and terrestrial molluscs from locations between 15 and 25 km distant, in conjunction with a plant assemblage lacking any domesticates, but dominated instead by those gathered wild plant foods whose importance to human diet has been demonstrated in analogous arid American environments (Beresford-Jones 2005). The consumption of the most important of these, the pods of *Prosopis*, is evident in human coprolites from those contexts.

Finally, the identification of Mound 23 as a relict nabkha is in itself indicative of gradual environmental change. Only land surfaces that are already subject to considerable wind erosion give rise to nabkha formation. The degraded Callango Basin in the lower Ica Valley is today largely dominated by multiple nabkha formations and these are not environments conducive to maize cultivation, because of the very strong winds of the region (Figure 7).
Why Did Change Occur?

This model for how geomorphological and ecological change occurred on H-13 in the upper Samaca Basin argues that a significant factor in change was diminution of riparian vegetation in general and *Prosopis* in particular. Understanding the importance of *Prosopis* cover and why changes occurred, requires a proper incorporation of the profound role the tree plays within the riparian ecology of which humans and their other food sources are a part. It also requires consideration of the human agency evoked by the model. Put simply: only humans chop down trees.

The role of *Prosopis* as a ‘key-stone’ species in deserts and arid agroecosystems has been studied extensively in the botanical and agroforestry literature (Pasiecznik et al. 2001) and supplemented by our observations on the Peruvian south coast (Whalley 2004, Beresford-Jones 2005).

Most obviously in an environment that frequently experiences winds of well over 100 km/h and extremely erratic river flows, trees with extensive root systems physically maintain soil stability (Dutton 1992, Sene 1996, Pasiecznik et al. 2001). The microclimate beneath the *Prosopis* canopy maintains cooler soil and air temperatures convivial to microorganisms and the decomposition of litter fall (Fisher 1990, Asencio Díaz 1997, Geesing et al. 2000). *Prosopis* produces copious litter fall, which carpets the desert under the tree, increasing soil humus content and contributing nutrients as it decomposes (Singh 1996, Bhojvaid and Timmer 1998, Garg 1992, 1998, Mishra and Sharma 2003). This *poña* is still used today on the Peruvian south coast as a fertilizer by people too poor to afford commercial products. Litter ‘mulching’ further enhances microclimatic alterations at the soil surface.
Together these contribute to less friable soil properties, further decreasing the effects of wind erosion.

Nitrogen shortage is the single most limiting factor in plant growth. The quantities of nitrogen and other nutrients added to the soil by *Prosopis* are highly significant (Dommergues 1992, Geesing et al. 2000). In the rhizosphere, through ‘autocatalytic relationships’ with *Rhizobium* sp. bacteria and micorrhizoid fungi, leguminous *Prosopis* fixes nitrogen in the soil, improves soil structure and respiration (Abrams et al. 1990, Johnson and Mayeux 1990, Purohit et al. 2002, Bird et al. 2002). *Prosopis* in the Sonoran desert with only a 30% canopy cover is recorded as fixing 40-50 kg of nitrogen per hectare per annum (Virginia & Jarrell 1983). Soil fertility and nitrogen contents beneath *Prosopis* are much greater than among agricultural intercrops, even when these include leguminous beans as demonstrated in semi-arid Mexico (Reyes-Reyes et al. 2002). Rhizosphere biological activity increases CO$_2$ partial pressures that contribute to dissolution of insoluble CaCO$_3$; the calcrete whose wide extension on H-13 today is both evidence of past flooding and of long standstill condition. The high pH of ground waters is counteracted by the remarkable effects of the genus on soil pH, electrical conductivity and exchangeable sodium percentage (Bhojvaid and Timmer 1998, Garg 1999, Mishra and Sharma 2003). Through these combined influences the, ‘soil beneath *Prosopis* grows richer as the tree grows’ (Nabhan 1984).

Archaeological interpretations of the south coast are replete with observations of the ‘limitations’ and ‘restrictions’ of its environment (Kroebber 1944, Menzel et al. 1964, Kosok 1965, Paul 1990, Silverman 1991, 1993, Sawyer 1997, Silverman and Proulx 2002). However, given protection from strong winds afforded by *Prosopis*, the region’s 350 days of sunshine per year and annually replenished alluvial soils are
among the most productive in the world. Chilean agro-industrial concerns in the Middle Ica Valley, using a year round cropping on a 120-day cycle, today attain production levels of 65 tonnes per hectare of tomatoes per annum, comparable to the highest in the world (Wellmann 1998).

The region’s obvious limitation might appear to be water availability and archaeological interpretations invoke the hydrological poverty of south coast rivers (Menzel et al. 1964, Craig and Psuty 1968, Silverman 1993, Sawyer 1997, Silverman and Proulx 2003) relative to the coastal valley systems to their north. Surface flow impressions however may be misleading. The Río Ica and the Río Grande de Nazca show quite distinct configurations compared to the broad fan-shaped delta complexes of most of the major Peruvian westward flowing coastal rivers because their access to the sea is blocked by the uplifted formations of the Tablazo de Ica and the ancient batholith of the coastal cordillera (Figure 2). However this same topographic peculiarity preserves high groundwater levels and subsurface flows, while these rivers lose little water to the sea. Estimated subsurface flows for the Río Ica total over 155% of average surface flow (ONERN 1971, Taltasse 1973) and the actual populations and agricultural hectares sustained today in the Middle Ica Valley often by groundwater pumping are greater than those of its northern neighbors (Beresford-Jones 2005).

Some Prosopis species influence soil moisture, especially in a region characterized by zero precipitation, predominantly sub-surface groundwater hydrology and high night time air humidity (Sudzuki 1985 a,b, Mooney et al. 1980). Deep dimorphic root systems access water at great depth and through the recently described process of ‘hydraulic lift’ (Richards and Caldwell 1987, Dawson 1993, Caldwell et al. 1998, Horton and Hart 1998, Jackson et al. 2000) may deposit part of that water amid its dense superficial root network. Furthermore through capture of
atmospheric humidity upon the huge surface area of its brachyblasts/leaflet clusters and also likely its absorption through the leaves and ‘reverse hydraulic lift’, *Prosopis* further contributes to the moisture of upper soil horizons (Went 1975, Mooney et al. 1977, Schulze et al. 1998, Smith et al. 1999, Whaley 2004). Thus, the ‘islands of fertility’, observed around *Prosopis* in arid regions (Barth & Klemmedson 1982, Carrillo-Garcia et al. 1999, Geesing et al. 2000, Reyes-Reyes et al. 2002, Rossi & Villagra 2003), might also be appropriately termed, ‘islands of moisture’. These *Prosopis* influences on the agriculture and riparian plants of the Samaca Basin are part of, ‘an emerging view that not all plant-plant interactions are necessarily negative and that facilitation is an important process in plant communities’ (Caldwell et al. 1998: 157).

**A Model of Landscape Change**

The model of gradual change recorded in the Samaca basin starts with old-growth woodland of a relatively undisturbed riparian ecology dominated by *Prosopis pallida* forma *pallida*, (or *P. limensis*) and *Acacia macracantha*, underpinning a riparian assemblage. Giant *Prosopis* over a millennium old are, ‘tall, growing sideways as contorted mountains’ (Calancha describing the city of Ica, 1639, cited in Sánchez Elías 1957; first author translation). Today only a few small relics of old growth *Prosopis* forest remain in the Quebrada Usaca, Río Poroma and in various pockets on the Rio Grande: the approximate analogues of the ancient *huarangals* (*Prosopis* woodlands) of the south coast of Peru (Figure 9). They bear little resemblance to the modern degraded immature scrub-forest *monte* that colors archaeological interpretations.
Through a process of gradual anthropogenic change this woodland is converted to a controlled, canal irrigated agricultural landscape on H-13 during the Early Intermediate Period. This is a process with considerable time depth that begins around the middle of the preceding Early Horizon period, the date of the earliest ceramic fragments recovered during survey. At this time human agro-ecology invokes the modern analogue of the Escuela Libre de Puerto Huamaní organic farm in the lower Samaca Basin (Benavides 2004) and the ethnobotany of riparian parts of the North American Sonoran (Castetter and Bell 1942, Nabhan 1979, 1986, Felger and Moser 1987, Hodgson 2001, Beresford-Jones 2005). Agriculture of maize, pumpkins, cotton, beans and other cultivars is carried out in very small fields whose raised edges conserve water from irrigation and other elements of a, ‘continuum of hydrostatic manipulations’ (Nabhan 1979:246) (Figure 11) and along which grow dense Prosopis/Acacia hedgerows and woodlands. Seen from above this is still a landscape largely dominated by trees.

Notwithstanding successful agriculture, our H-13 archaeobotanical data indicate that gathered wild plants, including, Portulaca sp., Amaranthus spp., Chenopodium spp., Lippia sp., Crotalaria sp., Cyperaceae, cf. Solanum pimpinellifolium (wild tomatoes), but most notably, Prosopis pods, still constitute the major food source, especially between harvests (Beresford-Jones 2005). Again this invokes the Sonoran analogue, in which one fifth of the total desert flora is edible (Hodgson 2001). It is also in broad agreement with all available Peruvian south coast archaeobotanical data (Silverman 1993, Piacenza 2002, Roque et al. 2003, Cook and Parish 2005), even if not always expressly recognized in its interpretation.

The famously naturalistic Early Intermediate Period Nasca iconography is interpreted as celebrating the abundance of life forms and agricultural fertility factors
(Sawyer 1961, 1979 and 1997, Peters 1991, Reinhard 1993, Silverman 1993, Silverman and Proulx 2002). Although the tree itself may be depicted in one of the Nazca pampa geoglyphs, *Prosopis* is only rarely explicitly displayed in the manner of cultivated crops such as maize, peppers and beans. Again, invoking the analogue of the role of *Prosopis* (mesquite) in the lives of the peoples of the Sonoran, this is *because of* its all-pervading importance in their lives. It was, ubiquitous in the desert environment and, unlike cultivated crops, required no human intervention for virtually unfailing provision of fruit and material (Felger 1977). Instead, we observe that the forms of the *huarangal* woodland, with its distinctive, contorted growth, pervade the entire Nasca artistic canon during this period (see Figure 12).

And yet as we have argued, the importance of *Prosopis* to human ecology goes far beyond provision of its, ‘unfailing crop’ of highly nutritious pods (Felger 1977: 155). No other desert tree has a more pervasive influence upon neighboring vegetation, soils, sub-canopy microclimate, wildlife and insect populations (Mares et al. 1977).

In this model most *El Niño* years are not great catastrophic disasters. On the contrary, they are years of abundance. River channel forms are preserved by dense riparian vegetation, particularly by *Prosopis* phreatophytes. High-energy, potentially erosive flow is maintained in narrower river channels and irrigation systems are easily maintained. Groundwater levels are replenished. Dense riparian growth about the river thalweg prompts low-energy, standing floods that deposit huge amounts of rich alluvial sediments over extensive areas. The fine particle sizes of these deposits preserve their moisture content from evaporation as waters subside and provide conditions for highly productive floodplain agriculture.
By the subsequent Late Nasca period gradual *Prosopis* removal has undermined all its beneficial influences for soil structure, quality and moisture; floodplain protection; and microclimatic amelioration of the effects of strong insolation and wind. Diminution of riparian vegetation from the floodplain has permitted high-energy lateral instability in channel form and river entrenchment. Once critical geomorphological and ecological thresholds are breached a series of positive feedbacks drive processes of land degradation that in this arid ecosystem become irreversible. Although chaotic fluctuations in the biophysical environment like that of the S.U. 19 flood event are likely responsible for actually breaching those thresholds, the seeds of sudden instability are sown long previously through processes of gradual change. Irrigation systems are damaged in the short term by the resultant flood events and rendered inoperative over the medium term by the river's entrenchment. The extraordinary wind regime of the region is entraining particles from a dry surface, some of which were being deposited in nabkhas like that of mound 23, forming about isolated large *Prosopis* individuals whose deep root systems still access ground waters. The rest are moved across H-13 until they become anchored in the climbing dune that builds up gradually along the western flank of the basin. The aeolian deflation of the H-13 surface has begun.

By the time the Middle Horizon occupants of the Samaca Basin use the shade and shelter of nabkha Mound 23 to consume a diet entirely composed of gathered food resources from distant marine locations and *lomas* (coastal fog-supported vegetation communities), supplemented by wild plant foods including *Prosopis* beans, agriculture on H-13 itself has been abandoned. At some point prior to the Late Intermediate Period even the large individual *Prosopis*, about which Mound 23 has formed, has died, or been dug out for firewood or construction materials. The process
of ecological change on H-13 is complete, *Prosopis* removed from the model and geomorphological change under the wind increases. No cultural materials from this or later cultural phases are noted on H-13.

This model shows correlation with wider changes in the archaeological record. The significant decrease and rearrangement in habitation sites, the abandonment of the Cahuachi ceremonial center and the fracturing of the Nasca iconographic style after Nasca 3 are usually linked to major climatic perturbations (Silverman 1993, 2002, Silverman and Proulx 2002, Orefici and Drusini 2003), specifically droughts evidenced by the Quelccaya ice core record (Thompson *et al.* 1985). Other data substantiate hypotheses of deteriorating environmental conditions. Studies of human skeletons from mortuary contexts in the Nasca Valley (Drusini *et al.* 2001) indicate a tripling in the infant mortality rate and a fall of seven years in average adult life expectancy from the Early Intermediate Nasca to the subsequent Middle Horizon period. Drusini *et al.* conclude, ‘worse conditions of the Wari population in comparison with the previous Nasca people’ (2001: 157). Analysis of archaeobotanical remains in the Ica Valley also provides some evidence of lower water availability. Menzel and Velarde’s analysis of the archaeobotanical record of the PV62-70 Nasca habitation site on the Pampa de Tinguíña, in the upper Ica Valley show a decrease or disappearance of beans, maize and ají peppers in upper strata associated with Nasca 7 occupation, and increasing quantities of squash. They interpret these changes as reflecting the onset of drought conditions (Menzel 1971). Cook and Parish’s analysis of the archaeobotanical data from the Middle Horizon Casa Vieja site in the Callango Basin in the lower Ica Valley also shows, ‘evidence that the south coast drought hypothesis is worth further consideration’ (2005: 135).
Based upon the evidence from H-13 in the Samaca Basin we argue that
*Prosopis* woodlands were a widespread and locally dominant feature of the Early
Intermediate Period landscape on the south coast of Peru; and that incorporation of
their ecological importance and the consequences of their removal is as essential to
interpretations of landscape and cultural changes, as that of major climatic
perturbations.

**Conclusions**

Today, some 1,000 years after the Middle Horizon, the extant surface of H-13
with its canal system thrown into inverted relief, its mixed scatters of ceramic
fragments from various time epochs and its fossil evidence sealed beneath the
climbing dune, stands in testimony to this story of gradual biophysical change.
Human agency, or what Doolittle (2000) calls ‘anthropogenic geomorphology’, is
evident throughout this model: from the hydrostatic manipulations of water sources
including the canal systems which converted riparian dry forest into agricultural, or
more accurately agroforestry, lands, to the gradual destruction of the key-stone
riparian species, *Prosopis*, and its consequent impact upon the Samaca Basin
landscape.

The history of the deforestation of the coast of Peru is an old and gradual story
traced through the Spanish chronicles, administrative records and recent memory
(Yacovleff and Herrera 1934, Rostworowski 1981, Grados and Cruz 1996). On the
south coast in particular, the story is now all but complete. Deforestation of the
Middle Ica Valley reached vertiginous rates during the 20th Century (Horkheimer
about the City of Ica that were described by Vázquez de Espinosa as, ‘impenetrable at many points …with many savage wild animals’, and stretching for five leagues along the road from Ica to Nazca, ‘so thick that the highway is the only way to get through them and one sees nothing but woods and sky’ (1942 [1629]: 485), are gone. They are replaced by a modern landscape of *pueblo joven* shanty urban sprawl, fallen water-tables, degraded saline soils, the wide fields of agro-industry and shifting dunes and *monte* scrub that continue to color our archaeological interpretations.

In the Samaca Basin of the lower Ica Valley however, the evidence presented here is that comparable, human-induced gradual degradation precipitated catastrophic landscape change and the abandonment of relict terrace H-13 long before the Late Intermediate Period. Ultimately therefore and despite (or perhaps because of) its preponderance of ecological argument and data, this paper seeks to argue for a less environmentally determined interpretation of changes in cultural trajectories. Samaca is but the smallest of five basins of the lower Ica Valley. Our ongoing research however records similar, related changes over the much larger scale in the Ullujaya basin.

Moreover this has contemporary resonance. The tiny last remaining ‘old-growth’ riparian forest relicts remaining on the south coast today resound to the chain-saws of illegal charcoal burning operations. The problems of degraded arid ecosystems, saline soils and high population densities on the Peruvian coast are part of a wider global phenomenon. One fifth of the world’s poorest inhabitants live in arid lands (Barker and Gilbertson 2000) and almost 1 billion hectares of these have suffered human-induced degradation (Szabolcs 1994). We are more aware than ever that the course of our current relationship with our environment is unsustainable. We have important lessons to learn through the rediscovery of past human understandings.
of their environments; and in particular of the importance of *Prosopis* woodlands for sustaining livelihoods and creating permanent islands of moisture and fertility within arid environments.

*Acknowledgements.* We would like to thank all the members of the *Proyecto de Investigación Arqueológica Samaca* for their fieldwork and other contributions and in particular Mario Advíncula, Claudia Grimaldo, Kevin Lane, Sandy Pullen and Fraser Sturt; the *Instituto Nacional de Cultura* (INC) for granting us research permits; Martin Jones, Charly French, Elizabeth DeMarrais, the members of the George Pitt-Rivers Archaeobotanical Laboratory (Department of Archaeology, University of Cambridge); Warwick Bray, Carmela Alarcón and Ing. Cesar Patroni for their help and advice; Don Mariano Cabrera, and most importantly the people of the *Escuela Libre de Puerto Huamaní* and Don Alberto Benavides G. for being the father of it all. Funding was provided by the National Environmental Research Council (NERC), the British Academy and the McDonald Institute for Archaeological Research.
References

Abrams, M.M., Jarrell, W.M., Smith, H.A. and Clark, P.R.


Asencio Díaz, F.W.


Barker, G.W.W. and Gilbertson, D.D.


Barth, R.C. and Klemmedson, J.O.


Benavides, A.G.


Bendix, A., Bendix, J., Gämmerier, S., Reudenbach, C. and Weise, S.


Beresford-Jones, D.G., Arce Torres, S. and Grimaldo Giraldo, C.

Beresford Jones, D.G.


Beresford-Jones, D.G., Lewis, H.A. and Boreham, S.


Bhojvaid, P.P. and Timmer, V.R.


Bird, S.B., Herrick, J.E., Wander, M.M., and Wright, S.F.


Caldwell, M.M. and Richards, J.H.


Caldwell, M.M., Dawson, T.E., and Richards, J.H.


Carrillo-Garcia, A., León de la Luz, J.L., Bashan, Y., and Bethlenfalvay, G.J.

Castetter, E.F. and Bell, W.H.

1942. *Pima and Papago Indian Agriculture*. University of New Mexico Press, Albuquerque, NM.

Cook, A.G.


Cook, A.G. and Parish N.


Cooke, R.U. and Reeves, R.W.


Craig, A.K. and N. Psuty


Dawson, T.E.

Díaz Celis.

1995. Los Algarrobos. CONCYTEC, Lima, Peru

Dommergues, Y.


Prosopis Species. Aspects of their Value, Research and Development.

Proceedings of the Prosopis Symposium. Centre for Overseas Research and 
Development, University of Durham.

Dutton R.W.


Dutton, R.W., editor, Prosopis Species. Aspects of their Value, Research and 
Development. Proceedings of the Prosopis Symposium. Centre for Overseas 
Research and Development, University of Durham.

Felger, R.S.

1977. Mesquite in Indian Cultures of Southwestern North America. In Simpson, 

Series; 4, Halsted Press, 151-176.

Felger, R.S. and Moser, M.B.


University of Arizona Press.

Ferreyra, R.

1987. Estudio Sistemático de los Algarrobos de la Costa Norte del Perú. Lima:

Dirección de Investigación Forestal y de Fauna

Fish, S.K.

Fisher, R.F.


French, C.


Galan de Mera A.


Galera, F.M.


Garg, V.K.


Geesing, D., Felker, P. and Bingham, R.L.


Grados, N. and Cruz, G.


Graf, W.L.


Hackenberg, R.A.

Hodgson, W.C.

Horkheimer, H.

Horton, J.L. and Hart, S.C.

Ibrahim, K.M.

Jackson, R.B., Sperry, J.S. and Dawson, T.E.

Johnson, H.B. and Mayeux, E.B.

Kosok, P.

Kroeber, A.L.


Kroeber, A.L. and Collier, D.


Maizels, J.K.


Martin, P.S.


Massey, S.A.


Menzel, D., J.H. Rowe and L.E. Dawson,

Menzel, D.


McCauley, J.F., Breed, C.S. and Grolier, M.J.


Mishra, A. and Sharma, S.D.


Mom, M.P., Burghardt, A.D., Palacios, R.M. and Alban, L.


Moseley, M.E.


Nabhan, G.P.


1986. Papago Indian Desert Agriculture and Water Control in the Sonoran Desert,

ONERN.

1971. *Inventario, Evalación y Uso Regional de los Recursos Naturales de la Costa.*

Orefici, G. and Drusini, A.


Pasiecznik, N.M., Felker, P., Harris, P.J.C., Harsh, L.N., Cruz, G., Tewari, J.C., Cadoret, K. and Maldonado, L.J.


Paul, A


Peters, A.H.


Piacenza, L.


Pozorski, S. and Pozorski, T.

Purohit, U., Mehar, S.K. and Sundaramoorthy, S.


Reinhard, J.


Reyes-Reyes, G., Baron-Ocampo, L., Cuali-Alvarez, I., Frias-Hernandez, J.T., Olalde-Portugal, V., Varela Fregoso, L. and Dendooven, L.


Richards, J.H. and Caldwell, M.M.


Rogers, K.E.

2000. *The Magnificent Mesquite*. University of Texas Press, Austin, TX, USA.

Roque J., Cano, A. and Cook, A.


Rossi, B.E. and Villagra, P.E.

Rostworowski de Diez Canesco, M.


Sánchez Elías, J.E.


Sawyer, A.


Schulze, E.-D., Caldwell, M.M., Candell, J., Mooney, H.A., Jackson, R.B., Parson, D., Scholes, E., Sala, O.E. and Trimborn, P.


SENAMHI-Ica.


Sene, E.H.

Shimada, I., Schaaf, C., Thompson, L. and Mosely-Thompson, E.


Silverman, H.


Silverman , H. and Proulx, D.A.


Singh, G.


1999. Reverse Flow of Sap in Tree Roots and Downward Siphoning of Water by


Stone, E.L. and Kalisz P.J.


Strong, W.D., Willey G.R. and Corbett, J.M.


Strong, W.D. and Evans, C.


Sudzuki, F.


1985b Environmental Influence on Foliar Anatomy of *Prosopis tamarugo* (Phil.).


Szaboles, I.


Taltasse P.

Thompson, L.G., Mosely-Thompson, E., Bolzan, J.F. and Koci, B.R.


Vázquez de Espinosa, A.

1942 [1629]. *Compendium and Description of the West Indies*, translated by Upson Clark, C. Smithsonian Miscellaneous Collections Vol 102.

Vildoso, C.


Virginia R.A. and W.M Jarrell


Weir, G.H. and Eling Jr., H.H.


Wells, L.E. and Noller, J.S.

Wellmann, A.P.


Went, F.W.


Whaley, O.Q.


Yacovleff, E. and Herrera, F.L.

Figure Captions

Figure 1 – Simplified Ica Valley Prehispanic chronology

Figure 2 – The study area

Figure 3 – Selected *Prosopis* macrofossils recorded on Samaca H-13

Figure 4 – Buried land surfaces in Test Pits 1 and 1/030

Figure 5 – DEM isometric view north of the Samaca Basin

Figure 6 – Test Pit 2, relict canal fragment Feature 40

Figure 7 – Midden mound Feature 23 and relict nabkha character

Figure 8 – S.U. 19 sheet flood event, upper Samaca Basin

Figure 9 – Last old-growth *Prosopis* woodland fragment, Quebrada Usaca, Río Poroma

Figure 10 – Variation in pollen down 1/031 context sequences compared with modern Usaca woodland analogue

Figure 11 – Huerto Huamani field systems, hedgerows and agroforestry

Figure 12 – The forms of the huarangal
<table>
<thead>
<tr>
<th>Relative Chronology (Periods)</th>
<th>Lower Ica Valley Sequence</th>
<th>Approximate Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late Horizon</td>
<td>Inca Influence</td>
<td>1400 - 1534 AD</td>
</tr>
<tr>
<td>Late Intermediate</td>
<td>Ica-Chincha</td>
<td>1000 – 1400 AD</td>
</tr>
<tr>
<td>Middle Horizon</td>
<td>Derived Wari</td>
<td>800 - 1000 AD</td>
</tr>
<tr>
<td></td>
<td>Late Nasca – Wari Influence</td>
<td>600-800 AD</td>
</tr>
<tr>
<td>Early Intermediate</td>
<td>Nasca</td>
<td>0 - 600 AD</td>
</tr>
<tr>
<td>Early Horizon</td>
<td>Ocucaje (Paracas)</td>
<td>400 BC (?) - 0 AD</td>
</tr>
<tr>
<td></td>
<td>Chavinoid</td>
<td>1500 (?) - 400 BC (?)</td>
</tr>
</tbody>
</table>

Figure 1 – Simplified Ica Valley Prehispanic chronology
Figure 2 – The study area
Figure 3 – Selected *Prosopis* macrofossils recorded on Samaca H-13

From top to bottom:

A H-13 relict huacango trunk exposed by recent civil engineering work.

B-F Selected relict huacango trunks from Samaca H13 (T10 - Test Pit 8, T3&T4, T14 - Test Pit 7, T7, T5 respectively).

G Calcite *Prosopis* leaf litter pseudomorphs and rhizoliths exposed by wind erosion in H-13 calcrites.

H Detail of G.
Figure 4 – Buried land surfaces in Test Pits 1 and 1/030

Top to bottom:
A  View south of expanded Survey Pit 1/030 as Test Pit 1 under excavation.
B  Human footprint in surface of S.U. 5 in Test Pit 1.
C  Western Profile of Test Pit 1 with thin section monolith sampling marked.
Figure 5 – DEM isometric view north of the Samaca Basin
Top to bottom:
B  North Profile of Test Pit 2, canal Feature 40.
C  West Profile of Test Pit 2 canal Feature 40, showing anthropogenic calcrite S.U. 69.

Figure 6 – Test Pit 2, relict canal fragment Feature 40
Figure 7 – Midden mound Feature 23 and relict nabkha character

From top to bottom:
A View south of Mound Feature 23 showing Test Pit 5 under excavation.
B Base of southern profile of Test Pit No. 5 showing nabkha contexts underlying Middle Horizon midden.
C S.U. 51 500 μm flotation sample showing dominance of huarango polka.
D Marine molluscs from S.U. 48 flotation heavy fraction sample.
E Erythroxylum sp. (coca) seeds from S.U. 32 2 mm flotation sample.
F Huarango pods from S.U. 48.
G Modern nabkha formation in the lower Sanaca Basin.
Figure 8 – S.U. 19 sheet flood event, upper Samaca Basin
Figure 9 – Last old-growth *Prosopis* woodland fragment, Quebrada Usaca, Río Poroma

Top to bottom:
A  View of Quebrada Usaca old growth forest fragment
B&C  Ancient *Prosopis* individuals, Usaca
Figure 10 – Variation in pollen down 1/031 context sequences compared with modern Usaca
Figure 11 – Huerto Huamání field systems, hedgerows and agroforestry

Top to bottom:
A  Prosopis and Acacia protecting canal course, Huerto Huamání, lower Samaca Basin.
B  Huarrango hedgerow above bean field.
C  Prosopis and Acacia respectively; left in middle of field & coppiced for firewood.
D  Huarrango and pumpkin along field edge. Note rich Prosopis understory growth.
Figure 12 – The forms of the huarangal