

THE ROLE 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

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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 to retrace changes in geomorphology, ecology, and land-use in Samaca, one of the riparian oasis basins of the lower Río Ica, with the aim of investigating when, how, and why such changes took place. Archaeological interpretations of culture change in the region often invoke the impacts of major ENSO perturbations (El Niño). While our investigations confirm that major El Niño events around the end of the Early Intermediate Period likely offer part of the explanation for marked landscape change in the Samaca Basin, we also demonstrate the significance of more gradual, human-induced destruction of Prosopis pallida (huarango) riparian dry-forest. Huarango is a remarkable leguminous hardwood that lives for over a millennium and provides forage, fuel, and food. Moreover, it plays a crucial role in integrating fragile desert ecosystems, enhancing soil fertility and moisture, and accomplishing desalination and microclimatic amelioration. We propose that south coast valleys remained densely forested well into the Early Intermediate Period, attenuating the impact of El Niño events and supporting hitherto underappreciated agroforestry adaptations. Gradual deforestation eventually crossed an environmental threshold: river and wind erosion increased dramatically and precipitated radical desertification, feeding back into cultural changes in the Middle Horizon. Thus we argue Prosopis-human ecological relationships merit proper recognition in our archaeological interpretations of the south coast of Peru.

En la actualidad, el valle bajo del río Ica, ubicado en el litoral hiperárido del Perú, se encuentra prácticamente despoblado y carente de toda actividad agrícola. Los vestigios arqueológicos, sin embargo, sugieren la presencia de sustanciales concentraciones de población durante tiempos prehispánicos. En este artículo describimos nuestras investigaciones arqueológicas en Samaca, uno de los oasis ribereños del valle bajo del río Ica, dirigidas a reconstruir los cambios geomorfológicos, ecológicos y de uso de la tierra con el fin de averiguar cuando, como y por qué 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. Aun cuando 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 ribereño de Prosopis pallida (huarango), un proceso más gradual y de origen humano. El huarango, notable leguminosa de madera dura capaz de vivir más de mil años, no sólo provee forraje, combustible y alimento sino que además sabemos es crucial en la integración del frágil ecosistema desértico, mejorando la fertilidad y humedad del suelo y logrando desalinización y mejora microclimática. Proponemos que los valles de la costa sur estaban densamente forestados durante una buena parte del Período Intermedio Temprano, lo cual atenuó los impactos de eventos El Niño y permitió el surgimiento de adaptaciones agroforestales poco reconocidas hasta hoy. Sostenemos que la deforestación gradual eventualmente sobrepasó un umbral ambiental que condujo al dramático incremento de la erosión fluvial y eólica, precipitando un proceso de desertificación, el cual ha contribuido y ha sido causado por los cambios culturales del Horizonte Medio. 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.

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Latin American Antiquity 20(2), 2009, pp. XX-XX
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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 (Cook 1999; Massey 1991; Strong et al. 1943). 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. While recognizing the importance of these within a model of “punctuated equilibrium,” we need also to attempt to distinguish their impacts 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* or *Taco* (Yacovleff and Herrera 1934:291). According to D’Antoni and Solbrig (1977:191) this means “the tree” or “the one,” which might be indicative of its importance and cultural antiquity if it were better justified with appropriate linguistic citation.¹ Its mention in archaeological literature is almost inevitably in reference to its use as construction material or fuel. We will argue, however, that its importance to archaeological interpretation should go far beyond an appreciation of its value as a human resource.

Prosopis is crucial to ecological integration and biodiversity in many of the fragile desert ecosystems of the Americas. 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 moderating 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 the interpretations we derive 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 (see Beresford-Jones et al. 2004; Beresford-Jones 2005; Beresford-Jones et al. 2007 for details on our methodologies). 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?

A Note on *Prosopis* Identification on the South Coast

Some preliminary observations are in order regarding the taxonomy of *Prosopis* on the south coast of Peru. The systematics of the genus are complex and subject to ongoing revision. Like many arid area plants, the genus shows great phenotypic plasticity in response to environmental fluctuations (Ibrahim 1992) and frequent interspecific hybridization (Solbrig et al. 1977). Confusion over its taxonomy began with the Spanish conquerors, who called the tree they encountered *el algarrobo de las Indias* because it resembled the algarrobo, or carob tree (genus *Ceratonia*) of the Mediterranean (D’Antoni and Solbrig 1977; Vildoso 1996). “Algarrobo” is today the most common vernacular name for *Prosopis* tree species across most of South America (Pasicznik et al. 2001), including the north and central coast of Peru. On the south coast the genus is known locally as “huarango” or “guarango.” Again confusingly, the name “huarango” on the north coast of Peru refers to the other predominant coastal arboreal species *Acacia macracantha* (Brack Egg 1999), known on the south coast as “espino.” In the United States, various *Prosopis* species are known as “mesquite.”

The development of *Prosopis* taxonomy and its inherent difficulties on the coast of Peru can be traced through the work of MacBride (1943), Weberbauer (1945), Burkhart (1976), Burkhart and Simpson (1977) and Ferreyra (1987), Díaz Celis (1995), Pasicznik et al. (2001), Mom et al. (2002) and Harris et al. (2003), and see Beresford-Jones

2005 for a comprehensive survey. As Díaz Celis observes, “the systematic treatment of the algarrobo in Peru has been variable and confused” (1995:47, first author translation).

Rather unsurprisingly then, difficulties with *Prosopis* taxonomy abound in the archaeological literature. Yacovleff and Herrera (1934:291) originally identified artifacts of “algarrobo” wood as *Prosopis juliflora*. Towle, likely following MacBride (1946), considered this identification mistaken, stating that “*juliflora* does not occur in Peru” and that the Peruvian equivalent is *P. chilensis*, “a plant very similar to *P. juliflora* and often confused with it” (1961:56). Most archaeological authors continue to follow Towle in identifying materials as *P. chilensis* (for example Menzel et al. 1964; Shimada and Shimada 1985; Silverman 1993; Cook 1999; Silverman and Proulx 2002).

Scrupulously, these identifications are almost certainly incorrect. As Pasiiecznik et al. caution, “initial misidentification without correction can be repeated continually” (2001:21). *P. chilensis* is, in fact, one of the most distinctive *Prosopis* species in its live condition, by virtue of its larger leaf morphology (see Pasiiecznik et al. 2001:33). None of the many trees that we have observed on the south coast of Peru today show the *P. chilensis* leaf type (see Beresford-Jones 2005; Whaley 2004). Following Burkart and Simpson (1977), Díaz Celis (1995), Pasiiecznik et al. (2001), and Harris et al.’s (2003) systematics, and in agreement with most other current taxonomic authorities, we identify them as *P. pallida*, although, as discussed in Mom et al. (2002) the name *P. limensis* may now be even more appropriate. Likewise, all of the features of the large numbers of desiccated *Prosopis* macrofossils obtained from archaeological contexts in the course of this research, including leaves, brachyblasts, and pods, are those of *P. pallida* (Beresford-Jones 2005; cf. Piacenza 2002).

Indeed, archaeological wooden artifacts from *anywhere* on the coast of Peru are rather unlikely to be of *P. chilensis* (Molina) Stuntz, which occurs only in disjunct populations in higher altitude, dry intermontane locations, mainly in the south of the country (Brack Egg 1999; Burkart and Simpson 1977; Díaz Celis 1995; Pasiiecznik et al. 2001), and much more likely to be of the so-called “*P. juliflora* - *P. pallida* complex” (see Pasiiecznik et al. 2001). The botanist Herrera was likely well aware of this

in making his original identification of coastal algarrobos as *P. juliflora* (Yacovleff and Herrera 1934), since he had already identified the *Prosopis* of the high intermontane valleys, as *P. chilensis* (Díaz Celis 1995).

Such specific identifications are arguably unnecessary for some purposes of archaeological interpretation. All of them fall into Burkart’s section *Algarobia* of the genus (Burkart and Simpson 1977) and their ecological characteristics are broadly similar. As Felger observes on the importance of mesquite to the native cultures of the southwestern United States, “ethnobotanically it is both convenient and realistic to treat the North American members of the section *Algarobia* as a unit” (1977:150). References to *Prosopis* herein will therefore refer generally to all varieties of the *P. juliflora* - *P. pallida* complex, unless specified otherwise.

However, specific identifications are more important to considerations of *Prosopis* as a human resource. Peruvian accessions of *P. pallida* exhibit greater productions of larger, sweeter pods (Grados and Cruz 1996; Lee et al. 1992) and superior growth rates and forms (see, for example, Harris et al. 2003; Lee et al. 1992; Pasiiecznik et al. 2001), than other *Prosopis* species. Moreover, while *Prosopis* on the north coast occur both with and without thorns (Díaz Celis 1995; Ferreyra 1987), mature *P. pallida* on the south coast only rarely produce thorns (Beresford-Jones 2005; Whaley 2004). This is noteworthy because selection for thornlessness in some economic tree species is often almost the only observable phenotypic difference between so-called “wild” and “cultivated” varieties (most famously with the olive, *Olea europaea*). This leads us to speculate that those specific features we observe in the *P. pallida* of the south coast, and so widely appreciated in the agroforestry literature, may be the product of long processes of human selection (and see Pasiiecznik et al. 2001:51), preserved from subsequent backcrossing and hybridization by the relative isolation of its riparian ecosystems (Beresford-Jones 2005).

The Study Area

The Peruvian south coast is one of the oldest and driest deserts on earth. Its topography is typical of “Basin-range” deserts, characterized by enclosed drainage systems (Cooke et al. 1993). These ripar-

Relative Chronology (Periods)	Lower Ica Valley Sequence	Approximate Dates
Late Horizon	Inca Influence	1400 - 1534 AD
Late Intermediate	Ica-Chincha	1000 - 1400 AD
Middle Horizon	Derived Wari	800 - 1000 AD
	Late Nasca - Wari Influence	600-800 AD
Early Intermediate	Nasca	0 - 600 AD
Early Horizon	Ocucaje (Paracas)	400 BC - 0 AD
	Chavinoid	1500 (?) - 400 BC

Figure 1. Simplified prehispanic chronology for the Ica Valley.

ian basins have been the locus for human settlement since at least the Early Horizon (Cook 1999) (see 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 (see Figure 2). It is a well-defined and convenient landscape unit within which to assess particular human-environment interactions (French 2003). The climate is hyperarid, with an average annual precipitation of only .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 (although our theme here will invoke a third agent—humans).

The Río Ica exhibits a very different geomorphological configuration to the broad fan-shaped delta complexes of most of the major Peruvian westward-flowing coastal rivers. This distinction arises because of the widening of the coastal strip on the south coast, a result of the uplifted forearc basin known as the “Pisco Formation” (Dunbar et al. 1990). Blocked from the sea, the Río Ica is diverted south, parallel to the coast, for some 150 km, through a series of wide basins that it has incised into the sedimentary desert tableland of the

Tablazo de Ica (see Figure 2). It thus has no wide delta and deposits its alluvial sediments along its course within these basins. Life and human settlement in this desert are restricted to this “riparian oasis” corridor along the river which links the mountains to the ocean.

Surface flow in the Río Ica is extremely erratic and seasonal, fed by 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 m³. It has experienced occasional annual flows of over 800 million m³, which can be correlated with perturbations in the Southern Oscillation Index or *El Niño* (Beresford-Jones 2005), and many other years with practically no surface flow at all (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* (see Figures 2 and 6), are testimony to stability of this wind regime over great time depths (Beresford-Jones 2005; McCauley et al. 1977). Average monthly wind velocities in the Samaca Basin, measured continuously by Davis cabled weather station over

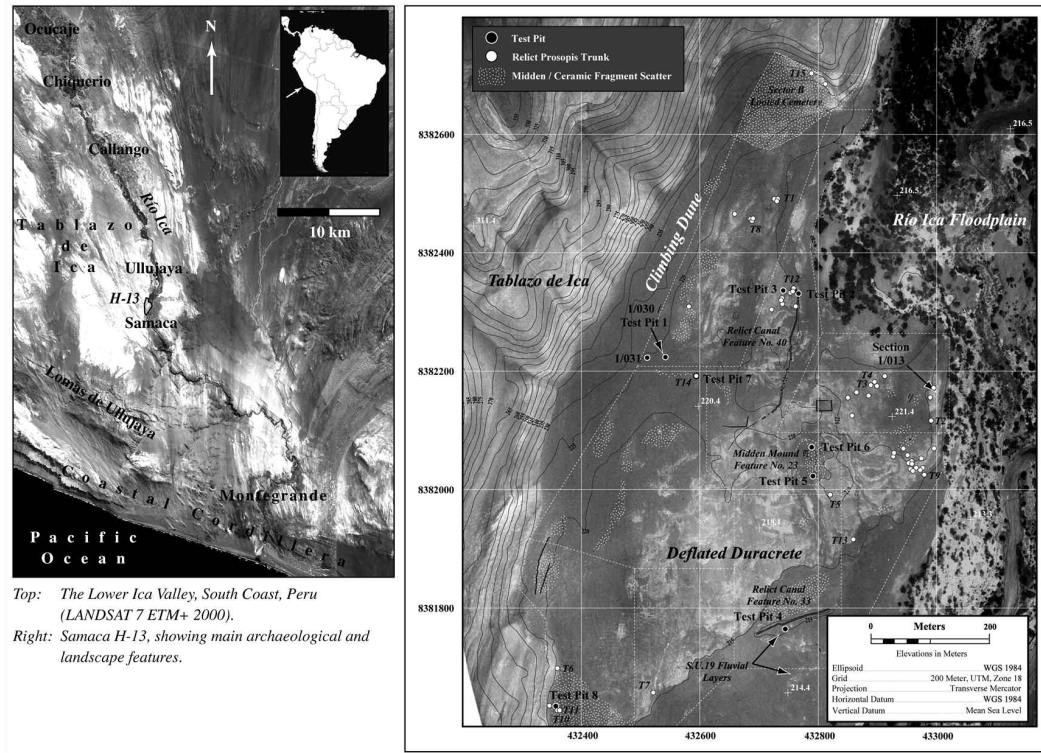


Figure 2. The study area.

seven months, ranged from 32.3 km/h (for October 2004) to 27.1 km/h (December 2004). Maximum gusts recorded varied between 115 km/h and 82.1 km/h respectively (Alberto Benavides G., personal communication 2006).

H-13, the focus of our investigation, defines an area of c. 60 hectares of relict river terrace, standing around 5 m above the floodplain and 10 m higher than the current Río Ica thalweg. It is entirely devoid 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 (see Figure 2). Cemented CaCO₃ 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 full force of the region's extraordinary wind regime. The effects of aeolian

deflation are evident across much of the H-13 landscape: its surface is scattered with multi-period palimpsests of ceramic sherds. Also, in a classic inversion of relief, wind deflation has created complex second-order landforms, whereby features such as canals, once cut into the land surface, are preserved by calcrete enrichment as upstanding features above the deflated surrounding landscape (see Figure 7) (Cooke et al. 1993; Maizels 1988).

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 (see Figures 2 and 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.



From top to bottom:

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

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

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

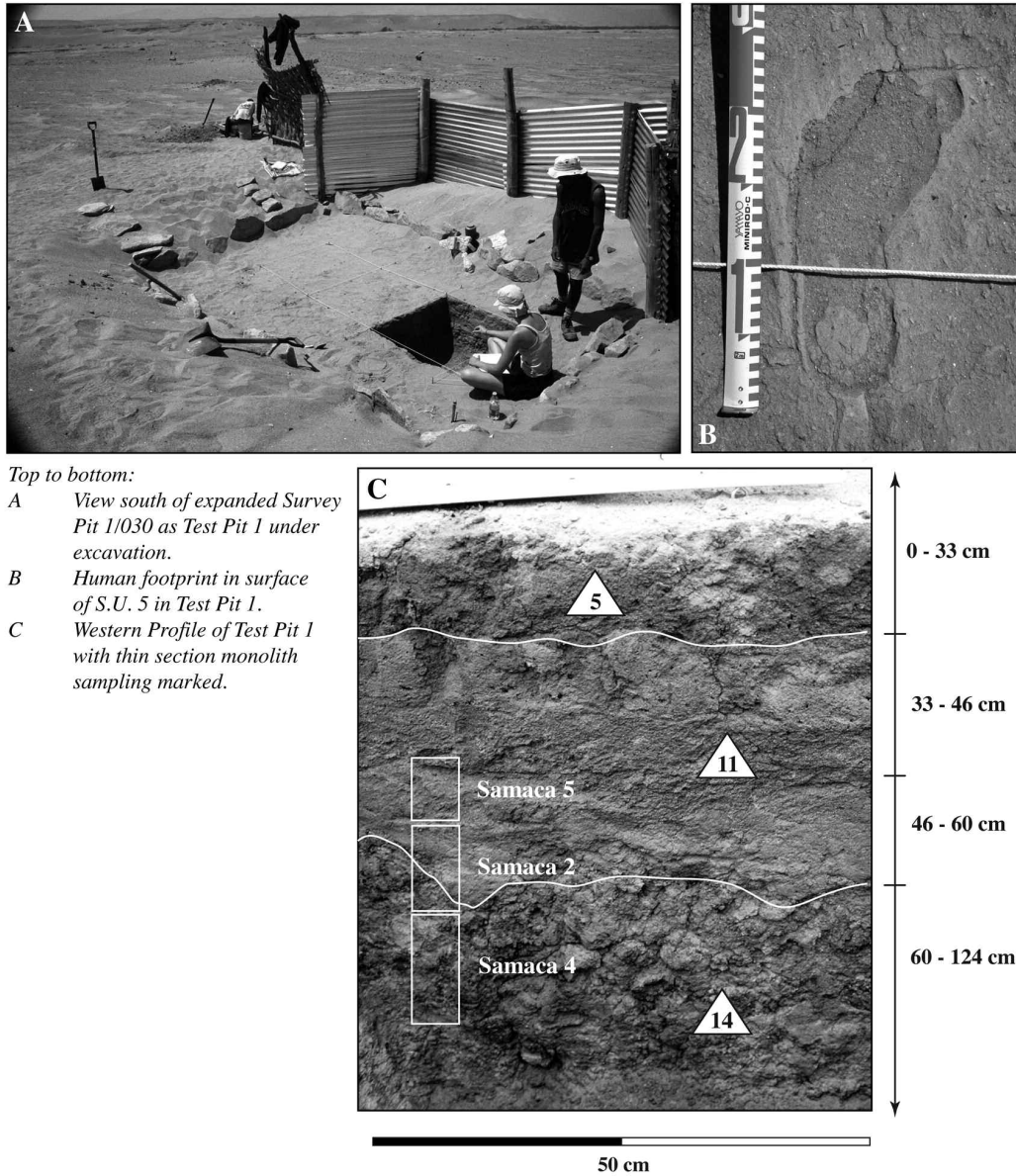
H Detail of G.

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

Many other *Prosopis* fossils were also recorded across H-13. These included expanses of duracrete with dominant calcite rhisoliths and leaf litter (or *poña*) pseudomorphs (see Figure 3G); desiccated roots, leaf litter, seeds, pods 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 all the Samaca H-13 excavations.

All these fossils likely represent trees growing at various different times. Nevertheless, since the lifespan of *Prosopis* can exceed 1,000 years, together they span extensive and overlapping periods. The dimensions of some of the relict trunks indicate that they existed on H-13 for many hun-



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 4. Buried land surfaces in Test Pits 1 and 1/030.

dreds of years, encompassing entire cultural periods. Thus, as witnesses of ecological change, *Prosopis* fossils effectively “compress time.”

Taken together, the total number, local groupings, and varied sizes of the many relict tree trunks and copious other *Prosopis* fossils suggest strongly that H-13 was once vegetated with more than just 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 obligate wetland species, in Test Pits 1, 1/030, 1/031, 2, 4, 5 (see Figure 2). Some of these were from anthropogenic midden contexts whose remains do not necessarily reflect the ecology of their immediate surroundings. However,



Top to bottom:

- A Selected decorated ceramic fragments – Mound 23 surface context. Middle Horizon – Epoch 2.
- B Selected decorated ceramic fragments – surface contexts (Sector D iv), wind deflated duracrete of H-13 relict terrace. Top row: Early Intermediate Period – Nasca phases 5. Middle rows: Early Intermediate Period – Nasca phases 2-4. Bottom row: Early Horizon – Ocucaje phase 10.
- C Decorated ceramic fragments - midden context, Test Pit 4 (S.U. 40). Early Intermediate Period – Nasca phases 2 to 4.
- D Examples of decorated ceramic fragments from within duracreted course of relict canal 33 (survey point no. 245) – showing black oxide staining, indicative of immersion in water. Early Intermediate Period – Nasca phases 2 to 4.
- E Selected decorated ceramic fragments – buried surface context Test Pit 1/031 (S.U. 76-80 cm), Early Intermediate Period – Nasca phases 2 to 4.

Figure 5. Selected Samaca H-13 ceramic fragments from excavation and survey.

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 as a record of the history of the terrace before

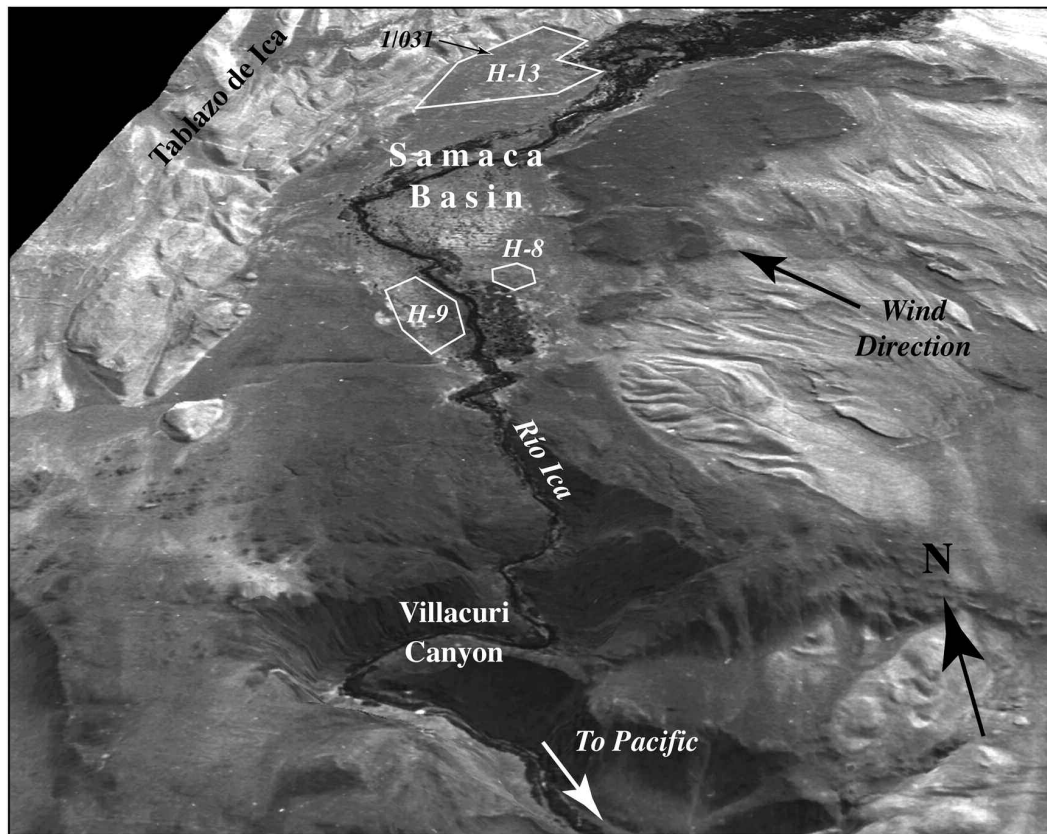


Figure 6. DEM isometric view north of the Samaca Basin.

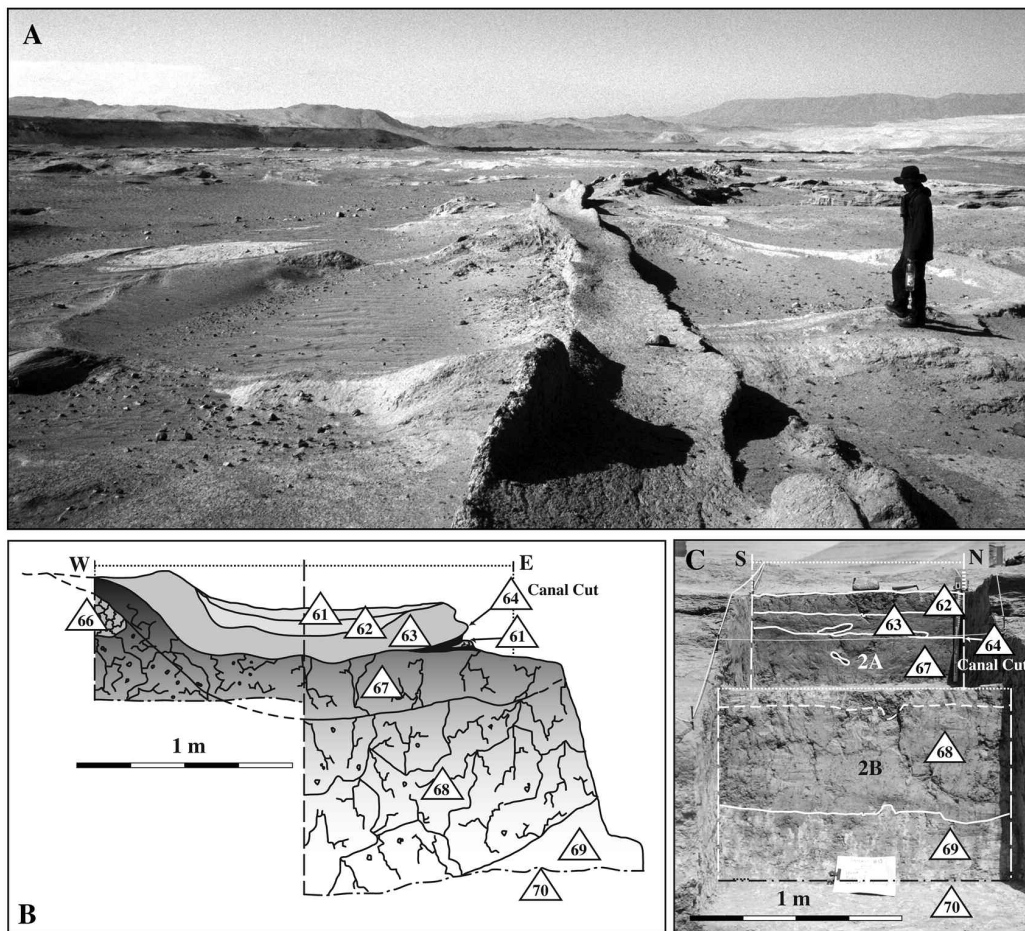
the archaeological remains were deposited on its surface. Grain size profiles down through this section suggest that in those deeper time contexts the deposition environment was radically different both from the upper stratigraphic unit proximate to the H-13 archaeological remains, and from the conditions that prevail today. In view of the relict canal system on the surface of H-13, these differences are interpreted as the result of human control, agriculture, and pedogenesis on the episodic clastic sediment regime of the underlying river floodplain. This also suggests that the relict river terrace was part of the active river floodplain when its canal systems were operational, and that the river down-cutting event(s) that formed this relict terrace *post-date* that time. This will be explored further below (see 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 can be found buried and sealed beneath the deposits of the climbing dune anchored along the western flank of the

Samaca Basin by its unimodal wind regime. Micro-morphological analysis of contexts from Test Pits 1 and 1/030 (Figure 4C) reveals buried soils beneath these dune deposits (Beresford-Jones et al. 2007). Today, these once *organic* soil horizons lie over half a kilometer to the west, about 5 m above the edge of the current floodplain amid a barren landscape (see Figures 2 and 4A). 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 (see Figure 4B), 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?

Archaeological remains provide a means of approximately dating the various elements of the H-13 landscape change. The ceramic seriations of the Ica



Top to bottom:

- A Relict canal Feature 40, view to south across Samaca H-13.
- B North Profile of Test Pit 2, canal Feature 40.
- C West Profile of Test Pit 2 canal Feature 40, showing anthropogenic calcrete S.U. 69.

Figure 7. Test Pit 2, relict canal fragment Feature 40.

Valley are relatively well studied. Indeed, they underlie Rowe's widely accepted master sequence for Andean prehistory (see Rowe 1967). Nonetheless, uncertainties remain as to their finer details, such as the so-called Dawson seriation for Nasca, widely cited but unpublished (see Proulx 1968, 2006; Silverman 1993; Silverman and Proulx 2002). Our dating by means of decorated ceramics is therefore conservative: we use only those wider, uncontroversial categories that are necessary for tracing ecological and cultural changes within a relatively broadly defined temporal framework. In the case of Nasca we follow the categories defined by Silverman (1993:36) on the basis of

those originally suggested by Rowe, which correspond more or less to those of Kroeber (Kroeber and Collier 1998) and Sawyer (1997). This effectively lumps together and thus avoids those details of the Dawson phases that remain of concern, pending clarification. For the Early Horizon we also draw upon Menzel et al. (1964) and Cook (1999); for the Early Intermediate Period we look to David Browne (personal communication 2007), as well as the works already cited; for the Middle Horizon we follow Menzel (1967) and Kroeber and Collier (1998); and for the Late Intermediate Period Menzel (1976).

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 (see Figure 5). 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 over the present-day land surface.

An important observation on the H-13 archaeological remains is the conspicuous absence of *any* material from the Late Intermediate or Late Horizon periods, despite the presence of two large habitation sites from those periods in the lower Samaca Basin: "H-8" and "H-9" (see Figure 6 and Cook 1994). We thus conclude that this H-13 landscape had already been abandoned prior to those periods. Further archaeological data refine this conclusion.

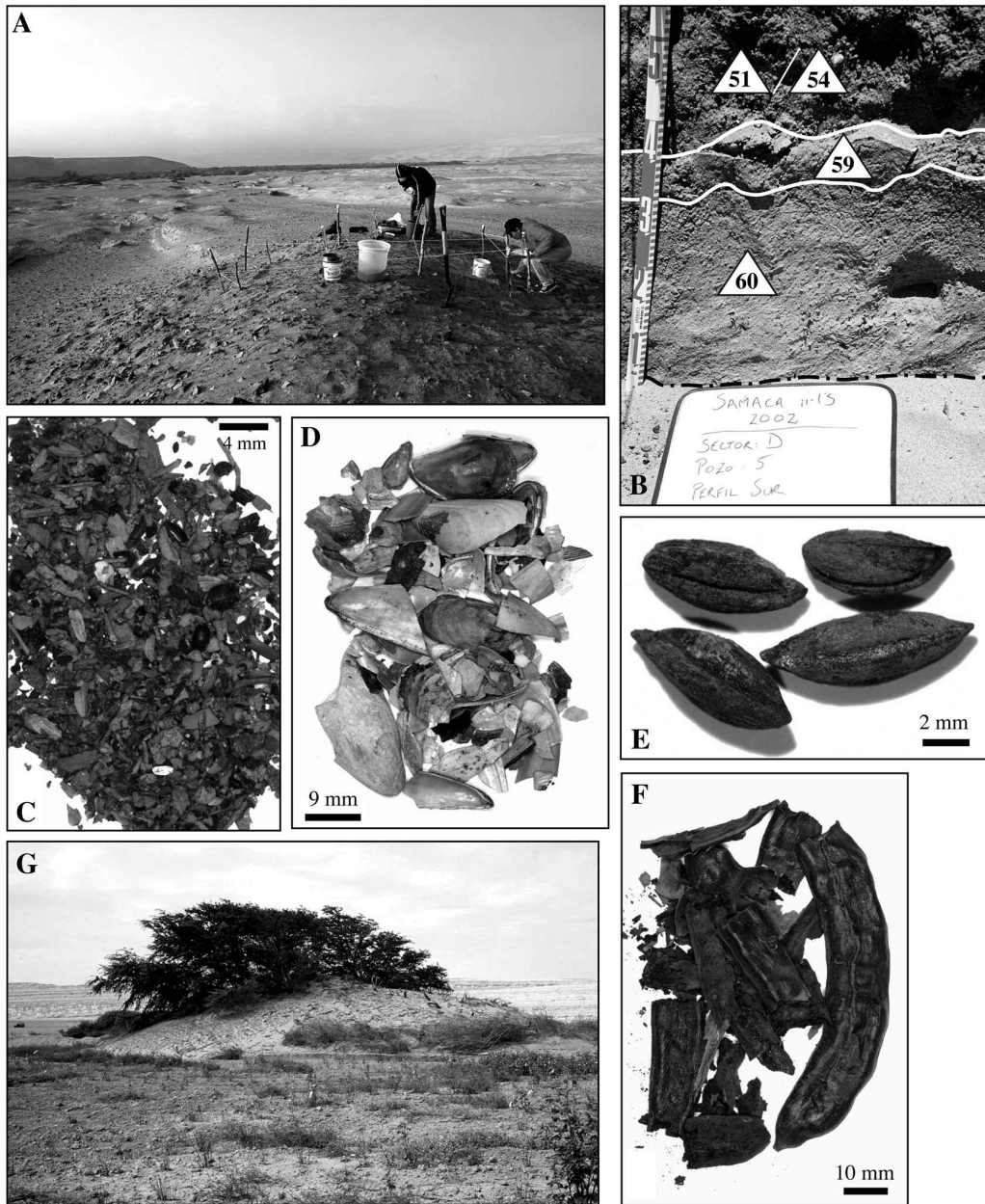
Survey demonstrates that the H-13 relict canal fragments were all once part of a contemporary system, though the precise dating of features such as canal systems, in use over extended time-periods, is problematic. Nevertheless, a range of evidence strongly suggests a *terminus ante quem* for this system accurately, but not precisely, to around the end of the Early Intermediate Period (Beresford-Jones et al. 2004; Beresford-Jones 2005). This evidence includes: ceramic finds excavated from the indurated evaporitic duracretes that now constitute the original courses of relict canals Features 40 and 33 (Test Pits 2 and 4, respectively), which show extensive iron oxide staining indicative of immersion in water; as well as contextual associations from ongoing wide-scale survey and excavation in the Samaca and adjoining Ullujaya basin. Calcite cementation to more than 3 m beneath their courses is evidence that these canals were in operation for considerable periods of time (Beresford-Jones et al. 2007; Machette 1985; see Figure 7).

The relict *Prosopis* trunks mapped across H-13 are clearly associated with areas of duracrete exposed by wind deflation (see 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 spanning some 800 years, from the later Ocucaje phases and Nasca phases, were found in mixed scatters across these deflated duracrete surfaces (Beresford-Jones 2005). The relict trunks show the effects of prolonged wind abrasion (see Figure 3). *Prosopis* wood is very dense and harder than oak or teak

(Ibrahim 1992; Pasiecznick et al. 2001; Rogers 2000), and in these hyperarid conditions can be preserved over millennia (Kroeber 1944; Kroeber and Collier 1998; Strong and Evans 1952). 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. These relict trunks in the H-13 duracrete are therefore interpreted as living trees that 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 (Beresford-Jones 2005). Its upper stratigraphic contexts yielded diverse midden materials from Middle Horizon Epoch 2B (see Figure 5). Below these, its character at depth includes tree throws and aeolian contexts dominated by *Prosopis* leaf litter, which establish Mound 23 as a relict nabkha, or phytogenic mound, formed by wind deposition about a large tree(s) (see Figure 8). The extant form of the mound, amid its surrounding deflated duracreted landscape covered with mixed ceramic fragments from earlier epochs, is imputed to its later age, to the binding effects of nabkha formation, and to the density of heavy ceramic and lithic midden materials on its surface.

Flotations of the midden contexts of Mound 23 yielded well-preserved desiccated plant assemblages (see Figure 8). In one stratigraphic unit (S.U. 32), these included coca seed (*Erythroxylum* sp.), leaf fragments of *Inga feuillei* (*pacay*), and seeds of *Psidium guajava* (*guava* or *guayaba*). Coca leaf, the useful part of the plant, first becomes visible in the south coast archaeobotanical record from Late Nasca to the Middle Horizon (Piacenza 2002; Silverman and Proulx 2002). Its presence in these contexts is thereby congruent with their dating to the Middle Horizon. The occurrence of coca seed in this conjunction of plant remains is furthermore noteworthy because of historical evidence for coastal coca plantations under *pacay* and *guayaba* shade trees (Rostworowski 1989). Moreover, these archaeobotanical remains suggest dramatically altered ecological conditions across a wider context beyond H-13, since neither coca nor the large, simple-leaved *pacay* and *guayaba* fruit trees can persist anywhere today in the wind regime of this part of the lower Ica Valley (Mariano Cabrera, per-



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 poña.
- D Marine mollusca 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 Samaca Basin.

Figure 8. Midden mound Feature 23 and relict nabkha character.

sonal communication 2002).

Together these data suggest that Samaca H-13 was vegetated until the Middle Horizon Period, but 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 that major climatic perturbations correlate with so-called “punctuations” evident in the archaeological record of the Peruvian coast (see for example Moseley 1992; Shimada et al. 1991; Silverman and Proulx 2002). Why a “punctuated equilibrium” model is important to archaeological interpretation is demonstrated by some of the H-13 data.

Excavation of Test Pit 4 (Figure 9C) revealed a thick fluvial layer, stratigraphic unit 19 (or, S.U. 19). This was one of 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 and deflated by wind erosion (see Figures 2 and 9A). The significance of this layer lies in its position and approximate dating: S.U. 19 directly caps midden contexts containing ceramic fragments from the Nasca 2/3 Early Intermediate Period.

The effects of any ENSO event may vary from one coastal valley to the next. 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 in the Samaca Basin downstream destroyed most of a substantial Late Intermediate/Late Horizon archaeological site recorded as “H-9” (Figure 6; Cook 1994). It follows that this was the greatest flood in the lower Ica Valley for at least the last 500 years.

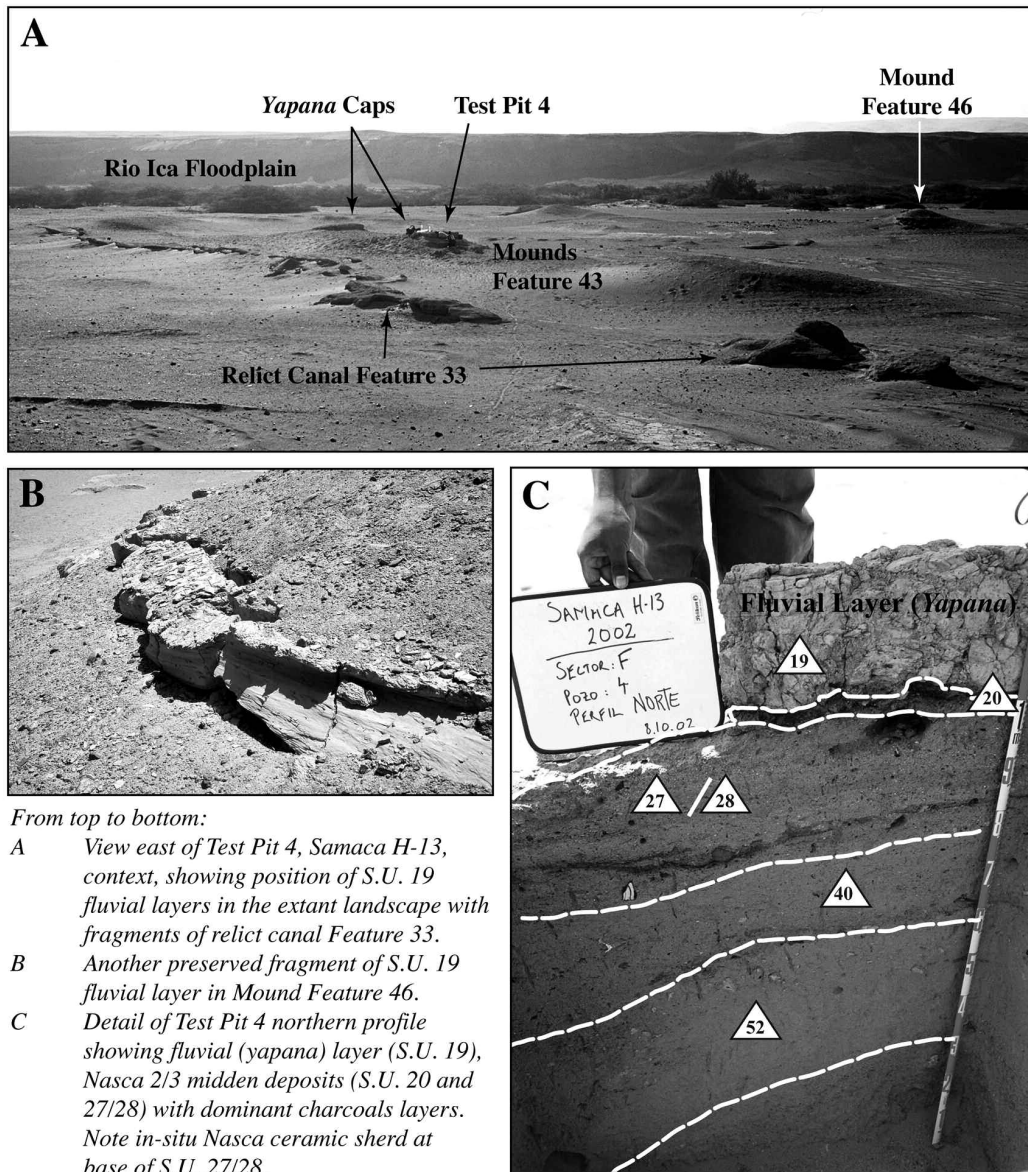
And yet this flood appears relatively minor in its spatial impact upon the upper Samaca Basin in comparison to the event that deposited S.U. 19. The surveyed altitudes of preserved fragments of S.U. 19, even on a conservative analysis, imply a

sheet flood across the equivalent profile in the Samaca Basin some 4 m higher than the maximum river level during the 1997/98 *El Niño*. This is illustrated in Figure 10 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, also in operation during the Early Intermediate Period (see Figure 9A), and an adjacent midden dating to the same period, were completely submerged by this flood event, as demonstrated by the stratigraphic sequence of Test Pit 4 (see Figures 9C and 10). For much of its length the edge of the H-13 terrace is defined by a steep embankment some 5 m high. This runs parallel to the river at the point where its erosive force would have been at its strongest during the postulated flood, and is the result of river incision (e.g., Section 1/013, Figure 10). Downstream from this embankment edge is a series of 2 m high relict braided channel banks, composed of large, sub-rounded cobbles deposited by the river in spate (Feature 18, Figure 10).

This stands as evidence of a major flood event, occurring at some time toward the end of the Early Intermediate Period, which spread a deep fluvial layer across the upper Samaca Basin, caused the river to cut some 5 m down into its floodplain, and had catastrophic effects upon the H-13 canal system. Our data thus reflects those wider observations on the likely catastrophic effects of major *El Niño* events along the coast of Peru.

While this recreation of the S.U. 19 flood event as a horizontal sheet flood is useful for illustrating its magnitude and identifying its landscape “footprint,” it is also necessarily somewhat simplistic. The erosion and deposition effects of any actual event would vary greatly across space and time. Within an area of general sheet flood there will be points of localized high energy: for example, the outer arc of an exceptional splay, responsible for the incur-



From top to bottom:

- A** View east of Test Pit 4, Samca H-13, context, showing position of S.U. 19 fluvial layers in the extant landscape with fragments of relict canal Feature 33.
- B** Another preserved fragment of S.U. 19 fluvial layer in Mound Feature 46.
- C** Detail of Test Pit 4 northern profile showing fluvial (yapana) layer (S.U. 19), Nasca 2/3 midden deposits (S.U. 20 and 27/28) with dominant charcoals layers. Note in-situ Nasca ceramic sherd at base of S.U. 27/28.

Figure 9. Context and details of Test Pit 4 and S.U. 19 flood layer.

sion between canal fragments Features 34 and 40; the accretion of the relict braided channel banks (Feature 18); and, the steep floodplain entrenchment represented by Section 1/013. Effects would also vary through time, as the river experiences a rapid transition from meandering to braided flow and then a more gradual transition back to meandering flow, depositing finer-grained sheet flood sediments, as represented by S.U. 19 (Beresford-Jones et al. 2007; Graf 2002; Schumm 2003).

However, what is potentially most misleading about this recreation of the S.U. 19 flood event is that it has been carried out on the Basin's *existing* topography. This conceivably conflates the effects of several high-energy flood events. More certainly, it means that our comparison of the relative magnitudes of the ancient flood event and the 1997/98 *El Niño* does not compare like with like: they stand on unequal topographical bases. It would therefore be simplistic merely to posit Figure 10 as the full

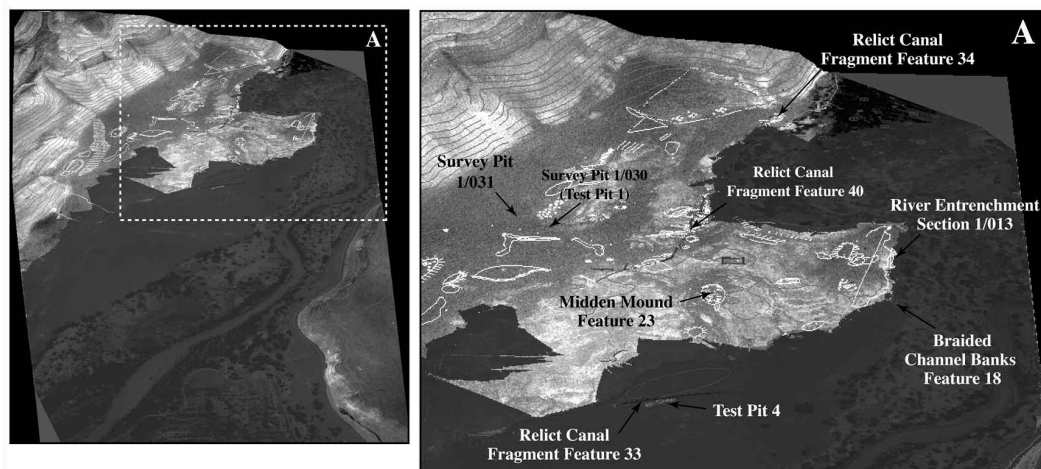


Figure 10. S.U. 19 sheet flood event, upper Samaca Basin.

story of how and why change occurred on Samaca H-13. A more complete interpretation requires us to take into account two further, related factors: riparian vegetation changes and river entrenchment.

Riparian Vegetation

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 [Cooke et al. 1993:153].*

The preeminent 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 typically extend to 2 to 3 times the diameter of the tree's crown, frequently access water tables 25 m deep, and have been recorded at well over 60 m long (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 comprises, in order of distance from the water's edge: *Tessaria intergrifolia* ('Pajara bobo'); *Phragmites* sp. ('Carizillo'); *Arundo donax* ('Carrizo' or 'Caña'); *Baccharis lanceolata* ('Chilco' or 'Chilca'); *Salix humboldtiana* ('Sauce'); *Acacia macracantha* ('Espino'); *Tecoma fulva* ('Cahuato'); *Galvezia fruticosa* ('Curil'?—local name not widely

known); *Vallesia glabra* ('Perlillo') and finally *Pluchea chingoyo* ('Toñúz'), found throughout the floodplain. The combined, heterogeneous root architecture and vegetation cover of this riparian assemblage makes for 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 south-western United States demonstrate how channel width decreases and channel sinuosity increases with increasing phreatophyte density, thanks to 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. It follows that 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 denser riparian vegetation in the floodplain when the S.U. 19 event occurred.

River Entrenchment

The other factor of topographic change intimately related to riparian vegetation cover is river entrenchment. In Test Pit 4 contexts beneath S.U. 19, desiccated plant macrofossils were found in such an excellent state of preservation that it appears 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 Feature 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 in this basin since the S.U. 19 event. That it has incised downwards, however, by at least 5 m or so, is evidenced by the terrace embankment described as Section 1/013. Incision diminishes a river's floodplain area, changing the relationship between river flood volume and the extent of the resulting sheet flood and thus undermining any easy comparison between the S.U. 19 and the 1997/98 events.

Moseley et al. (1983) identify river floodplain incision as the cause of progressive abandonment of canal systems in the Moche Valley on the north coast of Peru. To maintain a given area under canal irrigation following incision, canal intakes have to be extended further upstream. Since unlined canals exposed to high evaporation progressively lose water, they cannot be extended indefinitely and must eventually be abandoned. Moseley et al. postulate tectonic uplift as the cause of this entrenchment, based upon the occasionally uphill course followed by the Chicama-Moche inter-valley canal. Yet the Chicama-Moche canal system never actually carried water along its whole length, and its occasional uphill courses have since been interpreted as engineering failure rather than later 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 already been discussed above.

In the 1920s, the geomorphologist Kirk Bryan noted the rapid degradation in the Gila River Basin that had been taking place since the 1870s, 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).

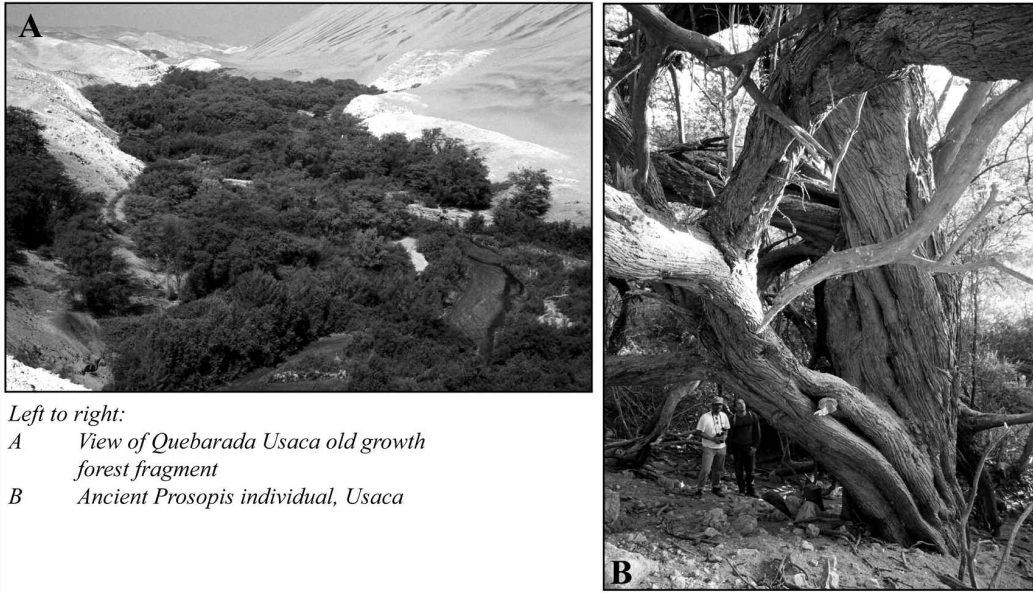
The major environmental damage occurs through loss of vegetation whose root structures formerly held the banks of streams and rivers in place.... Widened channels are cut deeper by subsequent rapid runoff, and the result is an arroyo, a deep trench cut to a depth of 50 feet or more into the terrain.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

The phenomenon of arroyo cutting (Cooke and Reeves 1976; Cooke et al. 1993; Graf 2002;) involves complex interplay between what Cooke et al. term "self-enhancing feedback mechanisms" of both climatic and human-induced effects (1993:160). As Hackenberg observes, "living streams with narrow channels, ideal for irrigation with primitive tools, became intermittent flood channels with crumbling and widening banks—impossible to control" (1983:162).

We suggest, then, a picture 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 an ongoing decline in riparian vegetation in the river floodplain, and in particular of *Prosopis* (see Beresford-Jones 2005 for the definition and justification of a limited analogy between the Gila and Ica river systems by reference to their comparable hydrology, basin-range geomorphology and flora).

Thus, the apparent difference between the extent of the ancient S.U. 19 and the 1997/98 *El Niño* flood event in the upper Samaca Basin could be the result of: (a) much greater riparian vegetation in the river floodplain in the past; and (b) 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. At the major Nasca period site of Cahuachi on the Río Nazca, Grodzicki identifies roughly contemporary effects of major *El Niño* impacts (Orefici



Left to right:

A View of Quebarada Usaca old growth forest fragment

B Ancient *Prosopis* individual, Usaca

Figure 11. Last old-growth *Prosopis* woodland fragment, Quebrada Usaca, Río Poroma.

and Drusini 2003), which again include river down-cutting and a narrowing of the vegetated floodplain. The point here is not to deny the significance of these chaotic fluctuations in the biophysical environment, but to observe that their impacts 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 us to superpose more 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 consecutive stratigraphic units from Test Pit 1/031 (Figure 2). Early Intermediate Period Nasca Phase 2/3 ceramic fragments from S.U. 76–80 cm provide a rough time framework for this sequence.

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 (data which are in themselves highly suggestive of processes of gradual change across H-13; see Beresford-Jones et al. 2007). This location formed an effective trap for wind-borne pollen blown across H-13 and for entomophilous (insect-pollinated) taxa in its immediate vicinity, including *Prosopis* and most other riparian arboreal species (see Figure 6). It also limited the possibilities of nonlocal contamination: witness the minor percentages of exotic pollen in Figure 12. The sequence was eventually buried and sealed by graded sand aeolian deposits of the climbing dune.

Figure 12 shows the pollen sequence from 1/031 compared with: (a) pollen preparations from the adjacent Test Pit 1/030 33–46 cm associated with Middle Horizon archaeological materials; and (b) the average of pollen preparations of modern samples taken from the floor of an old-growth wood-

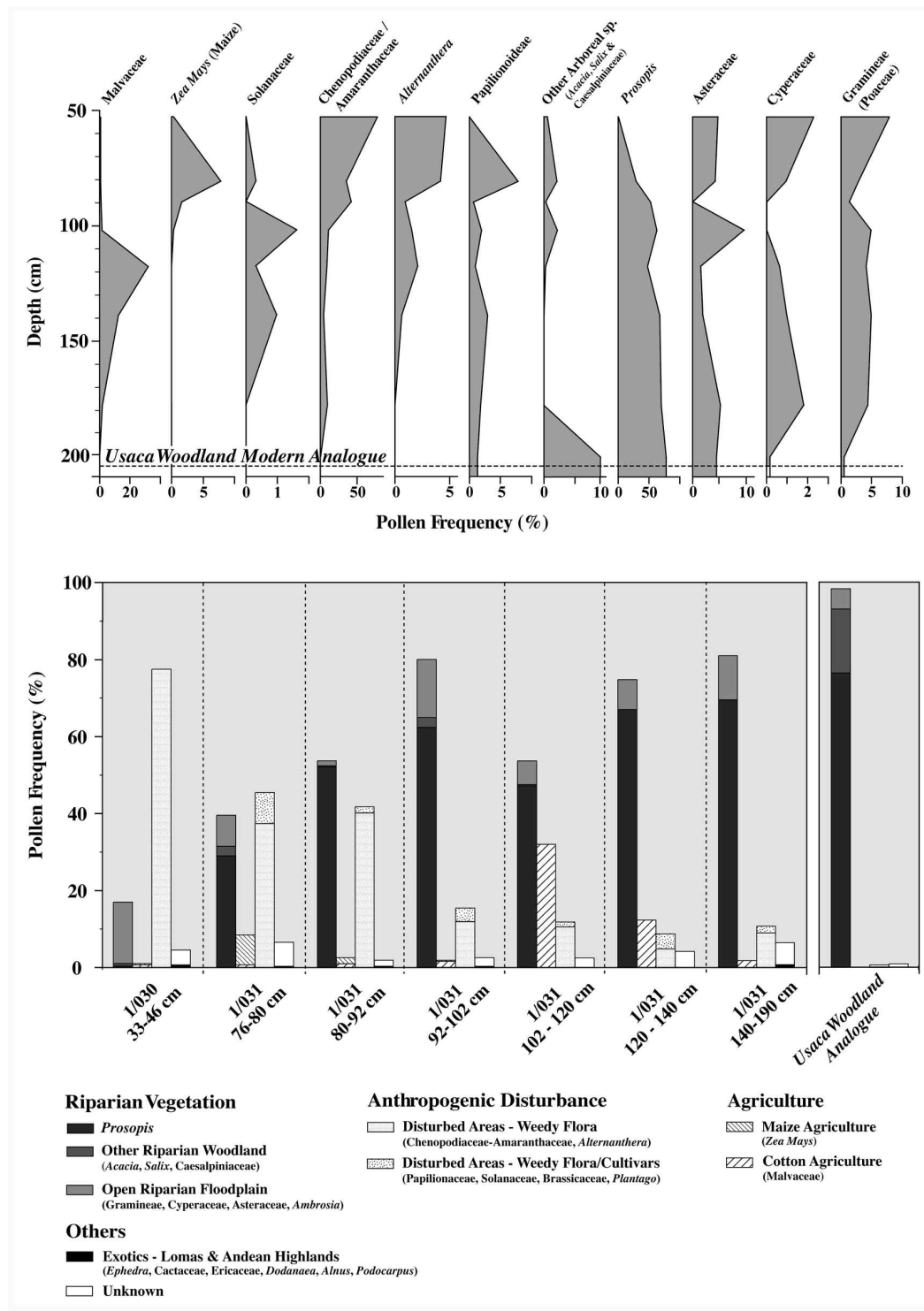


Figure 12. Variation in pollen down 1/031 context sequences compared with modern Usaca woodland analogue.

land fragment in Quebrada Usaca on the Río Poroma in the Río Grande de Nazca drainage (see Figure 11), 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 percent) 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, far from the vegetated river floodplain today (see Figures 2 and 6).

Prosopis pollen and *poña* macrofossils decline steadily up the sequence, as pollen from domesticated plants such as cotton (Fam. Malvaceae cf. *Gossypium* 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), so 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 during which the canal system on H-13 was in operation and imposing a controlled-energy regime of deposition quite distinct from the preceding, episodic floodplain clastic deposition (as observed in the geomorphological record of Section 1/013).

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 the pollen assemblage entirely, while *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 mollusca from locations some 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.

Moreover, 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 dominated by multiple nabkha formations, and these are not environments conducive to maize cultivation given the area's very strong winds (see Figure 8).

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 the progressive loss of riparian vegetation in general and of *Prosopis* in particular. To understand the importance of *Prosopis* cover, and why changes occurred, requires us to incorporate the profound role that this 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 (see Pasiecznik et al. 2001 for an excellent review) and supplemented by our observations on the Peruvian south coast (Beresford-Jones 2005; Whaley 2004).

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; Pasiecznik et al. 2001; Sene 1996). Successful agriculture is just not possible here without the protection afforded by trees. The microclimate beneath the *Prosopis* canopy maintains cooler soil and air temperatures convivial to microorganisms and the decomposition of litter fall (Asencio Díaz 1997; Fisher 1990; 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 (Bhojvaid and Timmer 1998; Garg 1992, 1998; Mishra and Sharma 2003; Singh 1996). 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 micorhizoid fungi, leguminous *Prosopis* fixes nitrogen in the soil and improves soil structure and respiration (Abrams et al. 1990; Bird et al. 2002; Johnson and Mayeux 1990; Purohit et al. 2002). *Prosopis* in the Sonoran desert with only a 30 percent canopy cover is recorded as fixing 40–50 kg of nitrogen per hectare per annum (Virginia and Jarrell 1983). Soil fertility and nitrogen content 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 CO₂ partial pressures that contribute to the dissolution of relatively insoluble CaCO₃, the calcrete whose wide extension on H-13 today is evidence of both past flooding and of long standstill conditions (Beresford-Jones et al. 2007). 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 1984:75).

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

The region’s obvious limitation might appear to be water availability, and archaeological interpretations duly invoke the hydrological poverty of south coast rivers relative to the coastal valley systems to their north (Craig and Psuty 1968; Menzel et al. 1964; Sawyer 1997; Silverman 1993; Silverman and Proulx 2002). Surface flow impressions can be misleading, however. As discussed above, the Río Ica and the Río Grande de Nazca show configurations quite distinct from the broad fan-shaped delta complexes of most of the major westward-flowing coastal rivers of Peru, 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). Yet this same topographic peculiarity also preserves high groundwater levels and subsurface flows, and these rivers lose little water to the sea. Estimated subsurface flows for the Río Ica total over 155 percent of average surface flow (ONERN 1971; Taltasse 1973). The human populations and agricultural acreages sustained today in the Middle Ica Valley, often by pumping groundwater, are in fact *greater* than those of its northern neighbors (Beresford-Jones 2005).

Furthermore, some *Prosopis* species influence soil moisture, especially in a region characterized by zero precipitation, predominantly subsurface groundwater hydrology and high night-time air humidity (Mooney et al. 1980; Sudzuki 1985a, 1985b). Deep dimorphic root systems access water at great depth and may deposit part of that water amid their dense superficial root network through the recently described process of “hydraulic lift” (Caldwell and Richards 1989; Caldwell et al. 1998; Dawson 1993; Horton and Hart

1998; Jackson et al. 2000; Richards and Caldwell 1987). Moreover, *Prosopis* captures atmospheric humidity on the huge surface area of its brachyblasts/leaflet clusters and also likely absorbs it through its leaves and “reverse hydraulic lift”, thus contributing still further to the moisture of upper soil horizons (Mooney et al. 1977; Schulze et al. 1998; Smith et al. 1999; Went 1975; Whaley 2004). The “islands of fertility” observed around *Prosopis* in arid regions (Barth and Klemmedson 1982; Carrillo-Garcia et al. 1999; Geesing et al. 2000; Reyes-Reyes et al. 2002; Rossi and Villagra 2003) might equally well be termed “islands of moisture.” These influences of *Prosopis* 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

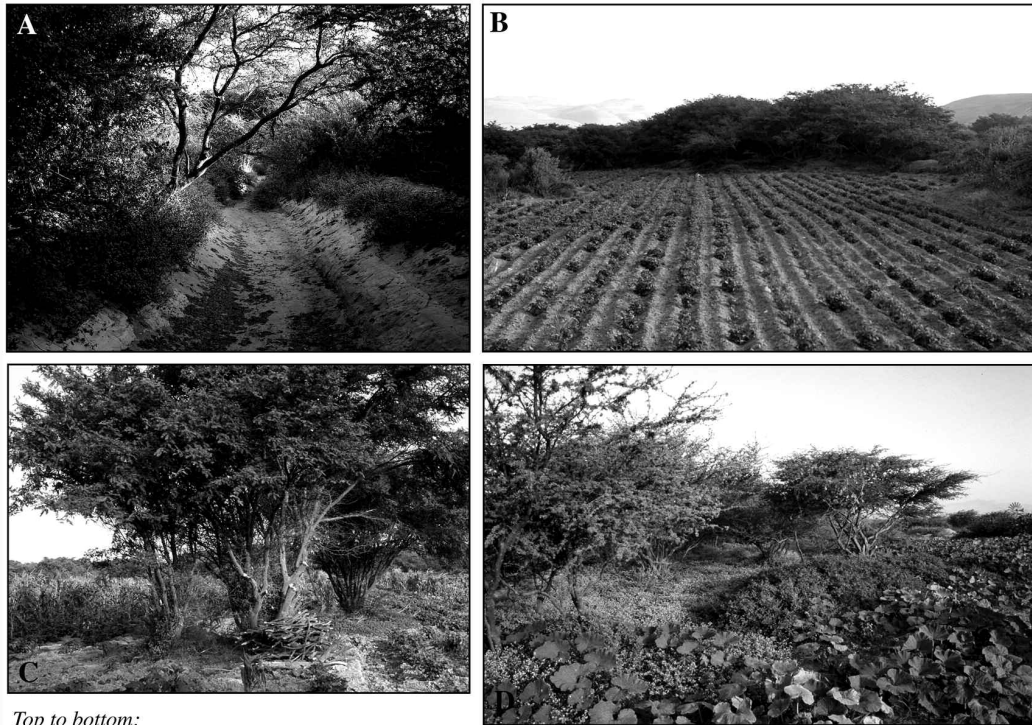
The model of gradual change recorded in the Samaca basin starts with old-growth woodland of a relatively undisturbed riparian ecology dominated by *Prosopis pallida* forma *pallida*, (or *P. limensis*) and *Acacia macracantha*, underpinning a riparian assemblage. Giant *Prosopis* over a millennium old are “tall, growing sideways like contorted mountains,” as described by Calancha [1639] in his account of the city of Ica (cited in Sánchez Elías 1957; first author translation). Today only a few small relics of old-growth *Prosopis* forest remain in the Quebrada Usaca, the Río Poroma and in various pockets on the Río Grande: our approximate analogues of the ancient *huarangales* (*Prosopis* woodlands) of the south coast of Peru (see Figure 11). They bear little resemblance to the modern degraded and immature scrub-forest *monte* that colors archaeological interpretations.

Gradual anthropogenic change converts this woodland into a controlled, canal-irrigated agricultural landscape on H-13 during the Early Intermediate Period. This is a process with considerable time-depth, beginning around the middle of the preceding Early Horizon, the date of the earliest ceramic fragments recovered during survey. As modern analogues for the human agro-ecology for this period, one might invoke 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; Felger and Moser 1985; Hodgson 2001; Nabhan 1979, 1986; see Beresford-Jones 2005 for a justification of this analogy). Maize, pumpkins, cotton, beans, and other plants are cultivated in very small fields whose raised edges conserve water from both irrigation and other elements of what Nabhan (1979:246) terms a “continuum of hydrostatic manipulations” (see Figure 13), 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 still constitute *the* major food source, especially between harvests. These include *Portulaca* sp., *Amaranthus* spp., *Chenopodium* spp., *Lippia* sp., *Crotalaria* sp., Cyperaceae, cf. *Solanum pimpinellifolium* (wild tomatoes), and most notably *Prosopis* pods (Beresford-Jones 2005). Again this invokes our analogue with the Sonoran, in which fully *one fifth* of the total desert flora is edible (Hodgson 2001). Even preeminent Sonoran agriculturalists, such as the Akimel O’odham and their predecessors the Hohokam, depended upon wild foods for up to 50 percent of their food supply. By far the most important of these were *Prosopis* beans (see, for example, Castetter and Bell 1942; Fish 2000; Hackenberg 1983). Castetter and Bell observe “mesquite constituted nearly, if not quite, the chief native of Pima [O’odham] diet” (1942:56). This model is also in broad agreement with *all* archaeobotanical data available for the Peruvian south coast (Cook and Parrish 2005; Piacenza 2002; Roque et al. 2003; Silverman 1993), even if not always explicitly recognized in its interpretation.

The famously naturalistic Early Intermediate Period Nasca iconography is interpreted as celebrating the abundance of life forms and factors underlying agricultural fertility (Peters 1991; Reinhard 1993; Sawyer 1961, 1979, 1997; 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



Top to bottom:

- A *Prosopis* and *Acacia* protecting canal course, Huerto Huamaní, lower Samaca Basin.
 B Huarango hedgerow about bean field.
 C *Prosopis* and *Acacia* respectively; left in middle of field & coppiced for firewood.
 D Huarango and pumpkin along field edge. Note rich *Prosopis* understory growth.

Figure 13. Huerto Huamaní field systems, hedgerows and agro-forestry.

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 *huarangel* woodland, with its distinctive, contorted growth, subtly pervade the *entire* Nasca artistic canon during this period (see Figure 14).

And yet, as we have argued, the importance of *Prosopis* to human ecology goes far beyond providing 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). Indeed, the ecological and archaeological evidence that we present here for *Prosopis* strengthens hypotheses of its wider, symbolic importance to Nasca society (see DeLeonardis and Lau 2004:107; Silverman 1993:193).

In this model, most *El Niño* years are not great

catastrophes. 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 within 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, which deposit huge quantities 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, the gradual removal of *Prosopis* has undermined all of its beneficial roles: its influence on soil structure, quality, and moisture; floodplain protection; and its microclimatic amelioration of the effects of strong insolation and wind. Reduced vegetation across the floodplain has permitted high-energy lateral insta-



Figure 14. The forms of the huarangal, ancient *Prosopis* in Usaca woodland fragment (line drawing courtesy of Ann Peters).

bility in channel form, and river entrenchment. Once critical geomorphological and ecological thresholds are breached, a series of positive feedbacks drive processes of land degradation, which in this arid ecosystem become irreversible. Although chaotic fluctuations in the biophysical environment—like the S.U. 19 flood event—are likely responsible for actually breaching those thresholds, the seeds of sudden instability had been sown long before 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, which begin to form around isolated large *Prosopis* individuals whose deep root systems still access ground waters. The rest are blown across H-13 until they become anchored in the climbing dune that gradually builds up along the western flank of the basin. The aeolian deflation of the H-13 surface has begun.

By Epoch 2 of the Middle Horizon, occupants of the Samaca Basin are using the shade and shelter of nabkha Mound 23 to consume a diet composed entirely of foods gathered 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* at the heart of Mound 23 has either died or been dug out for firewood or construction materials. The process of ecological change on H-13 is complete, *Prosopis* is removed from the model, and under the effects of the wind, geomorphological change increases. No cultural materials from this or later cultural phases are observed on H-13.

This model correlates with wider changes in the archaeological record. Habitation sites decline in number and are rearranged, the Cahuachi ceremonial center is abandoned, and the Nasca iconographic style fractures after Nasca 3—developments all usually linked to major climatic perturbations (Orefici and Drusini 2003; Silverman 1993, 2002; Silverman and Proulx 2002), specifically droughts evidenced by the Quelccaya ice core record (Thompson et al. 1985). The material culture record of the Middle Horizon in the lower Ica Valley shows none of the refined ceramic tradition sometimes associated with Wari expansion. It comprises a corpus of crudely made and decorated ceramics that stand in marked contrast to the elaborate fineware of the preceding Early Intermediate Period (Kroeber and Collier 1998; Menzel 1967; and see Figure 5).

Other data substantiate hypotheses that environmental conditions are deteriorating. Studies of human skeletons from mortuary contexts in the Nazca Valley (Drusini et al. 2001) indicate that from the Early Intermediate Nasca to the subsequent Middle Horizon period infant mortality tripled while average adult life expectancy fell by seven years, suggesting for Drusini et al. “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. In the archaeobotanical record of the PV62-70 Nasca habitation site on the Pampa de Tinguña in the upper Ica Valley, as analyzed by Menzel and Velarde, beans, maize, and ají peppers decrease or disappear from upper strata associated with Nasca 7 occupation, while quantities of squash increase. These changes are taken to reflect the onset of drought conditions (Menzel 1971). Cook

and Parrish’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 would argue that *Prosopis* woodlands were a widespread and locally dominant feature of the Early Intermediate Period landscape along the south coast of Peru, and that the ecological consequences of their removal are just as essential to our interpretations of landscape and cultural changes as the 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 calls “anthropogenic geomorphology” (2000:6), 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 Peruvian coast is an old and gradual one, which can be traced through the Spanish chronicles, administrative records and recent memory (Grados and Cruz 1996; Rostworowski 1981; Yacovleff and Herrera 1934). On the south coast in particular, the story is now all but complete. Deforestation of the Middle Ica Valley reached vertiginous rates during the twentieth century (Beresford-Jones 2005; Horkheimer 2004; Sánchez Elías 1957; Vildoso 1996:). The *huarangales* around the city of Ica, which Vázquez de Espinosa could still describe as “impenetrable at many points ... with many savage wild animals,” 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 then, and despite (or perhaps because of) its preponderance of ecological argument and data, this paper argues for a less environmentally determined interpretation of changes in cultural trajectories. Samaca is but the smallest of the five basins of the lower Ica Valley; though our ongoing research records similar, related changes over the larger scale of the Ullujaya basin.

Indeed, these findings have undoubted contemporary resonance. Deforestation and desertification are now so widespread in the region that no undisturbed reference ecosystems remain in either the Ica or Nazca valleys. The huarango's resilience and perfect adaptation means that it continues as a dominant part of the region's ecosystem, re-establishing itself largely through natural regeneration from sporadic flood events (including *El Niño*). What has changed dramatically, however, is the age profile of their population. The natural lifespan of these trees is over a millennium. Some of the individuals in Usaca woodland relict were already old when the Incas conquered the south coast. Today these tiny last remaining "old-growth" riparian forest relicts of the south coast resound to the chain-saws of illegal charcoal-burning operations.

Moreover, 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 (Pessaraki and Szabolcs 1999). 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; their successes and failures through constant iterations of change; and in particular the importance of *Prosopis* woodlands for sustaining liveli-

hoods and creating permanent islands of moisture and fertility within arid American environments.

Acknowledgments. We would like to thank all 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; Manuel Arroyo-Kalin, Elizabeth DeMarrais, Charly French, Paul Heggarty, Lila Janik, Martin Jones and the members of the George Pitt-Rivers Archaeobotanical Laboratory (Department of Archaeology, University of Cambridge); Carmela Alarcón, Warwick Bray and Cesar Patroni for their help and advice; Claudia Lüthi, Don Mariano Cabrera, and above all the people of the *Escuela Libre de Puerto Huamán* and Don Alberto Benavides G. for being the father of it all. Ours thanks also to the reviewers of this manuscript—one anonymous and Bruce Owen—for their many careful comments. Funding was generously provided by the National Environmental Research Council (NERC), the British Academy, and the McDonald Institute for Archaeological Research.

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Notes

1. It seems more likely (Paul Heggarty, personal communication 2008) that this name derives from the red color of its wood due to its very high tannin content.

*Submitted October 5, 2007; Revised April 16, 2008;
Accepted May 21, 2008.*