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Linking landscapes of lowlands to mountainous areas
3.1 A qualitative model for the effect of upstream land use on downstream water availability in a western Andean valley, southern Peru

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ABSTRACT

The rise and decline of pre-Columbian cultures in coastal Peru has been the subject of numerous studies. Availability of and access to water have long been recognised as the key issues for the habitability of valley oases in the coastal desert where agriculture depends on seasonal river discharge from the Andes. In general, the reason for cultural changes has often been seen in ‘natural disasters’ or climatic changes. We propose an alternative qualitative model to explain changes of human-environment interactions in the region. This model focuses on patterns arising from the exploitation of and adaptation to the limited – but on the whole not necessarily declining – resources of water and arable land. Agriculture along the rivers of the Peruvian coastal desert was probably first practised in the wide, gently sloping lowland valley floor areas at the foot of the Andes, where large tracts of land can be irrigated with relatively low expenditure of labour. Subsequent expansion of agriculture necessitated the utilisation of progressively marginal areas along the upstream reaches of the rivers. While the spatially limited valley floor areas can to a certain extent be irrigated with short irrigation canals, irrigation of the steep valley slopes of up-valley areas requires the labour-intensive construction and maintenance of canals and terraced fields in difficult – and arguably less productive – terrain. Diversion of water onto up-valley terraced fields can be expected to have reduced water availability in the lowland valley floor fields. Thus, the adaptation to the constraints of one limited resource (irrigable land) may have led to a suboptimal exploitation of another limited resource (water), leading to an overall decline in agricultural productivity per unit of arable land. Such a feedback between land use and water availability is consistent with archaeological findings such as declining population density and increasing conflict during the Early Intermediate Period.
KEYWORDS

qualitative modelling, Palpa Valley (Peru), Nasca, irrigation, water management, early agricultural land use systems (2800-550 cal BP)

INTRODUCTION

The Palpa Valley, a river oasis at the foot of the Andes in the desert of coastal southern Peru (fig. 1), has been inhabited for at least 3500 years. Settlement was based on irrigation agriculture which by distributing sediment-laden river water to the fields has created thick accumulations of irragic anthrosol (Hesse & Baade 2009). The Palpa Valley is a wide valley floor that is shared by the rivers Rio Palpa and Rio Vizcas and that has an area of approximately 15 km². Because mean annual precipitation is less than 10mm (ONERN 1971), agriculture depended completely on irrigation with river water before the introduction of mechanised pumping. Seasonal river discharge from the Andes therefore is the key factor for agricultural productivity in this and other coastal valleys.

In this environmental context, archaeological investigations document the rise and decline of pre-Columbian cultures (Reindel et al. 2001; Silverman 2002; Schreiber 1999). Both the availability of river water in terms of climatic fluctuations (Shimada et al. 1999) and the access to water in terms of irrigation technology, labour mobilisation and control (e.g. Pozorski & Pozorski 2003) have long been recognised as the key issues for the habitability of valley oases in the coastal desert. Several qualitative models have been suggested to describe and explain observed changes in the archaeological record. A qualitative model is a description of processes, interactions and cause-effect relationships within a system which can be compared with the observed characteristics of that system. It can thus help to improve the understanding of past societies where there is insufficient quantitative data. Taking into account the research history

Figure 1. Map showing the location of the Palpa Valley. The two valleys reaching the Palpa Valley from the east are the valleys of Rio Palpa and Rio Vizcas. See also full colour section in this book
in the study area, the purpose of this paper is to present a qualitative model that focuses on human-environment interactions and feedbacks rather than one-directional cause-effect relationships.

**QUALITATIVE MODELS FOR HUMAN-ENVIRONMENT INTERACTIONS**

Cultural development in the region is characterised by the rise and decline of the Paracas culture during the Early Horizon (2800-2150 cal. BP) and the Nasca culture during the Early Intermediate Period (2150-1300 cal. BP). A period of cultural decline (1300-950 cal. BP) was followed by renewed cultural elaboration during the subsequent Late Intermediate Period (950-550 cal. BP) (Reindel et al. 2001; Silverman 2002; Unkel et al. 2007). Several models have been proposed to explain changes in the archaeological record of coastal Peru. Most of them assume a strong impact of the environment on cultural development which may be conceptually problematic (cf. Van Buren 2001). The degree to which interactions between humans and their environment are taken into account varies from model to model.

**El Niño and natural disasters**

The most frequently cited natural phenomenon impacting societies on the coast of Peru are El Niño flood events which may destroy irrigation systems, fields and settlements (Reindel et al. 2001; Silverman 2002; Wells & Noller 1999; Zaro & Alvarez 2005). However, it has also been noted that the disruptive effects of El Niño events are of short duration and may partially be offset by positive effects such as the possibility of planting or herding in the greening desert (e.g. Murphy 1926; Arntz & Fahrbach 1991).

**Climatic change**

The impact of more gradual environmental changes toward drought and a shifting desert margin may have affected the ecology of the desert and pre-hispanic populations (Eitel et al. 2005). Presently, the balance of evidence does not support this hypothesis (Hesse & Baade 2007).

**Agricultural collapse (Irrigation system collapse)**

River incision necessitates the upstream shift of irrigation canal intakes and the lowering of canal gradients until diversion of river water onto fields becomes impossible and irrigation agriculture collapses (Moseley 1983). In the Palpa Valley, artificial straightening and narrowing of the Rio Vizcas has resulted in an incision by up to 5m since the middle of the 20th century. Rather than causing the abandonment of fields, this problem has been mitigated by an upstream displacement of four irrigation canal intakes by between 70 and 310m (Hesse 2008).

**Environmental degradation**

The destruction of riverine forests makes irrigated valley floor areas susceptible to deflation and fluvial erosion, ultimately leading to the abandonment of river oases (Beresford-Jones 2004). While this model has been developed for the Samaca Basin in the lower Ica Valley, it is not clear whether it can also apply to the Palpa Valley, which differs from the Samaca Basin in being much larger and in being topographically protected from deflation.
AN ALTERNATIVE MODEL

Common to most previously proposed models is the contention that cultural decline is to a large extent attributed to changes in the physical environment. Therefore, the purpose of the present paper is to explore whether or not the inherent dynamics of cultural landscape evolution in the context of irrigation-based societies can explain the observed changes in the archaeological record. Field observations in the upper valleys of Rio Palpa and Rio Vizcas had documented the presence of abandoned agricultural terraces (fig. 2). Such abandoned terraces cover 7500 km² in Peru (Moseley 1999). Their final abandonment is likely attributable to the early colonial collapse of the indigenous population (Cook 1981). A first appraisal of high-resolution satellite images in Google Earth covering less than 10% of the combined catchment area of Rio Palpa and Rio Vizcas yielded approximately 2 km² of abandoned terraces. These occur at elevations between 1580 and 3570m and occupy both valley bottom and valley slope locations. The lower terraces can be related to (likely seasonal) tributaries draining catchment areas well above 2000m fed by seasonal rainfall. By diverting runoff from tributaries onto irrigated fields, the river discharge at downstream locations is diminished. While water infiltration from irrigated fields may recharge local aquifers and increase base flow, the additional evapotranspiration leads to an overall negative effect on river discharge.

Based on these observations, the following sequence is proposed for the Palpa Valley (fig. 3):
1. Irrigation agriculture begins at least 3500 years ago in the central part of the valley where a wide, gently sloping valley floor can be irrigated with low expenditure of labour (Hesse & Baade 2009).

2. During the Paracas and early Nasca periods of cultural development (Reindel et al. 2001; Silverman 2002), the irrigation system is extended first to the south-eastern and then to the north-western sides of the valley. In the early Nasca period, the irrigation system reaches the limits of the easily irrigated valley floor (Hesse & Baade 2009).

3. Reaching these limits marks a crucial point in cultural landscape evolution: Expansion of agricultural activities now necessitates the utilisation of progressively marginal up-valley areas. Irrigation of steep slopes requires the labour-intensive construction and maintenance of terraced fields and canals in difficult – and arguably less productive – terrain.

4. Diversion of river water onto up-valley terraced fields reduces downstream water availability in the Palpa Valley. A decline in down-valley water availability is thus not necessarily driven by climatic fluctuations. Low and intermediate flows – which are those that can be harnessed for irrigation – are most strongly affected. This is contemporaneous with cultural decline (Silverman 2002), increasing violence and declining population (Schreiber 1999) as well as an up-valley shift of settlement during the middle and late Nasca periods (Reindel et al. 2001).

In this model of human-environment interactions, the adaptation to the constraints of one limited resource (irrigable land) leads to a suboptimal exploitation of another limited resource (water), to an overall decline in agricultural productivity per unit of arable land and to increasing vulnerability.

Given the presently hypothetical character of this model, some words of caution are in order. Until now, the total extent of abandoned up-valley terraces is unknown. More importantly for the validity of the proposed model, there are presently no temporal constraints on the periods of construction and use of these terraces. Furthermore, a quantitative analysis of the potential impact of up-valley water diversion

Figure 3. Qualitative model for human-environment dynamics in the Palpa Valley catchment.
on down-valley water availability has to be performed. Such an analysis will have to take into account the strong interannual variability of river discharge.

**CONCLUSIONS**

The cultural changes in the archaeological record of river oases in coastal southern Peru cannot be confidently attributed to any one of the competing qualitative models for human-environment interactions. Most previously proposed models explicitly or implicitly assume a strong environmental impact which may underestimate the ability of societies to adapt to such changes. The qualitative model presented here is driven by human behaviour in the exploitation of and adaptation to limited – but not necessarily declining – resources. The limiting factor in this case is the spatially constrained nature of irrigable land. The inherent dynamics of cultural landscape evolution between down- and up-valley irrigation agriculture create a pattern in which resource use feeds back onto resource availability. The evolution of resource use can create a situation where the overall efficiency of resource use is reduced, thus leading to a decline in overall productivity. It can qualitatively explain the observed broad changes in the archaeological record of the area without invoking ‘natural disasters’ or climatic changes.

The proposed model is, however, not meant to replace the previously proposed models. Rather, it is intended as a contribution to the ongoing debate on potential causes for cultural change in pre-hispanic coastal Peru. Comparing environmentally and culturally based models will help to develop new research designs. It may also be of wider applicability in studies regarding the development of irrigation-based societies. It is emphasised that at present this model is a working hypothesis and that further research is necessary, in particular regarding the time of construction and use of up-valley terraces as well as regarding quantitative analysis of the potential impact of upstream water diversion on down-valley water availability.

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