Adaptation to variable environments, resilience to climate change: investigating Land, Water and Settlement in Indus northwest India

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Abstract

This paper explores the nature and dynamics of adaptation and resilience in the face of a diverse and varied environmental and ecological context using the case study of South Asia’s Indus Civilisation (c.3000-1300 B.C.). Most early complex societies developed in regions where the climatic parameters faced by ancient subsistence farmers were varied, but rain falls primarily in one season. In contrast, the Indus Civilisation developed in a specific environmental context that spanned a very distinct environmental threshold, where winter and summer rainfall systems overlap. There is now evidence to show that this region was directly subject to climate change during the period when the Indus Civilisation was at its height (c.2500-1900 BC). The Indus Civilisation therefore provides a unique opportunity to understand how an ancient society coped with diverse and varied ecologies, and change in the fundamental environmental parameters. This paper integrates research carried out as part of the Land, Water and Settlement Project in northwest India between 2007 and 2014. Although coming from only one of the regions occupied by Indus populations, these data necessitate the reconsideration of several prevailing views about the Indus Civilisation as a whole, and invigorate discussion about human-environment interactions and their relationship to processes of cultural transformation.
Adapting to variable environments, being resilient to changing climates

Given the considerable importance of climate, climate change and human/environment relationships in the present, it is perhaps no surprise that there is ongoing interest in the way that humans cause and/or respond to environmental and ecological change in the past (Diamond 2005; Staubwasser and Weiss 2006; Barnes et al. 2013). Unquestionably there is much to learn from the past about the success or failure of adaptations to particular environments and ecological niches, and the sustainability and resilience of responses to environmental pressures and climatic threats. Disentangling these dynamics is not, however, a straightforward process, and it is increasingly recognised that responses to environmental change are neither deterministic nor straightforward; particularly because environmental parameters, human behaviour and the interrelationship between these two elements are inherently complex (McAnany and Yoffee eds. 2009; N. Miller et al. eds. 2011). This line of thinking recognises that humans and the environment are neither independent nor simple variables, rather they are both complex and interlinked in what has been described as both panarchy and a social-ecological system (SES) that witnesses cycles of resilience and adaptive change (e.g. Gunderson and Hollig 2002; Berkes et al. 2003). Leslie and McCabe (2013:116) have noted that while the concepts of resilience and adaptive change have been explored conceptually, empirical analysis remains rare, at least partly because resilience is difficult to measure in the context of complex socio-ecological systems. Archaeologists can play a unique role here as they are able to empirically investigate the ‘before’, ‘during’ and ‘after’ of past instances of success or failure, thus furthering understanding

Although archaeologists recognise that human behaviour is nuanced and varied, much of the debate about the impact of climate change on ancient civilisations has tended to be simplistic, both in terms of empirical approach and conceptual grounding. Debate has been dominated by numerous attempts to correlate global-scale climate records and the timing of local-scale cultural transformations that are visible in the archaeological record (e.g. deMenocal 2001; Haug et al. 2003; Staubwasser et al. 2003; Staubwasser and Weiss 2006), despite recognition that there is rarely direct evidence to link the two data sets (e.g. Aimers and Hodell 2011). As a result, inferences tend to be speculative, and end up in ‘correlation equals causation’ circularity. Furthermore, despite attempts to the contrary, there remains a fundamental disconnect between scientific approaches to understand global climate and the dynamics of climate change on the one hand, and humanistic approaches to understand how human populations perceive climate and respond to climate change on the other (Barnes et al. 2013). Part of the problem is that archaeologists often uncritically look to distant climate data sets to interpret local cultural dynamics, while palaeo-climatologists tend to uncritically look for cultural correlates to the climatic events that they observe (Aimers and Hodell 2011).

Archaeologists are now increasingly interested in understanding the ways that humans respond to change and the degree to which their societies and choices are sustainable and facilitate resilience (e.g. McAnany and Yoffee eds. 2009; N. Miller et al. eds. 2011).
This does, however, present significant empirical challenges as there is growing consensus that in order to properly comprehend human adaptation, sustainability and resilience, it is essential to consider local climatic and environmental conditions (e.g. Madella and Fuller 2006; Aimers and Hodell 2011; Dixit et al. 2014). In fact, it is arguable that an understanding of the local context is essential for establishing whether past human societies were willing, able, or in fact required to respond to global-scale pressures and potential threats.

Focussing on the local context also allows for nuanced exploration of the relationships between adaptation and resilience. While resilience can be viewed in terms of response to distinct step changes in climatic systems, behaviour may already be adapted to ecological regimes that are intrinsically variable during single years and between years, which may make them predisposed to resilience. This fits neatly with what N. Miller (2011) has described as ‘predictable unpredictability’, where populations make use of subsistence and cultural strategies that are tailored to absorb and mitigate risk.

This paper will explore the nature and dynamics of adaptation and resilience in the face of a diverse and varied environmental and ecological context using the case study of South Asia’s Indus Civilisation (c.3000-1300 B.C.), and although it will consider the Indus region as a whole, it will focus primarily on the plains of northwest India. Most early complex societies developed in regions where the climatic parameters faced by ancient subsistence farmers were varied, but rain falls predominantly in one season. The Indus Civilisation stands apart from other early complex societies for a number of
reasons, but the significance and ramifications of the specific environmental context within which it evolved is not widely recognised outside of Indus research circles. Importantly, the geographical spread of the Indus Civilisation spanned a very distinct environmental threshold, where winter and summer rainfall systems overlap, and steep rainfall gradients are also evident. It therefore provides a unique opportunity to understand how an ancient society coped with both diverse and varied ecologies, and change in the fundamental and underlying environmental parameters.

The cultural and environmental context of the Indus Civilisation

The Indus Civilisation was one of the great early complex societies of the Old World, and during its urban phase (c.2600-1900 B.C.) it spanned large parts of modern Pakistan and India (Marshall 1931; Sankalia 1962; Fairservis 1967, 1971; Wheeler 1968; Lal 1997; Kenoyer 1998; Chakrabarti 1999; Possehl 2002; Agrawal 2007; Wright 2010). The Indus Civilisation has, however, been marginalised or excluded in much of the comparative literature on early complex societies, which is unfortunate, as it has much to contribute. For example, it has been argued that that the Indus Civilisation does not neatly conform to the prevailing models for early complex societies; for instance, the major Indus architectural structures that have been exposed do not match expectations of monumentality (e.g. Possehl 1998; although see Yoffee 2005:228-9). While there is a lack of consensus about Indus socio-political structure and organisation (e.g. Kenoyer 1994; Possehl 1998; Wright 2010), this actually serves to emphasise that interpretation of socio-
economic structures can be challenging in the absence of texts that can be readily translated (e.g. Parpola 1994).

It is clear that following a protracted period of village-based settlement, the urban phase of the Indus Civilisation developed on the plains of modern Pakistan and north-western India (Fig.1a) during the mid-third millennium B.C. (~4.6-4.5 ky B.P.). It has been claimed that during this phase, Indus settlements were distributed across an area of c.1 million km², concentrated around the river systems of northwest South Asia (Possehl 2003:1; Agrawal 2007:3). While this is an overestimation of the actual area occupied by Indus populations, our present understanding of settlement distribution suggests that the Indus Civilisation was likely the most geographically extensive of all the early Old World Civilisations (cf. Wheeler 1968:4; Possehl 2003; Agrawal 2007).

Present knowledge indicates that there was a constellation of four or five particularly large Indus settlements, which are usually described as cities (Mohenjo-Daro, Harappa, Rakhigarhi, Dholavira and possibly Ganweriwala; Kenoyer 2008:188; Petrie 2013:91). The inhabitants of these cities produced, used and traded distinctive types of material culture, including painted pottery and figurines that were presumably made locally, and jewellery, standardised weights, and stamp seals that were made from raw materials typically obtained from medium- and long-range sources (the abundance of relevant specialist reports are reviewed recently in Wright 2010:148-166,182-203; also Coningham and Young 2015:211-223). In a landscape dominated by rural settlements, Indus cities appear to have been the exception rather than the norm (Petrie 2013). The substantial
distances between the major centres (at least 280 km) have been used to suggest that they controlled vast hinterlands (e.g. Kenoyer 1997:54, 1998:50, Table 3.1). It is, however, also probable that large and medium sized settlements played an important and perhaps an independent rather than subordinate role in both interactive processes and socio-economic control structures (Petrie 2013:91, 94-5; Sinopoli 2015:322).

To some extent the pattern of material evidence seen at the city-sites has also been observed at large, medium, and also small settlements, and this has led to the suggestion that there was marked uniformity in some aspects of Indus material culture (e.g. seals, weights, script; Chakrabarti 1999:179ff.; Kenoyer 2008:207; Agrawal 2007:7; Wright 2010:23, 327, 334; H.M.-L. Miller 2013). While similarities between some cultural elements have been emphasised, variation in material and human behaviour has been recognised for some time, and is increasingly being acknowledged (e.g. Possehl 1982, 1992, 2002; Joshi 1984; Meadow and Kenoyer 1997:139; Weber et al. 2010a; Wright 2010:180ff; Ajithprasad 2011; Petrie 2013:91, 95). This variation is particularly evident in subsistence practices (e.g. Vishnu-Mittre and Savithri 1982:215; Weber 1999; Weber et al. 2010a, 2010b; Weber and Kashyap 2016), settlement systems (Petrie 2013), and the production and use of particular categories of material culture, most notably figurines and ceramic vessels (e.g. Akinori 2011; Petrie 2013; Parikh and Petrie forthcoming).

It has long been recognised that there is considerable variation in climate, hydrology, and ecology across the extensive area in which Indus settlements are found (e.g. Agrawal and Sood 1982; Possehl 1982, 1992; Joshi 1984; also Chakrabarti 1999:153-160;
Shinde et al. 2006; Wright 2010:166-170), but the specifics of this diversity and the degree to which it maps onto cultural variation has not been addressed in detail. Environmental factors undoubtedly placed specific constraints on cultural behaviour and the choices open to the inhabitants of the various Indus regions, and it is arguable that comprehending the ways in which humans interacted with diverse and potentially changing environments over time and across space is critical for understanding the rise, floruit, and decline of Indus urbanism (cf. Agrawal and Sood 1982; Petrie 2013).

The under-appreciation of the degree and implications of cultural and environmental variation across the Indus zone is particularly telling when it comes to explaining the decline and ultimate abandonment of the Indus urban centres. This process appears to have been accompanied by a reduction in settlement density in the western and central parts of the Indus zone and an increase in the numbers of village-sized settlements in its eastern reaches (i.e. Haryana/Punjab and Gujarat; Fig.1b). Indus urban decline has been referred to as a collapse or a transformation, and from the beginnings of research on the Indus Civilisation, both natural and human factors have been invoked as likely causes (e.g. Marshall 1931; Ramaswamy 1968; Allchin 1995; Possehl 1997a, 1997b; Wright 2010).

There is, however, no consensus as to which factors are the most significant, and there have been substantial gaps in the evidence that might enable us to assess the process as a whole. These gaps include a shortage of focused research on the socio-economy of the post-urban and subsequent periods, a lack of absolute dates, and little high-resolution climatic and environmental evidence directly from the region.
Given these limitations in the evidence, it is perhaps unsurprising that there has been no agreement about the significance of climate and climate change on the Indus Civilisation. Some have argued that there is no conclusive evidence to show that there is any difference in annual rainfall patterns between 6000 B.P. and the present (e.g. Possehl 1997a; Kenoyer 1997, 2008:186), while others have posited climate change as the primary cause for the collapse and/or transformation of the Indus Civilisation (e.g. Shinde et al. 2006; Staubwasser and Weiss 2006; Clift and Plumb 2008:205-210; Giosan et al. 2012). Within the diverse zone occupied by Indus populations, environmental factors related to hydrology were certainly important, and shifting/drying rivers and floods have long been proposed as major culprits. There have, for example, been extensive arguments made for and against the impact of flooding at Mohenjo Daro (e.g. for: Raikes 1965, 1968; Raikes and Dales 1977; against: Lambrick 1964, 1967). We also now have detailed reconstructions of river shifts in Sind, which demonstrate the movement of the main Indus channel between 4000 and 2000 BC (e.g. Flam 1981, 1993, 1999, 2013; Jorgensen et al. 1993). Furthermore, remote sensing has suggested that settlement patterns in southern Punjab may have responded to the dynamics of the Beas River system (Wright and Hritz 2013). These reconstructions and other geomorphological investigations also provide insight into the other major topic of hydrological discussion, the impact of the drying of the Ghaggar/Hakra River, which is often equated with the ‘lost’ Saraswati River (e.g. C.F. Oldham 1874, 1893; R.D. Oldham 1886; Stein 1940; Wilhelmy 1969; Ghose et al. 1979; Yashpal et al. 1980; Mughal 1997; Lal 2002; Valdiya 2002; Shinde et al. 2006; Danino 2010; Clift et al. 2012; Giosan et al. 2012; also Flam 1999, 2013). In northwest
India, connections between climate change and river shift have been mooted (e.g. Giosan et al. 2012), and it has also been posited that neo-tectonic processes have been a factor in reshaping hydrology (e.g. Puri and Verma 1998).

A number of separate archaeological projects have incorporated multi-disciplinary analysis of environmental parameters impacting Indus populations, incorporating geology, geomorphology and bio-archaeology (e.g. Sindh Archaeological Project: Flam 1981, 1993, 1999, 2013; Jorgensen et al. 1993; Mission Archéologique Française en Inde: Francfort ed. 1985; Courty 1985, 1995; Gentelle 1985; Courty et al. 1989; Harappa Archaeological Research Project: Amundson and Pendall 1991; Meadow 1991; Belcher and Belcher 2000; Weber 2003; Beas Landscape and Settlement Survey; Wright et al. 2002, 2005a, 2005b, 2008; Schuldenrein et al. 2007; Wright 2010; Wright and Hritz 2013; Indus Project of RIHN: Shinde et al. 2008; Rajaguru and Deo 2008; Weber et al. 2011). However, thus far there have only been limited attempts to correlate and integrate the findings of these projects (e.g. Schuldenrein et al. 2007; Wright 2010: 25-44). There has also only been limited attention to proxy evidence for ancient climate that is proximate to the Indus zone and/or can be connected directly to the archaeological record.

Climate has long been considered an important parameter for understanding the Indus Civilisation, starting from Marshall’s (1930:2; after Stein 1931) suggestion that there has been a significant decrease in rainfall since the Indus period. In querying this interpretation, Raikes and Dales (1961:279) highlighted the “importance of integrating all types of evidence and checking on the inferences drawn from them”. However,
traditionally there has been an under appreciation of the relationships between the environmental and cultural dynamics that were in action. As elsewhere, archaeologists considering the Indus case have tended to either under- or overemphasise the possible role of climate (e.g. Possehl 1997a; Kenoyer 1997, 2008:186; Shinde et al. 2006; Staubwasser and Weiss 2006; Clift and Plumb 2008:205-210; Giosan et al. 2012). Furthermore, when climate has been invoked as a critical driver of social change, there has been a reliance on distant climate proxy data sets for support (e.g. Staubwasser and Weiss 2006; Giosan et al. 2012), which is at least partly because of the lack of proximate proxy data that might inform us about it impact on the diverse local context. A range of climate proxy data is certainly available from various locations in the subcontinent, particularly from dry lakes in Rajasthan (e.g. Enzel et al. 1999; Prasad and Enzel 2006), and new proxy data sets continue to become available (e.g. Liepe et al. 2014; S. Prasad et al. 2014; Sarkar et al. 2015), but they are typically not proximate to the Indus zone. Unfortunately the highest resolution proxy data currently available comes from regions far outside the Indus zone that are characterised by different weather systems (e.g. Oman: Fleitman et al. 2003; northeast India: Berkelhammer et al. 2011), while the more proximate data sets are either lacking in chronological precision or don’t actually cover the critical period of the late third and early second millennium BC (see Possehl 1999:259-263,Fig. 3.112; Madella and Fuller 2006:1287ff.,Figs 2,9). Until recently, the most direct insights from within the Indus zone have come from modelling of the Intertropical Convergence in central Punjab (Wright et al. 2008:42-3; see below).
While ‘top-down’ approaches that rely on distant proxy data provide broad-scale context, they do not provide the level of ‘bottom-up’ local-scale detail necessary to evaluate the nature of regional dynamics across a large and ecologically varied expanse. Arguably, such resolution is essential for establishing the nuances of local climatic and environmental conditions and whether human societies of the past were willing, able, or even required to respond to pressures and threats.

Given that the Indus Civilisation spanned a large and environmentally diverse area, it is unlikely that climate change would have had identical or even comparable effects in all regions. Similarly, hydrological shifts that may have been devastating in one area might have had no direct impact in others, or may even have been beneficial. Furthermore, human behaviour was likely already adapted to ecological regimes that are intrinsically variable between seasons and between years (see Wright 2010: 25-44, 312-3, 315-19).

Comprehension of the interrelationships between past climate and environment, and human actions and reactions can only result from integrated approaches and collaborative research projects that seek to identify the interconnections between the archaeological evidence and the evidence for climatology, hydrology, sedimentology and even ethnography, which are fundamentally interrelated, but are too often treated as independent data sets.

This paper integrates research carried out as part of the Land, Water and Settlement Project, which conducted collaborative work in northwest India between 2007 and 2014 (http://www.arch.cam.ac.uk/rivers/). It reviews the evidence for environmental diversity
in northwest South Asia, assesses the ramifications of recently obtained data on the ancient hydrology and climate of north-western India, and presents new archaeological evidence relating to geomorphology, settlement dynamics, the use of material culture, and subsistence practices in this region. Although coming from one of several regions occupied by Indus populations, these data necessitate the reconsideration of many prevailing views about the Indus Civilisation as a whole, and this paper aims to further invigorate discussion about human-environment interactions and their relationship to processes of cultural transformation.

**Factors influencing environmental diversity in northwest South Asia**

As noted above, the area across which Indus Civilisation populations lived spans an environmental threshold characterised by a zone of overlap between winter and summer rainfall systems and steep rainfall gradients for both systems. This particular location spans a range of distinct ecological zones, with modern Köppen-Geiger Climate Classifications (Kottek *et al.* 2006) ranging from areas of arid hot desert (*BWh*), to areas of arid hot steppe (*BSh*), and areas that are warm and temperate with dry winters and hot summers (*Cwa*) (Fig.2a-2b). An important consequence of this environmental context is that even without human interference, water is available from different sources at different times of the year, including winter rain (December-February), rain from the Indian summer monsoon (June-September), snow melt from the Himalayas, and the surface and river run-off that results from all of the above.
The lack of systematic and localised palaeo-climatic data means that it is not yet possible to fully reconstruct the distribution of rainfall at the time of the Indus Civilisation (see below). To frame our understanding, however, it is instructive to look at modern rainfall patterns to gain some insight into the nature of rainfall variability across the same geographic region. Plotting annual rainfall averages calculated using global rainfall data for the period between 1900 and 2008 illustrates that over the last century, different areas in northwest South Asia received different amounts of rainfall during an average year, ranging from 0-1000 mm (Fig.1a-1b). In addition, there is also variation in the seasonal distribution of modern rainfall (Fig.3a-3b,4a-4b). The summer monsoon makes the dominant contribution to the average annual rainfall in many areas of the Indus zone, particularly those to the east, although a significant proportion of summer rain is lost through evapotranspiration. In contrast, the extensive areas of Punjab and Sindh that lie along the Indus and the rivers of Punjab receive rainfall in different intensities and at different times during the year. To further complicate matters, the historical record shows dramatic inter-annual fluctuations in the intensity of monsoon rainfall, with years of particularly heavy rainfall resulting in flooding and waterlogging interspersed with years of monsoon failure (Sarma 1976; Possehl 1999:286-7; Adamson and Nash 2013).

While this assessment of modern rainfall patterning is informative, it cannot be assumed that the seasonal rainfall fell in similar patterns in the past. On the basis of analysis of sediments at the mouth of the Indus River, Staubwasser and Weiss (2006) suggested that the mid-Holocene was characterised by high intra-annual rainfall variability in an
increasingly arid climate, but we have little comprehension of the nature of this variability on the ground. Wright et al. (2008) have used macro-physical climate modelling to make predictions about the intensity of summer and winter rainfall at Harappa between 14,000 B.C. and A.D. 2000. They modelled a protracted period of reduced rainfall between c.2100-1600 B.C., which corresponds to the period of Indus urban deterioration and was attributed to a reduction in both winter and summer rain. Wright et al. (2008) make it clear, however, that it is not feasible to extrapolate this record to other regions within the Indus zone (see also Balbo et al. 2014).

It is important to remember that beyond rainfall itself, an abundance of perennial and ephemeral rivers and streams redistribute water coming from the winter rains, snowmelt and summer monsoon, and these all influence the hydrological systems of the Indus zone (Flam 1993, 1999, 2013; Jorgensen et al. 1993; Wright et al. 2008). Furthermore, in addition to rainfall and hydrology, there is variation in the underlying geology, soils and geomorphology, and similar degrees of variation invariably existed in these elements in the past (e.g. Belcher and Belcher 2000; Schuldenrein et al. 2007).

The available data thus indicate that the region inhabited by Indus populations was marked by considerable diversity in the distribution of winter and summer rainfall, and variation in the quantity and intensity of rainfall in any one season in any one year. The Indus zone is thus ‘predictably unpredictable’ in multiple ways. The variation in water supply combines with significant variation in hydrology and soils to create a broad zone comprising numerous ecological niches. All of these parameters enabled and/or
constrained the types and range of subsistence practices that were possible, and thus frame our understanding of Indus adaptation and resilience to climate change, and the relationship of these factors to Indus urban decline.

**Coping with environmental diversity**

Within the broader context of overlying environmental variability driven by climatic gradients, it is clear that Indus populations also occupied a diverse range of ecological niches or habitat zones. The Indus Civilisation has long been regarded as riverine (e.g. Marshall 1931), and while many major Indus settlements were located close to rivers (e.g. Harappa, Mohenjo-Daro, Lothal), others were located in intermontane valleys (e.g. Dabar Kot, Periano Ghundai), or on alluvial fans (e.g. Nausharo and Ghandi Umar Khan), at the margins or inside of what are today arid zones (sites in Sindh, Cholistan and Gujarat), in areas that lack perennial rivers but are watered by monsoon rainfall (sites in Haryana and east Punjab), and even on islands (e.g. Dholavira) (Wright 2010:33-38; Petrie and Thomas 2012; Petrie 2013).

It is notable that each of the Indus cities was supported by a different hydrological regime. Harappa, Ganweriwala, and Mohenjo-daro are in areas on the alluvial Indus plain that differ from each other in amounts of rainfall and proximity to major water courses that provide water from both non-local rainfall and snow-melt in the Himalayas. Mohenjo-Daro also has evidence for the extensive use of wells (Jansen 1993, 1994:270), and examples are also known from elsewhere, including Harappa (Kenoyer 2008), and Dholavira (Bisht 2005; n.d.:138-145). It is presumed that in each of these instances the
inhabitants exploited both river and groundwater. In contrast, Rakhigarhi lies at some distance from known watercourses, but is in the zone where both summer-monsoonal and to a lesser extent winter rainfall systems operate today. It has been proposed that Rakhigarhi lay on the course of a now extinct watercourse, which is often referred to as the Drishadvati (Suraj Bhan 1975:95-101; Nath 1998; Valdiya 2002). However, no evidence for this watercourse is visible today on the surface (Singh et al. 2010), and analysis of the satellite imagery suggests that only small-scale watercourses are preserved in the sub-surface (Mehdi et al. in press,Figs 2,10). It is not yet clear where the water used by the inhabitants of Rakhigarhi originated, though a combination of wells and ponds that collect monsoon run-off is a viable option (Petrie 2013). Dholavira is located in an area that today receives relatively limited rainfall, but is close to two seasonal streams or runnels and has a system of dams that help channel water into a series large stone-lined reservoirs and tanks, all of which presumably helped compensate for the unpredictable water supply (Bisht 2005, n.d.:138-169). Recognition of this diversity in settlement location and availability of water is essential for understanding both adaptations to different environments and responses to environmental challenges in the Indus context.

It has long been hypothesised that there was variation in the subsistence practices used by Indus populations (e.g. Vishnu-Mittre and Savithri 1982; Chakrabarti 1988), and this fits with the theme of coping with diverse environments. Although primarily speaking about Sindh and Baluchistan, Fairservis (1967:10,42, 1971:169-172,228-232) argued that Indus farmers were adapted to the diverse environments that they inhabited,
particularly in terms of the **adaptating** practices to the available water resources. Speaking more broadly, Possehl (1982, 1992) and Joshi (1984) have both posited the existence of eco-cultural ‘domains’, and more recently models have been proposed for helping to identify ‘Harappan Agro-ecological zones’ and several distinct eco-zones have been identified (Weber et al. 2010a). However, robust evidence to support these suggestions is not widely available. For instance, Wright (2010:170) has pointed out that the archaeobotanical evidence that informs us about Indus populations is “uneven and dependent upon limited excavation”.

Indus agriculture is typically characterised as being dominated by the exploitation of a particular set of animals (primarily zebu, goat, sheep, water buffalo), and a range of winter and summer crops (Meadow 1996; Weber 1999; Wright 2010:168-170). The exploitation of particular crops appears to have been variable and it has typically been argued that two broad zones can be differentiated - with the predominant use of winter crops (rabi – wheat, barley, pea, lentil, chick-pea) in some areas, and the predominant use of summer crops (kharif – millet, rice, tropical pulses) being evident in others (Kajale 1991:173; Meadow 1996:398-400; Weber 1999:818-822, 2003:180-185; Fuller and Madella 2001; Fuller 2006, 2011; Madella and Fuller 2006; Weber et al. 2010b:36-7,Fig. 1; Weber and Kashyap 2016:9,11,Fig.1; Wright 2010:169-170; Pokharia et al. 2014). It is also asserted that there was an increased use of summer crops from the beginning of the second millennium B.C. onwards, and Wright (2010: 43) has suggested that this agricultural diversification may have been a response to ecological challenges.
Variation in practices is typically presented through comparison of Harappa in Punjab, which shows the predominant use of the winter cereals barley and wheat and the limited use of summer crops like millets (*Panicum*) in what has been described as a complex multi-cropping system (Weber 2003:181), and Rojdi and Babar Kot in Gujarat, which show an almost complete focus on summer crops (e.g. Weber 1991, 1999:816-8; Reddy 1994, 2003; Weber *et al.* 2010b; Wright 2010:169-170; Weber and Kashyap, 2016; see also García-Granero *et al.* 2016). Winter and summer crops have been reported from several sites in northwest India, including rice and millet from pre-urban/Early Harappan period contexts at Banawali, Balu and Kunal (e.g. Saraswat *et al.* 2000; Saraswat 2002; Saraswat and Pokharia 2002, 2003). It has, however, been argued that these attestations should be discounted because of a lack of quantification in the final publications, and a lack of direct absolute dates (e.g. Fuller 2006:13,16, 2011; see Petrie *et al.* forthcoming). Furthermore, winter and summer crops are also seen at Farmana in northwest India, though rice is not present in the stratified contexts, but the significance of this is difficult to interpret as only presence and absence information for macro- and micro-botanical remains are provided, alongside summative figures for seed density and ubiquity (Weber *et al.* 2011:Tables 11.1-11.2; Kashyap and Weber 2013; Weber and Kashyap 2016).

Given that we lack published quantified assemblages from most Indus sites where archaeobotanical analysis has been carried out, it is likely, however, that interpretations based on contrasting Harappa and sites in Gujarat is too simplistic. The problems are partly related to coverage, but also interpretation. For instance, as noted above, it has
been argued that the cropping system at Harappa was a complex multi-cropping strategy (Weber 2003), which may have been a response to ecological challenges (Wright 2010: 43). The published evidence that includes quantification (e.g. Weber 2003), however, suggests relatively restricted use of crops grown in the non-dominant season. It could thus be argued that such low proportions of summer crops do not actually indicate extensive multi-cropping (Petrie and Bates forthcoming; Petrie et al. forthcoming). Petrie and Bates (forthcoming) and Petrie et al. (forthcoming) have therefore argued that while the archaeobotanical assemblages thus far published do demonstrate regional variation in subsistence practices (e.g. Weber 1999, 2003; Weber et al. 2010a; García-Granero et al. 2015; Weber and Kashyap 2016), they have not (yet) provided convincing evidence from any single location for cropping in two seasons in anything approaching equivalent proportions (see below). They thus advocate the use of more precise terminology to characterise the variation that is observed (Petrie and Bates forthcoming).

Although Indus populations may well have selected specific plant crops, the degree of variation in local environmental conditions, vegetation, rainfall, and water supply would invariably have necessitated specific adaptations to farming practices for successful farming in different regions. These adaptations would likely have included a range of approaches to water supply (cf. H.M-L. Miller 2006, 2015; Petrie and Thomas 2012), and a spectrum of cropping strategies ranging between a heavy focus on winter or a heavy focus on summer crops; with the middle ground being made up of a nuanced array of strategies where different combinations of winter and summer crops were
utilised according to local conditions and choices (Petrie and Bates forthcoming; also Petrie 2013; see below).

It is clear that the degree of ecological diversity encompassed by the Indus Civilisation and the variability of adaptation and response across that area is critical for understanding the developments of the Indus period. However, this diversity in socio-ecological systems can only be characterised adequately by detailed research in each of the relevant zones. This research has only recently begun to be carried out at a suitable resolution. In Pakistan, the most important contributions have come from the Sindh Archaeological Project (Flam 1993, 1999, 2013; Jorgensen et al. 1993) and the Beas Landscape and Settlement Survey (Wright et al. 2002, 2005a, 2005b, 2008; Schuldenrein et al. 2007; Wright 2010; Wright and Hritz 2013), whilst in India knowledge is advancing most overtly in Gujarat through the North Gujarat Archaeological Project (Madella et al. 2010; Balbo et al. 2014; Garcia-Granero et al. forthcoming) and in Haryana/Punjab/north Rajasthan through the Land, Water and Settlement Project, and the earlier Mission Archéologique Française en Inde (Francfort ed. 1985; Courty 1985, 1995; Gentelle 1985; Courty et al. 1989). The evidence gathered by the Land, Water and Settlement project will be explored further below, covering five key areas: monsoon dynamics, the palaeo-Ghaggar/Hakra, monsoon flooding, settlement dynamics, and variation in material culture and subsistence.
Changes in intensity of the Indian Summer Monsoon during the Holocene

The significant environmental variability of the Indus region and the apparent flexibility of Indus populations in coping with this range of environments both form a critical backdrop to debates about the impacts of climate change. As noted above, until recently, however, debates about the impacts of climate change on Indus populations have been hampered by a lack of direct and proximate climate data. Proximate data is essential for establishing whether there was any local impact of globally detectable climate change on the plains of northwest South Asia during the Holocene.

New proxy records have been collected from within the Indus zone as part of the Land, Water and Settlement project, and these inform understanding of variation in the climate affecting Indus populations. The most relevant is the climate proxy record from Lake Kotla Dahar in southern Haryana (Figs.1a-1b), which indicates that there were two distinct shifts in rainfall distribution and intensity during the mid-late Holocene that affected northwest India (Dixit et al. 2014). In the early Holocene, Kotla Dahar was a deep lake, implying regular and consistent rainfall input to offset evaporation, which given its location, would have been primarily monsoonal (Dixit et al. 2014). The first shift occurred at some point between c.4400 and 3760 B.C. (c.6400-5760 B.P.), when there was a decrease in monsoon rainfall and a progressive lowering of the lake level. This initial shift is roughly coincident with the evidence for change from Didwana (Zone D5) and Lunkaransar lakes (Zone 3) in Rajasthan, though there are no reliable dates for the transitions at either (Enzel et al. 1999; Prasad and Enzel 2006; Madella and Fuller 2006).
The second of these changes is more directly relevant, as it shows Kotla Dahar becoming completely ephemeral c.2200-2000 B.C. (c.4100±100 B.P.) as a result of an abrupt weakening of the monsoon (Dixit et al. 2014). This shift in the monsoon is visible as a 300±100 year ‘event’ in speleothem records in Oman (Fleitman et al. 2003) and northeast India (Berkelhammer et al. 2012), and appears to match a change in levels of discharge from the Indus between c.4200 and 3600 B.P. (Staubwasser et al. 2003). The Kotla Dahar evidence indicates that the shift in the intensity and extent of monsoon rainfall specifically in northwest India was both dramatic and protracted, resulting in an ephemeral lake that continues to the present (Dixit et al. 2014).

The degree to which the data from Kotla Dahar might be extrapolated to other parts of the Indus zone is debatable, and the relationship between climate and culture change remains ambiguous. It is nonetheless tempting to highlight correlations. The weakening in monsoon strength c.2200-1900 B.C. appears to correlate broadly with both the maximum extent of occupation at Mohenjo-Daro and Harappa, and the onset of Indus urban decline, though this was not a uniform process (e.g. Wright 2010: 43). The chronological correlation between the data sets is, however, imprecise due to the limitations of radiocarbon dating techniques in terms of precision (Staubwasser and Weiss 2006; Dixit et al. 2014).

The Kotla Dahar proxy record suggests that climate must be formally considered as a contributing parameter in the process of Indus de-urbanisation, at least in the context of the plains of northwest India. This is, however, inevitably only part of the story, and it is
the human response to this change in climate that is the critical element. For example, it has been suggested that decline in monsoon strength led to the diversification of the Indus crop assemblage through the adoption or intensified use of more summer crops such as millet and rice (Madella and Fuller 2006; Wright 2010:321ff.; Giosan et al. 2012). This reconstruction is perhaps overly simplistic, as it advocates the greater exploitation of summer crops at a time when the summer rainfall weakened, and it does not consider the different lengths of growing seasons required for millet and rice, or the fact that each of these crops is suited to somewhat different ecological conditions. It has also been at least partly superseded by new evidence that gives fresh insight into the nature of environmental adaptation that Indus populations engaged in even before the development of urban centres (see below).

The role of the palaeo-Ghaggar/Hakra River in northwest India

Alongside the considerations of climate and climate change, there has been considerable discussion of the role of the palaeo-Ghaggar/Hakra River in the origin, floruit and transformation of the Indus Civilisation. It is often suggested that this palaeo-channel provided an important source of water for Indus populations living in various areas (e.g. Yashpal et al. 1980; Kenoyer 1997; Mughal 1997; Lal 2002; Valdiya 2002; Tripathi et al. 2004; Danino 2010). However, the lack of dates for the perennial flow of water in this palaeo-channel and the lack of clarity about the source of that water means that this claim is largely speculation.
Although traces of a palaeo-channel were observed on the ground in Rajasthan and Punjab in the 19th century, today it is primarily known thanks to a large linear feature visible on satellite imagery (Yashpal et al. 1980; Bhadra et al. 2009). Analysis of sections exposed in wells and electrical resistivity surveys in various locations along the palaeo-Ghaggar/Hakra in northwest India have suggested that this feature was one or more large relict river channels (Saini et al. 2009; Sinha et al. 2013; Mehdi et al. in press).

There have now been several attempts to date the flow of perennial water through these palaeo-channels, in both Pakistan and India. There is growing consensus that the major palaeo-channel ceased to be a perennial watercourse before the Holocene (Saini et al. 2009; Lawler 2011:23; Clift et al. 2012; Giosan et al. 2012). However, there is some evidence of water flowing through various channels during the mid-Holocene (Saini et al. 2009; Clift et al. 2012; Giosan et al. 2012), and ongoing debate about whether the palaeo-Ghaggar/Hakra was an earlier course of the modern Sutlej (Lawler 2011:23), or an earlier course of another river, perhaps the Yamuna (Clift et al. 2012).

Despite being visible on satellite imagery, the fact that a large river channel is not visible on the ground in many areas demonstrates that there has been a considerable alluviation in the channel since perennial flow ceased. The precise sub-surface architecture of the palaeo-Ghaggar/Hakra and Punjab hydrological systems, the date at which particular channels carried perennial water, and the source of that water, continue to be debated, but there is a real possibility that the palaeo-Ghaggar/Hakra did not carry perennial water during the Indus period. If this is true, it has profound implications for
interpretations of the importance of this hydrological system for Indus populations, not least because it means that while water continued to flow through the palaeo-Ghaggar/Hakra seasonally, it was not a perennial river in the centuries before, during or after the Indus Civilisation.

Taken together, the new data stand in contrast to a range of historical attestations to the existence of a mighty perennial river along this course in northwest India (e.g. Chakrabarti and Saini 2009; Danino 2010). It is, however, important to point out that the extant documentary records are unlikely to conform neatly to modern distinctions between ephemeral and perennial water flow. What might have appeared as a mighty river in times of monsoon-induced spate may have been dry at other times of the year. If the water flow in the modern Ghaggar is any indication, rivers in this environment can be virtually empty for much of the year, and full to overflowing during the monsoon.

Perhaps more importantly, the watercourse need not have been perennial to have been important for the ancient inhabitants. The new data suggest that the settlements along the course of the palaeo-Ghaggar/Hakra such as Kalibangan, Banawali, and Bhirrana were not sited to exploit a perennial river, but to gain access to water via reliable annual monsoon run-off and overbank flooding. Water was undoubtedly exploited for different purposes when it was available, and captured and stored for use at other times, and it is likely that the palaeo-Ghaggar-Hakra was important during the Indus period for reasons that are quite different to those usually claimed. Overall, the likelihood that the palaeo-Ghaggar/Hakra was not a perennial river has important implications for the way
in which Indus populations were adapted to a diverse and variable environment, and the type of responses that were needed when that environment changed dramatically.

In addition to its implications for understanding Indus settlement systems in northwest India, the possibility that the palaeo-Ghaggar/Hakra did not carry perennial water is particularly significant for understanding the evidence for extensive Indus settlement in Pakistani Cholistan. Giosan et al. (2012:3) have suggested that “reliable monsoon rains were able to sustain perennial rivers earlier during the Holocene”, which “explains why Harappan settlements flourished along the entire Ghaggar-Hakra system without access to a glacier-fed river”. However, the monsoon is unlikely to have provided a sustained source of water throughout the year; instead it produces a ‘charge’ between June and September to the hydrological system that may have otherwise been dormant. Rather than seeking to explain the Cholistan settlement concentration by proposing that summer monsoon rainfall is capable of supporting perennial river-flow, an alternative possibility is presented by a critical re-examination of the dynamics of the Cholistan settlement system.

As published, the Cholistan survey data show that there were considerable numbers of sites occupied in the pre-urban, urban and post-urban Indus periods, each of which were up to five centuries in duration (Mughal 1997). As is true for many regions of the world, it is assumed that settlements were occupied for the entirety of each period. Unfortunately we know very little about the life-ways of the people living in these settlements as no excavations have been published, and we have no robust data on local
subsistence practices, geomorphology or hydrology. We do know, however, that very small numbers of the Indus settlements were occupied in consecutive periods, and that in each period settlements were concentrated in different parts of the survey area. Use of the Dewar algorithm (1991) to assess settlement contemporaneity in the Cholistan data has suggested there is a reasonable statistical likelihood that as few as 5-10% of settlements may have been occupied contemporaneously during the pre-urban, urban and post-urban periods (Petrie and Lynam forthcoming).¹ In contrast, using the same algorithm to analyse the data from the Rakhigarhi Hinterland Survey from northwest India reveals a significantly high degree of contemporaneity of occupation at settlements during the pre-urban, urban and post-urban periods in that region (75%; Petrie and Lynam forthcoming). These data suggest that it may be a mistake to assume that the large numbers of settlements recorded for each phase in Cholistan represent concentrated and dense settlement. Rather, Cholistan may have been characterised by an unstable settlement system with little continuity of occupation between periods at individual settlements, and only a sub-set of settlements may have been occupied at any one time.

While this suggestion is provocative, we currently lack the data to determine whether it is sound, and the river systems of Cholistan undoubtedly require further detailed investigation. Instability in the Cholistan settlement system may have been a product of the operation of a braided river system, which would have been susceptible to the

¹ Visit http://www.arcrange.com/webservices/aisettstats/
frequent small-scale avulsions during the periods of flooding that occur during monsoon rains. Such an environment may have required settled populations to be relatively ‘mobile’ in order to survive a constantly shifting hydrology, and there may have been high population mobility between settlement locales. Individual families or kin groups potentially spread their members between multiple settlements, and individuals or groups might have moved between settlements to access available water in times of shortage or stress. Such practices clearly have implications for our understanding of the degree to which Indus populations were adapted to a diverse environment, and the sustainability and resilience of those adaptations.

**Geomorphological evidence for monsoon-induced annual flooding**

The recent data from Kotla Dahar and the palaeo-Ghaggar/Hakra are congruent with the results of systematic geomorphological analysis of the context of Indus settlements on the plains of northwest India by the *Land, Water and Settlement* project. Analysis of soil and sediment samples taken adjacent to settlements lying in two areas along the palaeo-Ghaggar/Hakra in central Harayana (Burj, Bhirrana and Banawali) and northern Rajasthan (Dabli-vas Chugta and Kalibangan) has shown that during the Holocene the lower-lying areas in the landscape were probably more or less continually subjected to the slow, low-energy seasonal deposition of overbank flood deposits composed of fine sand and silt (Figs.5a-5b; Singh et al. 2010, 2012; French et al. 2014). These sediments are composed of very fine micaceous sands and silts, suggesting low energy water transport, and were presumably deposited by run-off associated with monsoonal rains.
and riverine overbank flooding, which lead to the seasonal aggradation of alluvium (Singh et al. 2010, 2012; Giosan et al. 2012). This reconstruction appears to correlate with Clift et al.’s (2012) reconstruction of the mid-late Holocene Sutlej and Yamuna River drainage, and Flam’s (1993, 1999, 2013) analysis of sedimentation in Sindh.

Today areas along and adjacent to the palaeo-Ghaggar are subject to flooding and associated sedimentation during the monsoon. The new geomorphological evidence from the Land, Water and Settlement project suggests that this process has been active for some time and was undoubtedly important for Indus farmers in this region (Singh et al. 2010, 2012; Neogi 2013; French et al. 2014). In turn, this has important implications for considerations of the impacts of climate change. The weakened summer monsoon in northwest India after c.2200 B.C. attested at Kotla Dahar would have resulted in at minimum a reduction in the intensity of that rainfall, which in turn will have decreased the amounts of annual overbank flood-induced sedimentation and erosion. Monsoon weakening will thus inevitably have had consequences for farmers relying on overbank flooding to water summer crops, and the concomitant stored soil moisture essential for the establishment of winter wheat and barley.

Settlement distribution data

To contextualise the new understanding of rainfall distribution, climate change, hydrology and geomorphology in northwest India, the Land, Water and Settlement project has also carried out extensive investigation of the settled landscape of this region. There is a sizable body of evidence for the distribution of pre-urban, urban and post-urban
Indus settlements throughout Pakistan and northwest India (e.g. Joshi et al. 1984; Possehl 1999; Kumar 2009). These data have been used to build models of long-term socio-cultural change, and highlight a potential shift of settlement towards the Ganges plains in the wake of the decline of the Indus urban centres (Joshi et al. 1984; Madella and Fuller 2006; Giosan et al. 2012).

The limitations of the core data set have, however, typically been overlooked. Detailed surveys in northwest India by the Land, Water and Settlement project have demonstrated that a significant proportion of these data are fundamentally unreliable. Reconnaissance and detailed surveys have both shown that there are significant errors in the published locations of many sites, highlighted that the knowledge of site distribution and density is dictated by the intensity and extent of previous surveys, and established that large numbers of sites of all periods have not been recorded (Singh et al. 2008, 2010b, 2011; Pawar 2012). These realisations have several important implications; for instance, it has frequently been stated that there is a close spatial correlation between the palaeo-Ghaggar/Hakra and the distribution of Indus settlements, and also that there is a profusion of Indus sites along this channel in the area to the east of Kalibangan (e.g. Lal 2002; Valdiya 2002; Danino 2010). The Rakhigarhi Hinterland Survey (Singh et al. 2010b) and Ghaggar Hinterland Survey (Singh et al. 2011) and compilations of other extant survey data (Kumar 2009) have revealed, however, that there are actually relatively few sites that lie directly along the course of the palaeo-Ghaggar/Hakra for much of its course across northwest India (Fig.6a-6b).
Despite its limitations, the extant survey data can be combined with the *Land, Water and Settlement* project results to show that urban and post-urban Indus settlements were not specifically concentrated along any river channel, but were in fact distributed across various parts of the plain. This distribution includes areas close to the palaeo-Ghaggar/Hakra, areas adjacent to ephemeral water courses, and areas that have no relationship to any visible water sources, including the desert margin in northwest India (Fig.6a-6b) (Singh *et al.* 2008, 2010b, 2011; Petrie 2013). Although there is no clear evidence for a large palaeo-channel in the vicinity of Rakhigarhi, the possibility that there is a sub-surface channel in this area cannot be discounted, though its age and precise course, and hence its relationship to the ancient settlements, will only be reconstructed through a targeted study to this end.

While there is general consensus that there was an increase in settlement in northwest India in the post-urban Late Harappan period, this conclusion is almost entirely based on inferences arising from the aforementioned unreliable survey data. Importantly, the *Land, Water and Settlement* project surveys have shown that there was no increase in the number of village-sized settlements in the central part of the plains during the post-urban phase, which implies that there was no substantial increase in the local population in these areas (Singh *et al.* 2010b, 2011). This observation suggests that if the perceived intensification of village settlement in northwest India during the post-urban/Late Harappan period is real, then it was concentrated elsewhere, most probably in the areas that are warm and temperate with dry winters and hot summers (*Cwa*), which lie along the Himalayan front and at the eastern edge of the plains (Figs.2b,3b,4b).
Today these areas receive more than 300 mm of direct monsoon rain per annum (Fig.4b), which suggests that they are likely to have received some rainfall even during periods of weaker monsoon, though this remains to be demonstrated. The cultural processes that led to this pattern of settlement have still not been examined systematically and additional areas in Haryana and the broad region along the Himalayan front in both Pakistani and Indian Punjab need to be surveyed if the nature of settlement distribution is to be properly understood. In particular it needs to be determined if and when specific habitats and environmental contexts were being selected preferentially.

This reassessment of the evidence for the distribution of settlements in northwest India suggests that the local Indus populations probably employed a range of approaches to land-use, even before cities developed. Perhaps the key element is that for populations to have lived in such environmentally diverse areas, their agricultural systems must have been far more flexible and adaptive to local conditions than is usually acknowledged. In some areas of northwest India, rainfall may have been sufficient to grow crops without irrigation while in others various methods of low-cost irrigation or active water management (bunds, canals etc.) may have been essential. It is thus likely that the ancient populations, in this area at least, made use of whatever water was available, whether it was from rainfall, runoff and overbank flooding, or water flow from streams and rivers (cf. H.M-L. Miller 2006, 2015; Wright 2010:33-34). It is also likely that attempts were made to capture and store water in ponds and tanks, and access to underground water using wells, as is prevalent among modern populations (Singh et al. 2008; Petrie 2013). Although canal-based irrigation is frequently dismissed as a
contributing factor in Indus farming practices, Chakrabarti (1988, 1999:327) has long argued that it must have played a critical role (cf. Gentelle 1985:Fig. 14; Francfort 1992). The identification of evidence for irrigation (or its lack) should be a priority of future research, and similarly, the role of ponds and tanks requires focused investigation, as both were potentially very significant during the Indus period.

The material culture and subsistence practices of village-based Early and Mature Harappan populations in northwest India

Although there is clear evidence for the widespread use of a range of distinctive material culture items and practices during the urban phase of the Indus Civilisation, it is arguable that the degree of material uniformity has been overstated (Petrie 2013). When excavations at Indus settlements are published it is the typically ‘classic’ Indus material (e.g. seals, beads, black-on-red decorated pottery) that is highlighted. However, a range of other cultural material is also recovered, and there are several instances where regionally distinct material, including decorated ceramic vessels and figurines, were produced and used locally. For example, excavations at the urban-phase site of Farmana in northwest India have shown that the population of this town-sized settlement predominantly used locally-produced and distinctively decorated ceramic vessels (comprising 80% of the assemblage), and made relatively limited use of the more distinctive ‘classic’ Indus ceramics well-known from sites like Rakhigarhi, Kalibangan, Harappa and Mohenjo-Daro (Uesugi 2011:179ff).
Excavations carried out as part of the *Land, Water and Settlement* project have deepened our comprehension of this regionality. At the smaller village-sized sites of Masudpur I and VII (Fig.7), which lie within the hinterland of Rakhigarhi, only region-specific styles of pottery were used during the urban phase, and no ‘classic’ Indus types were recovered from either the surface or the excavations (Fig.8; Petrie *et al.* 2009; Parikh and Petrie forthcoming). Other types of characteristically Indus material were present, however, including various types of beads and bangles (Fig.9a-9b), suggesting that the populations of these settlements remained connected to the interactive networks that linked Indus populations more broadly. This evidence for regional variation supports the suggestion that the widespread attestation of ‘classic’ Indus material is actually a ‘veneer’ that overlay a considerable degree of cultural diversity (Meadow and Kenoyer 1997:139; Petrie 2013).

There is also evidence to suggest that a diverse crop assemblage and thus diverse subsistence practices were being used in northwest India well before the post-urban period. The combined macro- and microscopic analysis of material from systematically recovered samples collected at Masudpur I and VII have revealed evidence for the exploitation of both summer and winter crops, and particularly the preferential exploitation of millet (both *Echinochloa cf. colona* and *Setaria cf. pumila*), rice (*Oryza*) and a range of tropical pulses including mung bean (*Vigna radiata*), urad bean (*Vigna mungo*), and horsegram (*Macrotyloma cf. uniflorum*) (Fig.10a-10b; Bates 2015; Petrie and Bates forthcoming; Petrie *et al.* forthcoming). This discovery confirms earlier indications that these crops were being used in this region (Saraswat and Pokharia 2002, 2003), but goes
further by dating their exploitation using both relative material culture indicators and direct AMS radiocarbon dates, to the Early, Mature and Late Harappan phases (Petrie et al. forthcoming). Millet appears to have been the dominant crop in all phases at both sites, and rice is the second most abundant crop at Masudpur I, appearing in higher quantities and proportions than either wheat or barley (Bates 2015; Petrie and Bates forthcoming; Petrie et al. forthcoming:Table S2-S3). These new dates confirm that summer crops were being used alongside winter crops before, during and after the existence of the Indus urban centre at Rakhigarhi, which is different to what is seen at Farmana (Weber et al. 2011).

The excavations by the Land, Water and Settlement project thus confirm that there was diversity in material culture both between regions and between different types of Indus settlements within regions. They have also definitively demonstrated that different subsistence pathways involving combinations of winter and summer crops were used in different areas, and that there was marked diversity in the crop assemblage within some regions before the Indus urban phase. They thus suggest that Indus populations in some regions were well adapted to living in diverse and changeable ecological and environmental conditions, and were thus well placed to make sustainable and resilient decisions in the face of environmental change. The choices that Indus populations made in the face of such change all potentially revolve around the consolidation of the rural/agrarian baseline, and include deurbanisation (and decentralisation), simplification of craft practices, population displacement, and widespread adoption of diverse approaches to subsistence.
Conclusions: adaptation, resilience and changing perceptions of Indus urban decline

There is much to learn from investigating the archaeology of human adaptation, resilience, and response to climatic and environmental change, and the adaptive and resilience strategies that complex socio-political systems may have to engage in to survive. If we are to understand how humans coped with climate change, it is important to understand how they were adapted to particular environments, and whether those adaptations enabled populations to be resilient in the face of episodes of climate change. For most ancient complex societies, water is a critical factor, and the availability of water and the way that it is managed and used provide critical insight into human adaptation, and the suitability and resilience of subsistence practices.

This paper has outlined a wide range of new evidence that encourages the reconsideration of several aspects of the nature of the Indus Civilisation, particularly the environmental and climatic context within which urbanism developed and ultimately declined. It is not yet possible to establish adequately how Indus populations responded to the change in rainfall patterns that affected the plains of north-western South Asia c.2200-2100 B.C. The evidence for climate change at a local scale indicates that there were clear changes to the patterns and intensity of summer rainfall in northwest India. Given the degree of environmental variation within the Indus zone, and the range of adaptations to farming that were being used across it, it is likely that these changes in summer rainfall would have had a differential impact; with some regions feeling the change directly and perhaps acutely, while others would have been impacted indirectly,
if at all. Ascertaining the nature of this differential impact is an obvious topic for future research.

The new archaeobotanical data produced by the *Land, Water and Settlement* project shows that models arguing that the collapse of Indus urbanism was caused by a shift in the summer monsoon (Staubwasser and Weiss 2006), which led to the diversification of the crop suite used, including the widespread adoption and/or more intensive exploitation of rice and millet (Madella and Fuller 2006; Giosan et al. 2012), are overly simplistic. They are also potentially paradoxical, as it was in northwest India that there appears to have been a reduction in the quantity of the summer rainfall needed to water these summer crops, and also potentially aid the growing of winter ones. Rather than being forced to intensity or diversify subsistence practices in response to climatic change, the evidence from Masudpur I and VII for the use of millet, rice and tropical pulses in the pre-urban and urban phases suggests that local Indus populations were already adapted to living in varied and variable environmental conditions before the development of urban centres. These environments are today marked by differences in ecology and are subject to considerable variation in rainfall patterns during individual years and between years, and similar patterns might reasonably be expected for the past. This pattern of ecological diversity and variable rainfall reinforces suggestions that different strategies must already have been adopted in different areas in response to different ecologies (Singh and Petrie 2009; Wright 2010; Weber et al. 2010a; Petrie 2013). This variation in approaches to subsistence is also matched by a hitherto underemphasised diversity in the nuances of cultural practices that have been at least
partly masked by the overt and widely used ‘veneer’ of distinctive (or ‘classic’) elements of Indus material culture.

Based on the work conducted by the *Land, Water and Settlement* project, we argue that it is this fundamental diversity in behaviour, particularly in the proportional exploitation of winter and summer crops, that may have made it possible for populations in some areas to adjust to the dramatic weakening in monsoon rainfall after ~4200 B.P./c.2200-2100 B.C. We also argue that true insight into suitable strategies for surviving in variable environments that undergo change can only come by establishing the degree to which subsistence systems were adapted to local conditions and resilient to factors such as water stresses, and the socio-economic and political stresses that result from climate change. It will, however, only be possible to characterise the level of variation in subsistence practices across the Indus Civilisation when evidence for the proportional exploitation of individual plant and animal species in a range of different regions is more widely available.

The impact of climate change upon the populations of the Indus Civilisation more broadly will inevitably also reflect the level and nature of interaction between the populations living in different regions. Looking at a global scale, it is clear that the patterns of impact and response to climate change were extremely variable (McAnany and Yoffee eds 2009; N. Miller et al. eds 2011), and we should expect the same from Indus populations. Humans are unlikely to have been passive in the face of
environmental change, and cities and civilisations did not simply disappear. Rather, populations adapt, adjust, move, die out or thrive, depending upon their circumstances.

In the Indus context, we know that the final phase of the urban period (the late Mature Harappan/Harappa 3C phase; c.2200-1900 B.C.), appears to be a phase of intensive interaction, at least in terms of networks of raw material acquisition and redistribution (Law 2011). It is also apparently the period in which Harappa was most densely occupied (Kenoyer 1991:57, 2005). It was, however, a period of transformation, such that by c.1900 B.C. a very different socio-economic and political structure is evident. On the basis of current data, it appears that in Sindh, the city at Mohenjo-Daro was significantly depopulated during the final urban phase and there was a reduction in the intensity of settlement in the region generally (e.g. Joshi et al. 1984; Possehl 2002:212,241,Table 13.2). By c.1900 B.C. in Cholistan, the largest settlements were abandoned or reduced in size and almost all others were displaced (Mughal 1997:51-2); while in Punjab, major settlements, including Harappa, reduced in size (Kenoyer 2005, 2008; Wright 2010:310). Analysis of pathologies visible on skeletons from Cemeteries R37 and H at Harappa, which span this protracted period of transition, has revealed evidence for various infections and diseases, including leprosy, and tuberculosis, which all indicate deteriorating health (Robbins Schug et al. 2013a, 2013b; Robbins Schug and Blevins 2016). The response in Haryana and Gujarat is visible in the abandonment of large settlements and a focus on smaller town or village-sized settlements.
The review presented here highlights internal dynamics and frames them in relation to a changing climatic context, but we also know that other cultural dynamics were also at play within the Indus zone and the surrounding regions. These include the deterioration of trade through the Persian Gulf, the increased evidence for contact with the populations of inner Asia (e.g. Bactria Margiana Archaeological Complex or BMAC), and the establishment of new settlements in borderland areas whose inhabitants used distinctive material culture (e.g. Pirak, Jarrige and Santoni 1979; see Wright 2010:228-230,308-325).

Precisely how all of these developments interrelate, and in turn articulate with a weakening of the summer monsoon is as yet unclear, but it is possible that climate change introduced a degree of entropy into a very complex and interactive urbanised system, potentially creating ‘unpredictable unpredictability’. Large cities and high local population densities may have become unsustainable, but sustainability, resilience and continuity may have been possible by resorting to embracing rural lifeways that saw the maintenance and dispersal of diverse approaches to substance. The need to respond to climate change is nevertheless only one factor that might have influenced Indus cultural transformation, and the adaptation of Indus substance practices to a range of ecological zones and the resilience of these adaptations in the face of climatic and social change remain critical topics for future research.
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Acknowledgements

The collaborative Land, Water and Settlement project laid the platform for the TwoRains project, which was awarded funding by the European Research Council in 2015 and will run until 2020. The Land, Water and Settlement project was primarily funded by a Standard Award from the UK India Education and Research Initiative (UKIERI) under the title “From the collapse of Harappan urbanism to the rise of the great Early Historic cities: investigating the cultural and geographical transformation of northwest India between 2000 and 300 B.C.”. Smaller grants were also awarded by the British Academy’s Stein Arnold Fund, the Isaac Newton Trust, the McDonald Institute for Archaeological Research and the Natural Environment Research Council (NERC). The PhD research of Sayantani Neogi was funded by UKIERI, and that of Jennifer Bates was funded by the Arts and Humanities Research Council (AHRC). The authors would like to thank a large number of individuals and institutions that have made this project possible. Firstly, Mrs. A. Vaish, Mr K.N. Srivastava and Dr Gautam Sen Gupta (Director Generals, Archaeological Survey of India [ASI]), Dr B.R. Mani (Additional Director General [ASI]) and Dr R.S. Fonia and Dr Subhra Pra Manik (Directors of Excavations and Explorations ASI) for granting us permission to carry out the field research. The collaborative agreement upon which this project is based was signed by Prof. Punjab Singh, Vice Chancellor of BHU and Dr Kate Pretty, Pro-Vice Chancellor of the University of Cambridge. We are also grateful to the current Vice Chancellors BHU, Prof. D.P. Singh and Dr Lalji Singh. We have been given abundant support by Prof. Sita Ram Dubey, former head of Department of AIHC and Archaeology, BHU and Prof. G. Barker, former
head of the Division of Archaeology, University of Cambridge and Director of the McDonald Institute of Archaeological Research. We would also like to acknowledge the assistance, advice and hospitality of Prof. Amar Singh (Rohtak University), Dr Naman Ahuja (JNU), Prof. M.K. Jones (Cambridge), Robert Knox (formerly British Museum), and particularly Dr R. Tewari (DG ASI, former head UP State Archaeology), Dr K.S. Saraswat (formerly Birbal Sahni Institute), and Dr P. Joglekar (Deccan College, Pune) all of whom joined us in the field. The authors would also like to offer grateful thanks to Profs Richard Meadow, Ken Thomas and Rita Wright, and Dr Ed Cork for reading early drafts of this paper and offering a range of helpful suggestions, correctives and safety ropes that helped us keep focussed. We would also like to thank Prof. Marco Madella, who has been a constant source of advice and direct support in several instances. Lastly, we would also like to thank the three anonymous reviewers that provided useful comments and criticisms. These readers may not completely agree with the opinions expressed in the final version of this paper, but their comments have hopefully made our arguments more robust, and helped us make this a better and more rounded paper.
Captions

Figure 1. Distribution of a) urban phase Indus settlements (including sites with Kulli and Sorath-Harappan material), and b) post-urban phase Indus settlements, and their relationship to the distribution of mean annual rainfall recorded between 1900 and 2008.

Figure 2. Distribution of a) urban phase Indus settlements and, b) post-urban phase Indus settlements and their relationship to Global Köeppen-Geiger Climate Classification Zones.

Figure 3. Distribution of a) urban phase Indus settlements and, b) post-urban phase Indus settlements and their relationship to mean winter rainfall (1900-2008).

Figure 4. Distribution of a) urban phase Indus settlements and, b) post-urban phase Indus settlements and their relationship to mean summer rainfall (1900-2008).

Figure 5. Geoarchaeology at Masudpur I showing a) an alluvially thickened, organic sandy silt buried soil horizon situated beneath c.1 m of archaeological deposits; and b) Close-up of micro-morphological slide taken from this section.

Figure 6. Distribution of a) urban phase Indus settlements and, b) post-urban phase Indus settlements in northwest India, and their relationship to mean annual rainfall (1900-2008). Major Indus sites and sites investigated by the Land, Water and Settlement project are shown in red.

Figure 7. Excavations being carried out in Trench XA1, Masudpur 1.
Figure 8. ‘Classic’ Harappan ceramics from Farmana, and ‘local’ ceramics from Masudpur I and VII (after Akinori 2009: Figs 6.126, 6.145, 6.161).

Figure 9. Indus material culture from Masudpur I and VII, including a) steatite, faience and agate beads, and b) Indus-style ceramic bangles.

Figure 10. Carbonised crop grains from Masudpur VII, including a) carbonised rice grains (Oryza), and b) carbonised millet (Echinochloa) grains.